25 Years of Endeavors to Protect Ethiopian Agriculture from the Ravages of Plant Pests

24th Annual Conference and the 25th Year Silver Jubilee

"Emerging and Re-emerging Plant Pests of Ethiopia: Status Interventionsand Future Prospectsin a Changing Climate"

Proceedings of the 24th annual conference and silver jubilee of the society

Edited by

Belay Habtegebriel (PhD)

Plant Protection Society of Ethiopia

SG 2000GCT

Participants of the 24th annual conference

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March 16 -17, 2018
Haramaya University

The Plant Protection Society of Ethiopia is a society formed by plant protection professionals in the country and is licensed and registered by the Charities and Societies Agency of the Ministry of Justice. The society has been in existence for more than two decades and has been conducting annual conferences every year by picking up a key plant protection issue of a year as a theme. The theme of the 24th annual conference and silver jubilee of the society was "Emerging and Re-emerging Plant Pests of Ethiopia: Status Interventions and Future Prospects in a Changing Climate" Invited papers and discussion are compiled into this proceedings.

The 24th annual conference was organized by the 2016 and 2017 PPSE executive committee members in collaboration with the Haramaya University conference organizing committee:

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2. Prof. Chemeda Fininsa,advisor of the Main Steering Committee
3. Dr Habtamu Terefe,secretary of the Main Steering Committee
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7. Dr Mashilla Dejene, member of the Main Steering Committee
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Welcome Address

Belay Habtegebriel (PhD)

President, Plant Protection Society of Ethiopia

Your Excellency, Ato Weldehawariat Assefa, Director General of Plant Health and Regulatory department of the Minister of Agriculture and Natural Resources (MoANR) and representative of Ato Tesfaye Mengiste,State Minister of MoANR

Your ExcellencyProf. Chemeda Fininsa
President of Haramaya University

Honorable guests, Members of the PPSE, Senior and founding members, representatives of our donors, Haramaya University community, conference participants
Ladies and gentlemen

I feel a great pleasure and honor to welcome you all to the 24th annual conference of Plant Protection Society of Ethiopia on behalf of the Executive Committee and on my own behalf. The society is thankful to you for devoting your precious time and travelling all the way to Haramaya University to contribute scientific papers and attend this historic conference.

Today, we are celebrating the 25th year, silver jubilee, of the Plant Protection Society of Ethiopia here at Haramaya University which is home to most, if not all, of you. I would like to congratulate you on the occasion of this historic event. The society was established 25 years ago in 1992 by committed plant protection experts (Plant pathologists and entomologists). Nowadays, the society has over 750 members who are one way or the other engaged in plant protection activities in all disciplines including plant pathology, agricultural entomology, weed science, postharvest protection, vertebrate pests, resistance breeding and the like. Since its establishment, the society has been holding regular annual conferences for the last 24 years including this one. Each of the conferences had particular, specific and timely themes relevant to plant protection. The deliberations and plenary scientific papers have been published in the society proceedings. Its scientific out let “the Pest Management Journal of Ethiopia” was established in 1997 and has been publishing outstanding scientific articles and has now reached its 20th volume published in 2017. In addition to this, the members of the society have been advising government and non-government stakeholders and taking part in a number of problem solving studies related to plant protection in the country.

Ladies and gentlemen

Although there are a number of exemplary engagements of the society in research and development activities, all is not perfect. Let me be a little bit critical about the society and its members including myself. The usual case is that we gather annually, discuss a few scientific papers presented in the conference, pay annual fees (50 -100 Birr), collect the journal and proceedings that cost 50 – 120 Birr each, collect a wonderful bag that costs 400-700 Birr and go back home. The rest is left to the executive committee of the society. This does not seem to be a fair play. We need to do a lot more to strengthen our society. For example, as members of the society, we have the obligation of paying our annual fees without defaulting and should volunteer in reviewing articles sent to the journal editorial committee. But this is not the reality on the ground. Although there are many who are really committed, some are observed to decline reviewing or to delay response and annual membership fees are not paid on a regular basis. The society does not have a permanent employee (at least an office manager) responsible for holding up to date records and running its website. The annual membership fee is far below expected for a society of such a high caliber. Thus I believe that we need to discuss on these issues seriously and reach in to consensus for the betterment of the society.

Ladies and gentlemen

It is also high time for the society to embark on to a more effective and active roles in protecting Ethiopian agriculture in the ever changing climate and at a time emerging and re-emerging pests are threatening our agriculture. Hence the theme of this year’s conference “Emerging and re-emerging plant pest of Ethiopia: status, interventions and future prospects in a changing climate” was purposefully selected to reflect the current threats that Ethiopian agriculture is facing. It goes without sayings that, since the new millennium alone, a number of pests have emerged, re-merged or have been introduced to Ethiopia, making the already low production even more endangered.Among the pests in discussion, the fall armyworm, maize lethal necrosis disease, the white mango scale, ginger bacterial wilt, faba bean gall disease, cochineal bug, cotton mealybug, the water hyacinth and the different wheat rusts are but a few examples of recent pest surges. Thus, more in-depth research needs to be done and proactive recommendations/technologies made available to tackle down the ravages. The society and its members must actively engage in delivering what the farmer needs.

I would like to say that the attention given to the plant protection profession is not as it should be. On the contrary, the country's production is being challenged by existing and new pests to the extent that has endangered the production of many food security crops. We need to speak loudly and say no to this situation.

The invited papers that will be presented today are focused on addressing the problems on the ground. They need to be seriously discussed and improved versions of the full papers made available to the scientific and development community as well as to the policy makers in the form of proceedings as a special issue marking the 25th year silver jubilee.

Ladies and gentlemen

Allow me to thank those who have been supporting the society since its establishment in different ways including financial and material support.

I would like to extend my sincere gratitude and special thanks to Haramaya University, for hosting this historic annual conference marking the 25th year silver jubilee. I would like to especially thank Prof. Chemeda Fininsa, President of the University, who took the first initiative to host the conference out of professional and scientific interest and to support the society in realizing this important event. My gratitude also extends to the conference organizing committee led by Dr. Awol Seid without whom this conference wouldn't have been realized.

I would also like to acknowledge the continued support from our donors the support of which has enabled us to realize this ceremonial conference. Please join me in applauding the following regular donors who supported as financially:

- The Food and Agriculture Organization of the UN (FAO)
- Ministry of Agriculture and Natural Resources
- Ministry of Science and Technology,
- Ethiopian Institute of Agricultural Research
- Ambo Plant Protection Research Center
- Melkassa Agricultural Research Center
- Bayer East Africa Ltd
- Adamitul Pesticide Processing Factory
- SG 2000
- Lions International Trading
- Chemtex PLC
- General Chemical Trading

I also acknowledge the dedications of all those who helped us in making this conference a reality. I wish all of you a memorable event and happy silver jubilee celebrations.Finally, may I inviteHis Excellency ProfessorChemeda Finninsato make key note speech to the silver jubilee of the PPSE.

Thank you!

Dr. Belay Habtegebriel delivering a welcome address

Opening Speech

Weldehawariat Asefa, Director General of Plant Health and Regulatory department of the MoANR and representative of Ato Tesfaye Mengiste,
State Minister of Minister of Agriculture and Natural Resources

Your Excellency Prof. Chemeda Fininsa, President of Haramaya University

Honorable guests, Members of the Plant Protection Society of Ethiopia,
Haramaya University community, Distinguished Conference Participants and, Invited Guests,

Ladies and Gentlemen

On behalf of the Ministry of Agriculture and Natural Resources of the Federal Democratic Republic of Ethiopia and on my own behalf, I would like to congratulate the Plant Protection Society of Ethiopia on the occasion of its remarkable stage, the Silver Jubilee. The plant protection society of Ethiopia is one of the pioneer professional societies in the country which have been actively engaged in promoting scientific plant protection practices and research for the last 25 years. The ministry of agriculture and natural resources recognizes its efforts of minimizing crop losses caused by various pests.

The society has been an important partner of the agriculture sector and has significantly contributed to the efforts made by the government and the private sector in protecting Ethiopian agriculture from the ravages of plant pests. It has also advised the government in many policy and strategic issues such as the Pest Management Support Service Strategy. Its members are important think tanks in the war against ever increasing pest problems causing serious damages to crop production in Ethiopia.

This year, the society has picked a very important and timely theme for its 24th annual conference. The theme "**Emerging and Re-emerging Plant Pest of Ethiopia: Status, Interventions and future prospects in a Changing Climate**"is a relevant one which truly reflects the problem that our crop production system is facing this days. Emerging and re-emerging pests are threatening our staple and strategic crops more seriously than ever. An example of such pests is the fall army worm which is the most recent introduction to our country. We have prepared a strategy to tackle down this devastating pest. But we also need to be prepared for the worst and unpredictable ones. With climate change, increased trade and fast transportation means, it is impossible to predict which pest is introduced into the country next. In this regard, much more is expected from all stakeholders including the society and its members.

Respected conference participants

It is a well established fact that the livelihoods of over 85% of Ethiopia's population depend on agriculture. Agriculture is also the major source of foreign currency to the county, income to 90% of people living in the rural areas and raw materials to many food industries in the country. In general agriculture is a key factor in the economy of the country. However, average crop loss of up to 40% is incurred by plant pests both at pre and post harvest stages. Minimizing these losses is equivalent to increasing production. Sustainable, science based, effective and efficient crop protection is a timely demand of our agriculture.

As you all know, by the end of the GTPII period, the amount of crop production by smallholder farmers during the main harvest season is set to increase from 270.3 million quintals in 2014/15 E.C. to 406 million quintals. This goal cannot be achieved without protecting the crops from the damage incurred by pests.

The government of Ethiopia is devoted to protecting Ethiopia's crops from the ravages of these pests. However, realizing concrete changes in this regard and ensuring increased productivity requires a concerted effort from small holder farmers, local and private investors, higher learning and research institutes and professional societies like the plant protection society of Ethiopia.

Distinguished members of the Plant Protection Society of Ethiopia

I would like to assure you that the MoANR will continue to support the society in its efforts and contributions towards food security of the country. Finally, I would like to extend my sincere gratitude to the organizers of this important conference. I hope that the conference will be critically dealing with the important issues of emerging and re-emerging pests that are seriously affecting crop production and productivity in the country.

Finally, I would like to congratulate all of you once again for celebrations of silver jubilee of the society.

I now officially declare the 24th annual conference of the Plant Protection Society of Ethiopia open. I wish you a successful conference.Thank

Mr. Woldehawariat Assefa, delivering an opening speech

Opening Speech

Prof. Chemeda Finninsa, President of Haramaya University

Dear Dr. Belay Habtegebriel, President of the Plant Protection Society of Ethiopia

Dear Officials of the Plant Protection Society of Ethiopia

Dear Members of Plant Protection Society of Ethiopia

Dear Conference Participants,

Distinguished Guests,

Ladies and Gentlemen,

It is a great pleasure for me to make a welcome address, and a brief remark on this very significant Annual Conference and Silver Jubilee Celebration of the Plant Protection Society of Ethiopia. For most of you, the School of Plant Sciences of Haramaya University is your beloved educational home. On behalf of the University community and myself I cordially welcome you all to your Educational home! Welcome to Haramaya University! Our University is pleased to jointly host this historical Annual Conference and the Silver Jubilee Celebration. I would like to thank the Society officials for giving us an opportunity to host the conference.

The theme of the Annual Conference **Emerging and Re-emerging Plant Pests in Ethiopia: Status, Interventions and Future Prospects in a Changing Climate** is timely as emerging plant pests on different economical crops have become a serious threat and challenge in different agro-ecologies to sustainably increase crop production volume, productivity and marketability. The emerging plant diseases, insect pests and invasive weeds currently have become a bottleneck in different agro-ecologies to effectively commercialize the Ethiopian crop production, and produce reserve food supply. Therefore, the emerging plant pests in Ethiopian crop production systems deserve due strategic attention and a serious endeavour of plant protection professionals, policy makers, research and higher learning institutions and the private sector.

This conference, in my view, will give us a great prospect to (1) know the different emerging plant diseases, insect pests and invasive weeds; (2) exchange the knowledge, information, management methods and technologies innovated and extended to farming communities to manage the pests; and ( ) examine how research institutions, plant protection re

To excel in our triple mandates, we have set a vision of becoming a research and postgraduate University. This requires diversified support of our alumni. On this occasion, I kindly request the Plant Protection Society of Ethiopia, and all its members to work with us wherever you are in partnership and collaboration on issues of plant protection research, education, development and others.

I would like to thank different Organizations for kindly and generously sponsoring the 24th Plant Protection Conference and its Silver Jubilee hosted at Haramaya University. I thank you all. I also thank the Haramaya conference organizing team, led by Dr. Awol Seid, for effectively organizing this conference.

Finally, I wish you a very pleasant stay here at Haramaya University with productive and successful deliberations during the two days, and wish you all ***a Happy Silver Jubilee Celebration***!

I thank you!

Chemeda Fininsa (Professor)

President, Haramaya University

16 March 2018

Prof. Chemeda Fininsa, delivering an opening speech

Welcome Speech

Dr. Awol Seid

Chairperson/focal person of the Main Steering Committee of the Haramaya University conference organizing committee

Your Excellency, Mr. Woldehawarite Asefa Director General of Plant Health and Regulatory Department of the Ministry of Agriculture and Natural Resources

Your Excellency, Professor Chemeda Fininsa, President of Haramaya University

Your Excellency, Dr Belay Habtegebriel, President of Plant Protection Society of Ethiopia

Distinguished Conference Speakers

Distinguished Guests

Dear Conference Participants

Ladies and Gentlemen

On behalf of the organizers, the organizing committee and myself, let me begin by saying how pleased I am to see this conference taking place here at Haramaya University. I am so pleased to see so many senior scientists, policy makers, colleagues, and families of plant protection professionals from different institutions, all in one place!

Some of you we have never even met before, we have known you only by name 'before this conference'; now we have the honor of knowing you personally. Some of you have circled half the Ethiopia to come to Haramaya University; some of you have come from places closer to this university. We are extremely grateful to have here with us representatives from Ministry of Agriculture and Natural Resources, Ministry of Sciences and Technology, Universities, National and Regional Research Institutes, International Research Organizations, business organizations and NGOs. We welcome you all to Haramaya University and its surrounding historical cities of Harar and Dire Dawa.

Ladies and Gentlemen

I would like to express my sincere gratitude to Prof. Chemeda Fininsa, the President of HU and Dr. Belay Habtegebriel, President of the Plant Protection Society of Ethiopia (PPSE) who have trusted the conference organizing steering committee to organize the conference here at HU. Furthermore, I would like to thank all my colleagues in the conference Organizing Steering Committee for their commitment in the preparation of this conference. More specifically the contribution of Dr Mashilla Dejene and Dr Habatamu Terefe was immense. Please, join me in applauding this conference organizing steering committee.

Ladies and Gentlemen

The main reasons we agreed to organize this conference here at HU were:

1) To stimulate interest in plant protection profession and increase the visibility and positive impact of the PPSE.
2) To review the previously gained achievements in plant protection sector, where emerging and re-emerging plant diseases, insect pests, invasive weeds and climate change have become a challenge for the farming communities.
3) To provide amiable opportunities for scientists, entrepreneurs, partners, growers, stakeholders and business communities working in plant protection and production sector to exchange information, knowledge and experiences they have accumulated over the years and form networks.
4) To enable stakeholders and policy-makers to review the social, economic, and political implications and impacts of making concerted efforts towards enhancing the plant protection profession.

In these two days long conference, together, we will strive to:

- Facilitate a lively discussion on the threats of emerging and re-emerging plant pests of Ethiopia
- Make farmers the center of our gravity and design better solutions to the challenges of our farmers,
- Connect expertise to find new solutions and
- Boost our innovation thinking in finding a better solution to threats of emerging and re-emerging plant pests. What will drive our success in the future is the shared dedication for innovation based on long-term commitment and passion for the discipline.

Ladies and Gentlemen

Such a conference could have been conducted at no better time than now when threats of emerging and re-emerging plant pests in a changing climate are affecting agricultural productivity and impact biodiversity and the services people derive from it have become a matter of common urgency for the entire nations of the world. Therefore, it is important that, we, scientists, experts, policy-makers, practitioners, and stakeholders from all walks of life come together as family members and deliberate on issues at stake in terms of averting the challenges posed by emerging and re-emerging plant pests on Ethiopian agriculture.

Ladies and Gentlemen

Haramaya University very much welcomes the scientific debate, the sharing of knowledge and the global dissemination of good practices. We are an outward-looking institution, available to interact with various national and international institutions in a 'cross-fertilization' process. It is worth mentioning to you that each year Haramaya University organizes and co-organize many conferences of diverse scientific disciplines, on which scientists from diverse areas and from all over the world (both national and international scientists) met to discuss sciences. This is one of the contributions that HU gives to Science.

Ladies and Gentlemen

It is absolutely clear to me that this conference is an event of great academic and scientific interest that brings much value to all the members of the PPSE, to Haramaya University and its academic community and the government at large. In this event, we are going to have the opportunity of hearing to most prestigious speakers, addressing topics of undeniable scientific relevance. It is therefore an opportunity for our community specifically concerned with research on emerging and re-emerging plant pests of Ethiopia, to share their recent achievements, to exchange valuable experiences and, not the least, to inspire young researchers for their so relevant work. I very much hope that the conference raises – as it is hoped – a plural, interdisciplinary and forward-looking discussion on emerging and re-emerging plant pests of Ethiopia: status, interventions and future prospects in a changing climate.

For all such reasons, it is quite gratifying for Haramaya University to host this conference and I take this opportunity to congratulate the members of this conference Organizing Committee for successfully organizing the 24th annual conference and silver jubilee of PPSE.

Ladies and Gentlemen

We are fortunate to have the support of a great cadre of sponsors, whom I hope you will get to meet during the conference. As special platinum sponsor we have Food and Agriculture Organization of the United Nations (FAO), Platinum status sponsor we have Chercher Oda Bultum Farmers' Cooperatives Union, as gold status sponsor we have SNV the Netherlands Development Association, as silver status sponsor Ethioagri-CEFT and Oromia Agricultural Research Institute (ORARI) while as bronze sponsors Bilateral Ethiopians-Netherlands Effort for Food, Income and Trade (BENEFIT), Ethiopian Biodiversity Institute (EBI) and Ministry of Agriculture and Natural Resources (MoANR) including several contributors (as depicted in the banner behind me) both in kind and Cash with their generous support we are able to successfully organize this conference. Thank you all our sponsors again. Please, join me in applauding our sponsors for their generous and vital support.

Finally, let me finish my welcoming speech on behalf of the organizing committee by saying this…

&'eaving the world a little "etter than we got it is a good measure of personal and professional legacies(.

Thank You Very Much for your attention!

Awol Seid (PhD), Chairperson of the steering committee to organize the 24th Annual Conference and Silver jubilee
Haramaya University, School of Plant Sciences, Plant Protection Program
16 March 2018

Dr. Awol Seid delivering a welcome speech

Keynote Speech

Tsedeke Abate, Founding member of the Plant Protection Society of Ethiopia and first editor in chief of the society's Journal (Pest Management Journal of Ethiopia)

Now Independent Researcher
Homegrown Africa
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Is PPSE Coming of Age? Where Do We Go From Here?

Abstract of a key note speech delivered to the 24th annual conference and Silver jubilee of the society

It is so gratifying and professionally fulfilling to witness that our society is where it is today from its humble beginnings more than a quarter century ago. I salute the men and women who have diligently worked to get us here. We celebrate this occasion with pride histories in mind of great contributions to Ethiopian agriculture by our dedicated scientists in the fields of entomology, plant pathology, weed science, and vertebrate pests. As I pointed out in my keynote address at the 16th Annual Meeting of this society in August 2009, we all remember the havoc caused by the bean stem maggots in legumes, bollworms and the tobacco whitefly in cotton and tomato, cereal rusts in wheat, coffee berry disease and coffee rust in coffee, scale insects in citrus, stalk borers in maize and sorghum, many noxious weeds in many field and horticultural crops, and several storage pests in the 1970s through 1990s, just to mention a few. It is fair to say that we have made significant advances in the management of these pests (sensu lato). We need to work with economists to put the Birr values (or rates of return to the government's investment in research and development) to the Ethiopian economy resulting from our successes.

It is also encouraging to read about the progress being made in the biological control of)artheniumhystrophorus and *uta a"soluta. The maize lethal necrosis and the fall armyworm arrived in recent years. The water hyacinth has been with us for such a long time but it is now being recognized as a major threat to our waterways and hydropower generation. The prickly pear (cactus) is a significant threat to grazing lands, especially in eastern parts of our country, but I have yet to hear about what measures are being taken to create awareness and seek solutions to alleviate it.

We have, therefore, lots of opportunities ahead of us to further prove our worth to Ethiopian agriculture – we will be limited only by our imagination and innovativeness. After all, professionalism is all about touching someone's life, near or far; satisfaction is all about bringing about change and being able to witness it; it is my belief that each one of us in PPSE have touched someone's life, in one way or another; and it's not too late even for those who have not had the chance to do so, because there is always tomorrow.

Dr. Tsedeke Abate delivering a keynote speech

Plant Pathology Papers

Maize Lethal Necrosis Disease in Ethiopia: Status, Intervention and Prospects

Berhanu Bekele

Ethiopian Institute of Agricultural Research (EIAR),

Ambo Plant Protection Research Centre (APPRC)

Abstract

+s in the case of su"$,aharan +frican countries, mai%e is an economic and key determinant of food security crop for smallholder su"sistence farming communities in Ethiopia. + recently emerged virus disease out"reak, first reported from -enya in 2.11 and diagnosed as /'0, is now considered a ma!or constraint to mai%e production and productivity. #n Ethiopia, its presence was first noticed in 1une 2.12 at 3pper +wash areas in the 4ift 5alley where it caused total mai%e plant failure in some commercial seed production fields. ,u"se6uent surveillances demonstrated that the disease is distri"uted over wider geographic locations in key production areas in central, south and west regions in Ethiopia. *his paper summari%es results of extensive surveys and diagnostics undertaken for /'0 from 2.12$2.17 main$ and short$rainy seasons in the country, alternate hosts so far identified and seed transmission studies conducted. #nterventions attempted to manage the disease through pu"lic awareness creation and 6uarantine measures are also discussed along with potential prospects to manage /'0 in Ethiopia.

INTRODUCTION

In sub-Saharan Africa (SSA), Maize (8ea maysL.) is the most important cereal crop covering over 25 million hectares of land. It is mainly produced by smallholder farming systems that produce over 38 million metric tons (MMT) of grain (FAOSTAT 2010). This represents 34% of cereal production and is 8% of the value of all crops in the region. It has been shown that maize is basically critical crop for food security in SSA, where eastern and southern Africa use 85% of the maize produce as food, while Africa as whole uses 95% as food (Shiferaw et al., 2011). In Ethiopia, in terms of area coverage and total production, maize ranks secondnext to tef. During the 2015/16 cropping season, 3.0 million ha of land planted to maize with a total production of 8.6 million tons (t), and productivity of 2.82 t/ha (CSA, 2016). In spite of its importance, diseases and insect pests are exceedingly becoming maize production constraints in the country.

A newly emerged serious maize disease outbreak diagnosed as maize lethal necrosis (MLN) was first reported from Kenya (Wangai et al., 2012a) in September 2011 in the Longisa Division of the Bomet District. By 2012, symptoms consistent with MLN were observed in a number of districts in the Central, Nyanza, Western, and Rift Valley Provinces of Kenya (Wangai et al., 2012b). Subsequently, it has been reported from most of neighboring countries bordering Kenya, viz. Tanzania and Uganda (Wangai et al., 2012b), Rwanda (Adams et al., 2014), Democratic Republic of Congo (DRC) (Lukanda et al., 2014), and more recently from Ethiopia (Mahukuet al., 2015b) and South Sudan (FAO, 2012). Wangai et al. (2012b), based on field observations, reported that the disease was affecting almost all commercial maize varieties, causing estimated yield losses of 30 to 100% depending on the stage of disease onset and severity. In 2012, MLN affected 77,000 ha in Kenya alone, translating into an estimated yield loss of 126 MMT valued at U.S.$52 million (Wangai et al., 2012b).

It is caused by synergistic co-infection of maize with /ai%e cholortic mottle virus(MCMV) from the genus /achlomovirus in the family *om"usviridae, and a virus from thefamily)otyviridae, especially 9heat streak mosaic virus (WSMV), /ai%e dwarf mosaic virus(MDMV) or ,ugarcane mosaic virus (SCMV, formerly MDMV-B) (Niblett and Claflin, 1978; Uyemoto et al., 1980; Goldberg and Brakke, 1987). Several other, unrelated viruses can alsocause synergistic reactions in co-infections with MCMV, and abiotic stresses can exacerbateMCMV infection to cause MLN.

Maize-infecting potyviruses are common; SCMV, in particular, has a worldwide distribution and has been known in Kenya since the 1970's (Louie, 1980). Thus, emergence of MCMV infection in maize is generally sufficient to trigger MLN.

In Ethiopia, MLN syndrome was first noticed in the Up

Figure 1. High level damage incurred on Maize due to Maize Lethal Necrosis infection in various locations in Ethiopia, 2014 and 2017.

1.2.History

Earlier identified in the USA in 1976 (Niblett & Claflin, 1978), the disease had largely remained within the Americas (Peru, Argentia, Mexico). First reports have recently been recorded for China (Xie et al., 2011), Taiwan (Deng et al., 2014) and East Africa (Wangai et al., 2012a). Since the initial outbreak in East Africa (Kenya) (Wangai et al., 2012a), MLN has now been reported in Tanzania (Wangai et al., 2012b), Uganda and South Sudan (FAO, 2012), Rwanda (Adams et al., 2014), the Democratic Republic of Congo (Lukanda et al., 2014) and Ethiopia (Mahuku et al., 2015b) (Table 1), and is likely to be of wider distribution in Africa.

Table 1. Global occurrence and consecutivereports of / ai%e chlorotic mottle virus (MCMV).

Location	**Date reported**	**Potyvirus**[a]	**Reference**
Peru	1973	NR	Castillo and Herbert (1974)
U.S. Mainland	1977	WSMV/MDMV	Niblett and Claflin (1978)
Argentina	1982	NR	Teyssandier et al. (1983)
Thailand	1982	NR	Klingkong and Subatra (1982)
Mexico	1989	NR	Carrera-Martinez et al. (1989)
U.S. Hawaii	1992	MDMV	Jiang et al. (1992)
Colombia	1999	NR	Morales et al. (1999)
China	2011	SCMV	Xie et al. (2011)
Kenya	2012	SCMV	Wangai et al. (2012a)
Tanzania	2012	SCMV	Wangai et al. (2012b)
Uganda	2012	SCMV	FAO (2012)
Rwanda	2013	SCMV	Adams et al. (2014)
DRC[b]	2013	SCMV	Lukanda et al. (2014)
Taiwan	2014	SCMV	Deng et al. 2014
South Sudan	2012	SCMV	FAO (2012)
Ethiopia	2014	SCMV	Mahuku et al.(2015b)

a=Potyviruses reported with MCMV. WSMV, 9heat streak mosaic virus; MDMV, / ai%e dwarf mosaic virus; SCMV, ,ugarcane mosaic virus; NR, not reported. b=DRC, Democratic Republic of the Congo.

The viruses causing MLN and Insect vectors

Maize chlorotic mottle virus: MCMV belongs to the family *om"usviridae and genus /achlomovirus. Ithas 30 nm icosahedral virions (Fig. 2A) encasing a ca. 4.4 kb single-stranded, positive sense RNA genome (Scheets, 2004). It's genome encodes six overlapping open reading frames, five of which are required for replication and movement in the plant. Depending on the plant's genetic background, its developmental stage at the time of infection and prevailing environmental conditions, MCMV infection of maize develops an array of symptoms viz. mild chlorotic mottling to severe mosaic and stunting, yellowing and necrosis, premature plant death, shortened male inflorescences with few spikes, and/or shortened, malformed, partially filled ears. Uyemoto et al. (1981) showed that yield losses due to MCMV infection range between 10-15% in natural infections, and up to 59% in artificially inoculated maize plots.

Ethiopian isolates of MCMV was whole genome sequenced (Mahuku, 2015b) to determine genetic resemblance to other isolates from east African (especially from Rwanda and Kenya) countries using IlluminaMiSeq (2 samples) and IlluminaHiSeq (4 samples) following procedures described by Adams et al. (2014). The result confirmed that all the six samples tested contained MCMV. Phylogeney analysis, based on the complete genomes of MCMV isolates from Ethiopia, indicated that Ethiopian isolates were highly similar (>99% identity) to those found previously in East Africa (Adams et al. 2013, 2014).

Insect vectors of MCMV: MCMV can be experimentally transmitted in a semi-persistent manner by a number of Chrysomelid beetles, including several :ia"rotica species (Nault et al., 1978). Maize thrips (;rankliniella williamsi) were also identified as vectors of MCMV (Cabanas et al., 2013). A recent report suggested that western flower thrips (;. occidentalis) may also be a vector although attempts made to transmit the Kenyan isolate of MCMV with ;. occidentalis were unsuccessful (Zhao et al., 2014). As in the case of beetles, thrips transmit MCMV after acquisition periods of 3 h, with no evidence for a latent period; both larvae and adults retained the ability to transmit the virus for up to 6 days after acquisition (Cabanas et al. 2013).

The range of vectors for MCMV in Africa is not known, although thrips have been observed in all fields where maize is grown, including in MLN and MCMV-affected fields. It is possible that thrips and other vectors could be playing a major role in MCMV movement within and between fields in the affected countries in Africa. Maize thrips were reported in East Africa in 2009 (Nyasani et al., 2012; Moritz et al., 2013), and surveys of maize in Kenya and Uganda between 2008 – 2010 indicated the vector was present in almost every maize growing region from the coast of Kenya to the borders of Uganda and DRC. Maize thrips were observed on several other graminaceous crops including babycorn, rice, sorghum and wheat, and were also observed frequently on onions (Moritz et al., 2013). The wide distribution of ;.williamsi indicates that maize thrips were present in East Africa for several years prior to the first report of MLN.

Other than ;. williamsi, surveys for thrips infesting maize in East Africa revealed the presence of several other species. Among 189 thrips specimens collected from 19 locations (5 – 10 maize plants per location), six ;. occidentalis, 62 ;. schult%ei, four ,cirothrips sp. and three *. ta"aci, which are known vectors of tospoviruses (Riley et al. 2011), were identified. The highly polyphagous ;. occidentalis, ;. schult%ei, *. pusillus and *. ta"aci are widely distributed in the region (Moritz et al., 2013). Preliminary experiments suggest ;. schult%ei and *. ta"aci, as well as ;. williamsi can transmit MCMV.

It remains possible that other vectors might be playing a major role in MCMV movement within and between fields in Africa. For instance, field collections of beetles from maize in Kenya revealed the presence of several Chrysomelid beetles such as <haetocnema pulicaria that are potential vectors of MCMV (Nault et al., 1978). Further research is needed to determine the competence of these vectors in virus transmission, their ecology and their role in the epidemiology of MLN. Robust diagnostic tools are available for thrips occurring in East Africa (Moritz et al., 2013), but such tools need to be developed for other potential vectors.

Host range of MCMV: In contrary to the earlier report that maize is the only known natural host of MCMV (Scheets, 2004), recent studies in east Africa (Kenya and Uganda) disclosed MCMV infection of sugarcane, finger millet, sorghum, Napier grass and Kikuyu grass (). clandestinium) (Wang et al.,2014; Kusia et al., 2015; Mahuku et al., 2015a) from symptomatic and field collected samples tested by ELISA. While Bermudagrass (<ynodon dactylon), Napier grass ()ennisetum purpureum), Common wild oat (+vena fatua), Pearl millet ()ennisetum glaucum), Brome grass (=romus inermis), Sand lovegrass (Eragrostis trichodes), Wheatgrass (+gropyron repens), barnyard grass (Echinochloa crus$galli), Smooth crabgrass (:igitaria ischaemum), Nut grass (<yperus esculentus), wheat (*riticum aestivum cv. 'Fuller' and 'Hatcher'), and oat (+vena sativa cv. 'Robust', 'Rasmusson', 'Quest', 'Tradition', 'Lacey') were immune to MCMV, developing no symptoms and remaining free of MCMV when checked by ELISA and RT-PCR (Mahuku et al., 2015a) . In Ethiopia, when 19 nonmaize symptomatic grass samples collected from central Rift Valley were tested by DAS-ELISA with polyclonal antibodies produced against the East African strains of MCMV, it was detected in Johnsongrass, :igitaria sp., sedge, ,etaria sp., sugarcane and an unidentified grass species (Mahuku et al., 2015b). The results of these findings substantiate earlier report (Bockelman et al., 1982) of possible existence of wide host range that may serve as virus reservoirs.

Seed Transmission of MCMV:Earlier work by Jensen et al. (1991) revealed that seed transmission rates of MCMV ranged from nil (0%) to 0.33% in 17 lots of maize seed from MCMV-infected plants. To investigate the potential role of seedtransmission in the spread of MCMV in Africa, Mahuku et al. (2015a) isolated RNA from 25 seeds harvested from MCMV-infected maize plant and tested for the presence of MCMV by RT-PCR. The test resulted in 18 (72%) positive seeds. Mahuku et al. (2015a) also showed that MCMV wasdetected by RT-PCR of isolated RNA in 12 of 26 ten-seed samples pooled from 26 lots of locally purchased seed. In recent works in Ethiopia, Bekele et al. (2017) reported that seed health testing generated variable results depending on the type of crop and crop varieties analyzed. In tests made on various maize and popcorn varieties, seed infection rates ranged from 0.25% - 25%, with same sample gave different results when tests were made directly from seed and using plants raised from seed (Bekele et al., 2017). Infection rate was high when seeds are directly tested than when plants raised from seed are tested. This result appears in agreement with the report by Mahuku et al. (2015a) that MCMV contaminates seed from virus-infected plants, but the presence of MCMV in seed does not necessarily indicate that MCMV is transmitted to progeny plants. However, it is important to mention that low rate of seed-transmission is epidemiologically significant, as a virus may be introduced into new areas through seed. In addition, in conjunction with secondary spread by insect-vectors, low rates of seed transmission can translate into high numbers of infected plants,resulting in epiphytotics (Maule and Wang, 1996). Some unsolved doubtful issues on differential results related to seed transmission rate such as possible influence of maize genetic background and environmental factors be investigated and settled under strictly controlled conditions.

Soil transmission of MCMV: Soil transmission of MCMV was studied by Mahuku et al. (2015a) in Kenya using contaminated soil from MCMV-affected fields and sterile soil and was planted to seeds collected from Zimbabwe (supposed to be MLN free country). The result of ELISA testing demonstrated that MCMV was detected in nearly 70% of the emerging seedlings planted into contaminated soil, but only 4% of seedlings planted into sterile soil were infected, signifying the importance of contaminated soil in MLN transmission.

Sugarcane mosaic virus (SCMV): As in the case of all east African countries, MCMV was always found associated with SCMV in causing MLN in Ethiopia (Mahuku et al., 2015b). Earlier, an inventory made to determine viruses infecting maize in Ethiopia showed that four viruses from maize, namely maize streak virus (MSV), sugarcane mosaic potyvirus (SCMV), maize dwarf mosaic potyvirus (MDMV) and maize mottle chlorotic stunt virus (MMCSV) (Delassus 1973; Alemu et al. 1997) were identified. SCMV is a member of the genus)otyvirus, family)otyviridae. All potyviruses have single-stranded positive sense RNA genomes and flexuous rod-shaped virions of about 15 x 700 nm (Fig. 2B). SCMV is a phylogenetically diverse species for which genome sequences of isolates from maize and sugarcane cluster by host and geographic origin (Li et al., 2013), with sequence identities ranging from less than 70 to 99%. Potyviruses cause mosaic symptoms and dwarfing in susceptible maize hybrids and cultivars, with the symptoms induced by SCMV generally being fairly mild. Maize-infecting potyviruses are naturally transmitted by about 25 aphid species in a non-persistent manner (Brault et al., 2010). SCMV can also be seed transmitted with transmission rates of 0.4 to 3.9% depending on the genotype (Li et al., 2011).

The association of SCMV with MCMV in causing MLN in Ethiopia was first confirmed by ELISA followed by real time PCR and sequencing using IlluminaMiSeq and IlluminaHiSeq as described by Adams et al. (2014).Phylogenetic tree constructed using coat proteins of the sequenced SCMV isolates from Ethiopia were found to be similar to each other and to those found in Rwanda (Adams et al., 2014) with 96% identity, but relatively distant from those originally found in Kenya (Adams et al., 2013).

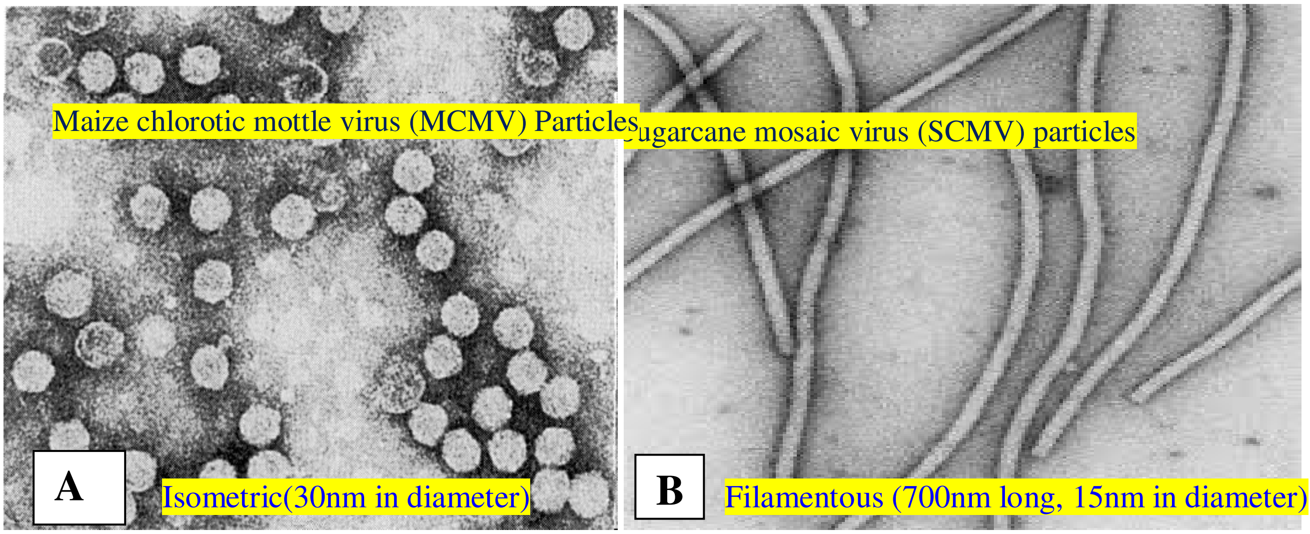


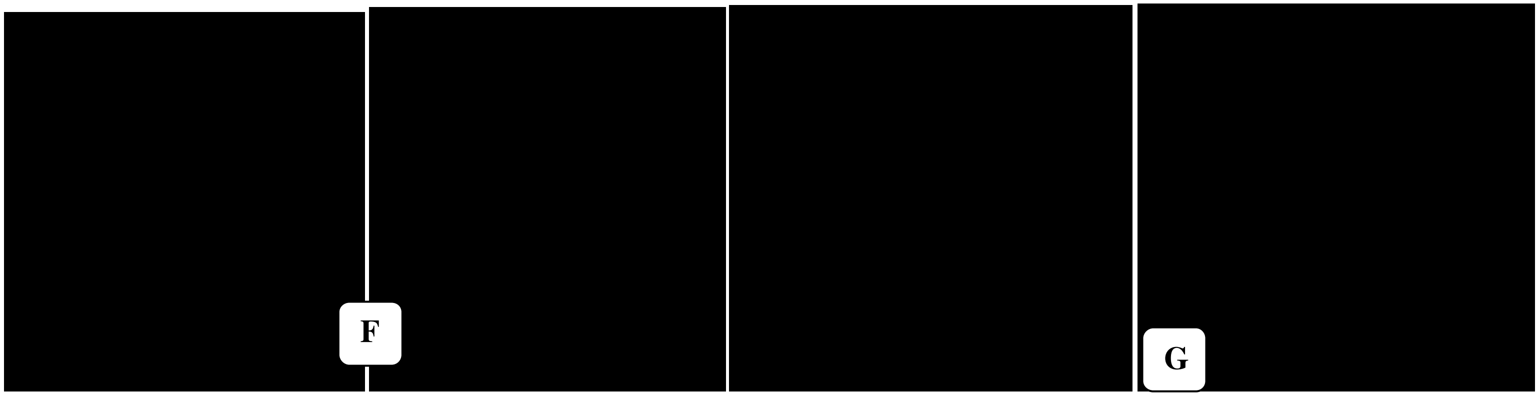
Figure 2. Size and shape of MCMV (A) and SCMV (B) virions

Symptoms of MLN

Symptoms of MLN observed in the field vary widely depending on germplasm, time of infection, prevailing environmental conditions, ratios of the viruses infecting the plant and the symptoms can easily be confused with drught, micro-nutrient deficiency or stalk borer infestation. Field symptoms, however, can be best used when combined with other methods of diagnosis. The most commonly observed symptoms associated with MLN infection are shown in Fig. 3.

[redacted]

Shortened internodes and severe chlorotic mottle ‘Dead Heart’ symptoms’



Premature drying of the husks

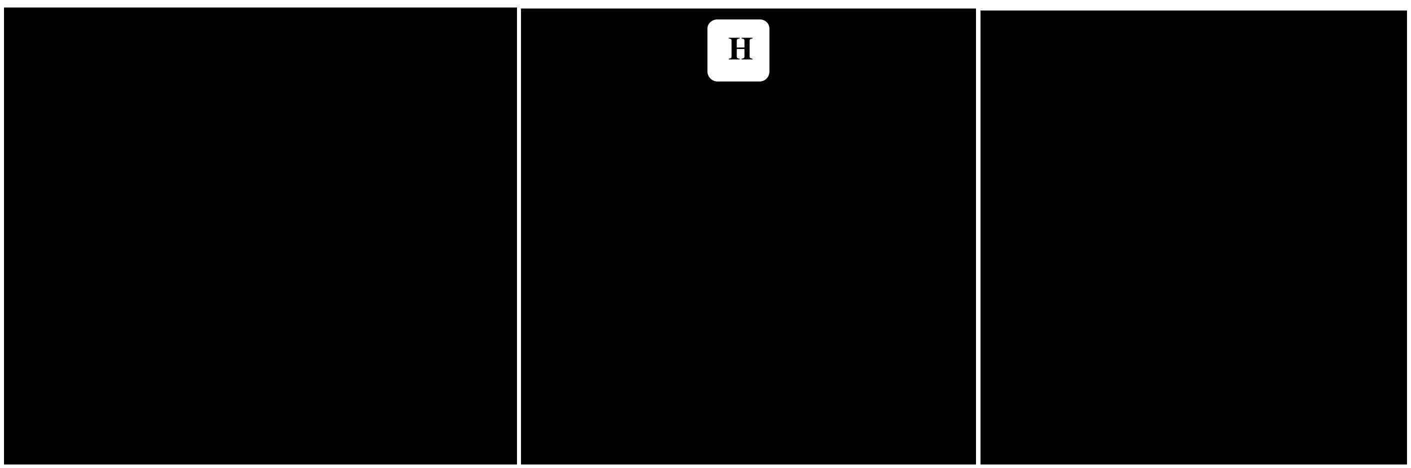


Figure 3. Symptoms of MLN on maize: A, Symptoms in artificially inoculated maize plants in screen house to MCMV and SCMV; B-H, Various types of symptoms expressed on maize due to MLN infection.

MLN Status and Distribution in Ethiopia

Since its first report in June 2014, a consecutive surveys to monitor spread and imporance of MLN and viruses causing the disease were carried out in major maize growing areas in the country. Below are summary of results of an extensive surveys conducted over the last four years (2014 – 2016) across the country with emphasis on major growing areas in Oromia, SNNPR, West Amhara, and Central and South zones of Tigray regions during both the main- and off-seasons (Fig. 4).

Figure 4. Map shows MLN distribution in Ethiopia from 2014 – 2016 main- and short- rainy seasons in Oromiya, SNNPR, Amhara and Tigray regions.

Based on visual disease assessment during the 2014 main season, MLN incidence as high as 100% were recorded in Oromiya (Central rift valley, Jimma and east Wellega zones), SNNPR (Hadiya and Walayta) and Benishangule-Gumuz (kemashi zone at private seed multiplication farms). Incidences ranging from 30-60% were also

Interventions to Manage MLN

First instance surveys demonstrated that MLN is a serious threat to maize production in Ethiopia, and distributed in almost all the major maize growing areas of the country, with incidences as high as 100% were recorded in private, regional and federal seed enterprises and as well as in small scale peasant holdings. The disease also recorded in both main season and irrigated maize fields in the off-season, and all available commercial maize varieties were affected at different magnitude (Mahuku et al., 2015b; Bekele et al., 2017). Understanding the economic significance of MLN in the country, the Ethiopian government has undertaken several interventions aimed at reducing the impact of the disease viz.: Formation of a task force and monthly technical consultative forum; Convening a regional workshop on the management of Maize Lethal Necrosis; Surveillance and monitoring of MLN spread; and Seed health testing and conducting sensitization programs across the country.

As a component of integrated management of MLN (see best practices below), several consecutive consultation workshops, and theory-practical trainings (Table 2) were organized by Federal Ministry of Agriculture (MoA), Regional Bureau of Agriculture (RBoA), EIAR and FAO-Ethiopia in collaboration with experts from EIAR and CIMMYT-Ethiopia to concerned key stakeholders in order to create public awareness about the disease and support disease management endeavors at grass root level.

Table 2. List of theory-practical trainings and consultative workshops held in Ethiopia to manage MLN*.

No.	Date(s) of training	Organizer	Subject	Venue	Participants from
1	29 Sept. 2014	MoA	MLN	Adama	RBoA experts
2	15 -17 December 2014	MoA & FAO-Et	MLN	Bishoftu	RBoA + clinics
3	14 – 16 February 2015	OBoA	MLN	Adama	RBoA experts
4	27 March 2015	MoA	MLN	Addis Ababa	RBoA experts
5	29 July – 1 August 2015	MoA	MLN	Bishoftu	RBoA + clinics
6	21-26 Nov. 2016	ESA	Seed pest of major Crops	Bishoftu	Seed companies
7	20-21 April 2017	ATA	MLN & FAW	Bishoftu	RBoA, Clinics
8	20-21 May 2017	ARCS	MLN & FAW	SARI, Hawassa	RARI, HLI,
9	6 June 2017	PPRC	MLN & FAW	PPRC, Ambo	W & SW Shewa BoA
10	27 June 2017	PPRC	MLN, FAW, maize seed mult.	PPRC, Ambo	TM staff, EIAR
11	15 June 2017	NMRP	MLN & FAW	PPRC, Ambo	Maize researchers
12	5th October 2017	PPRC & CIMMYT	MLN & MLN survey toolbox	EIAR HQ, AA	FRI, RRI, clinics
13	Oct. 12, 2017	NMRP	Consultative Meeting and field visits: The public maize research and its future direction.	Bako ARC, Bako	Key actors in the maize research, extension and seed system

*MoA, Minstry of Agriculture; OBoA, Oromia Bureau of Agriculture; ESA, Ethiopian seed Agency; ATA, Agricultural transformation agency; ARCS, Agricultural research council secretariat; PPRC, Plant protection research center; NMRP, National maize research program; RBoA, Regional bureau of agriculture; RARI, Regional agricultural research institute; FRI, Federal research institute; RRI, Regional research institute; EIAR, Ethiopian Institute of agricultural research.

Best Practices to avoid Maize Lethal Necrosis (adapted from CIMMYT)

The following practices, most of which are cultural, are suggested to avoid/lessen the effect posed by MLN on maize:

- Use clean tools and equipment's during cultivation, i.e., keep farm equipment clean and disinfect after and before use.

- Avoid alternative host during or prior to maize cultivation. Remove the weed and other alternative hosts before and during the crop cultivation.

- Insect Management: If possible it is good to spray suspected or infected field with systemic insecticide in consultation with local Ministry of Agriculture.

- Do not use seeds from infected maize plants or fields for planting.

- Don't feed infected MLN plants to livestock (cattle, sheep, goat, etc).

- Rogue suspected MLN plants: Rogue the infected plants and burn them.

- Discuss within community and get common solution in consultation with the Ministry of Agriculture.

- Crop rotation: Grow non-maize crop like legumes after the maize crop to avoid regular MLN host.

- Disease-free certified seed: Use certified seeds from a reputed seed agency or company.

- Maize free period: Avoid growing maize up to 2 months.

- Avoid visiting your maize field once in contact with any MLN-affected maize field.

Prospects to manage MLN in Ethiopia:

- Feedbacks obtained from various stakeholders in different locations on success stories of performance/implementation of locally possible MLN management endeavors suggested above through successive trainings and awareness creations.

- In some regional states, internal quarantine is imposed of seed and green maize movement from infected areas to free areas/regions

- CIMMYT developed elite MLN tolerant/resistant varieties found promising in Kenya are under evaluation at various locations in Ethiopia.

- Effective seed dressing chemicals targeting MLN causing viruses are also under evaluation for use in integrated MLN management.

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Newly Emerged Plant Virus Disease in Ethiopian agriculture: Status, Causes and Control

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Abstract

/any plant virus diseases that have either newly emerged or expanded their distri"ution in the last two decades are causing considera"le crop losses in Ethiopia. *he eight most significant of these are mai%e lethal necrosis disease (/'0:), sweet potato virus disease (,)5:), to"acco "ushy top disease (*=*:), tomato yellow leaf curl disease, legume stunt, fa"a "ean necrotic yellows and stunt, enset leaf streak and ca""age mosaic. /'0:, ,)5: and *=*: are caused "y synergistic interaction of at least two viruses while others are caused "y single infection. +ll the causal viruses are transmitted "y insect vectors. ;ive of the viruses involved namely <hickpea chlorotic stunt virus, Enset leaf streak virus, Ethiopian to"acco "ushy top virus, ;a"a "ean necrotic stunt virus and ;a"a "ean yellow leaf virus are discovered and descri"ed for the first time in Ethiopia.)reviously known viruses may have either "een introduced to the country "y germplasm import, seed trade or other means whereas new viruses have likely co$evolved with their hosts in Ethiopia. #f the causal virus and its mode of field spread are understood, disease control practices used elsewhere can "e adapted and recommendation can "e made accordingly. @owever, for efficient and sustaina"le management "ased on integrated approach, local studies on epidemiological parameters are often necessary. *here is a considera"le gap in providing suita"ly large scale virus control measures that are effective and afforda"le for use "y farmers. *his is partly "ecause of the lack of well organi%ed research groups with ade6uate num"er of trained personnel and facilities to generate field$"ased data for specific diseases. +s a result, the overall research output has "een inade6uate compared to the magnitude of the virus disease pro"lems the country is facing. + possi"le way to address the pro"lem is to initiate a nationally coordinated research program on integrated management of ma!or virus diseases and allocate the necessary resources for its reali%ation.

-ey words> virus, emerging viruses, epidemiology, sustaina"le management

Introduction

Among the plant pathogens, viruses are considered second only to fungi with respect to economic losses in crops worldwide. A review by Abraham and Assefa (2000) documented the earlier studies on virus and virus-like diseases of crop plants in Ethiopia. Many of the virus diseases described therein such as yellow dwarf of wheat and barley, streak of maize, mosaic diseases of pepper and tomato and yellowing and stunt of legume crops are well established in the agricultural system and continue to negatively affect crop production. On the other hand, several virus diseases which have either emerged as new or increased their incidence in the last two decades continue to incur huge crop losses. The use of modern molecular technologies in the diagnosis and identification of such established or newly emerged virus diseases has led to detailed understanding of the genetic structure of causal viruses and helped in generating useful information to devise ways for their management. Accordingly, about 70 distinct viruses have so far been identified as causing plant diseases in Ethiopia while many more are expected to be revealed in years to come.

Emerging diseases are defined as the ones that have appeared in a population for the first time, or that may have existed previously but are rapidly increasing in incidence or geographic range in the past 20 years causing considerable damage (Castillo et al. 2015, Damstegt, 1999). Worldwide, the number of newly emerged plant disease epidemics has dramatically increased in the last few decades. A critical appraisal of emerging infectious plant disease globally by Aronson et al (2004) indicated that among plant pathogens, viruses make up close to half (47%) of newly emerged plant diseases followed by fungi (30%), bacteria (16%), phytoplasma, nematodes and other taking the remaining 7%. Emerging plant virus disease may be caused by an existing virus when conditions are favorable or by new viruses or virus strains when they are introduced into a new area or a new vector species or biotype appears. This paper describes the top eight most significant virus diseases that have newly emerged or increased their importance in the last two decades in Ethiopia with emphasis on their causal agents, economic importance and options for their control. The virus diseases selected are maize lethal necrosis disease, sweet potato virus disease, tomato yellow leaf curl, tobacco bushy top, chickpea stunt, faba bean necrotic yellows and stunt, enset leaf streak and cabbage mosaic. Specific properties of the causal viruses such as particles morphology, genome structure and methods of transmission are presented in Table 1.

Newly emerged virus diseases of major significance

Maize lethal necrosis disease

The most important disease affecting maize in Ethiopia currently is maize lethal necrosis disease (MLND) caused by synergistic interaction of two unrelated viruses. In Ethiopia, the disease is caused by double infection *Maize chlorotic mottle virus* (MCMV, genus *Machlomovirus*, family *Tombusviridae*) and *Sugarcane mosaic virus* (SCMV, genus *Potyvirus*, family *Potyviridae*) (Mahuku et al. 2015). Among the two causal viruses, the new and the most important component is MCMV since SCMV known to commonly occur on maize in Ethiopia for long time causing mild mosaic symptom (Lencho et al. 1997). Major symptoms of MLND include drying of leaves, premature plant death, failure to tassel, sterility in male plants, malformed or no ears and premature drying or rotting of cobs. High yield losses in maize due to MLND ranging from 50 to 90% have been reported (Niblett and Claflin, 1978) and can reach 100% where the disease pressure is high.Single infection of maize with one of these viruses causes mild symptoms and does not cause MLND. Insect vectors transmitting the virus under field condition are thrips and beetles for MCMV and aphids for SCMV (Brunt et al. 2000). Low level of transmission through maize seeds has been reported for both MCMV and SCMV (Brunt et al. 2000).

In Africa, MLN has first been reported in 2011 in Kenya where it was reported to cause an extensive to complete yield losses to farmers (Wangai et al. 2012). The disease is first reported in Ethiopia in 2014 seasons causing various levels of damage ranging from low infection rate to total crop failure in some maize fields in rift valley area in East Shewa Zones of Oromia Region (Mahuku et al. 2015). Subsequent surveys revealed that the disease is widespread and has caused a total crop failure forcing farmers to replace maize with other crops in many areas of Oromia and SNNP regions (Fentahun et al. 2017, Guadie et al, 2018, in preparation, Demissie et al. 2016). Because both viruses are seed-transmitted although at low rate, the Ethiopian Ministry of Agriculture had decided maize seeds produced for sowing in 2014/5 growing seasons from MLN infected areas not to be distributed for sowing in next season unless they are tested for and confirmed to be free of MCMV to avoid possible virus spread to virus-free areas with infected seeds and insect vectors. Despite initial attempts, the decision was not enforced due to practical difficulties and the disease unfortunately has rapidly spread to nearly all major maize growing areas establishing itself as a major production constraints. The distribution and economic importance of MLND in the country however still varies with Oromia and SNNP regions being the most affected, and Amhara, Tigray and Benshangul-Gumuz regions being of much lesser prevalence and incidence (Demissie et al. 2016, Fentahun et al. 2017, Guadie et al. unpublished). Many MLND positive maize samples in Ethiopia were also shown to be infected with a polerovirus named Maize yellow mosaic virus (Guadie et al. 2017), although its role of this virus in symptom enhancement is not clear.

Since no single method can efficiently control MLND, research efforts are underway in Ethiopia to devise integrated management options. These include screening for resistant genotypes, the use of virus-free seeds and seeds treated with chemicals for vector control, and cultural practices like rogueing of infected plants early in the season and removal of alternate hosts and volunteer plants. Some introduced maize varieties released in Kenya as MLND resistant are found to be promising under field condition and thus being verified under controlled green-house inoculation.

Sweet potato virus disease

Sweet potato virus disease (SPVD) caused by dual infection of aphid-transmitted ,weet potato feathery mottle virus (SPFMV, genus)otyvirus, family)otyviridae) and whitefly-transmitted ,weet potato chlorotic stunt virus (SPCSV, genus <rinivirus, family <lostroviridae) is the most serious disease of sweet potato in Africa since 1940s.

Single infection of any of the viruses only causes milder symptoms and does not cause SPVD. The disease has not been reported in Ethiopia until the last decade. For example, Alemu (2004) reported a high incidence of SPFMV in some fields mainly from Wolayita zone but did not encounter SPCSV and thus suggested the absence of SPVD in the country. Few years later however, symptoms resembling those of SPVD were observed in some research and farmers' fields in southern Ethiopia. The unusually high infection rates of what appeared to be SPVD in 2006/7 cropping seasons in particular forced the national research system to temporarily stop the distribution of 16 improved sweet potato varieties released over a period of a decade

[illegible]

bodies to scale up the activities to have a meaningful positive impact in sweet potato production.

Tomato yellow leaf curl Disease

Tomato yellow leaf curl disease (TYLCD) is a major constraint of tomato production worldwide caused mainly by whitefly transmitted begomoviruses collectively called Tomato yellow leaf curl virus-like viruses (Aunpam and Malathi, 2003). The disease was not encountered in large scale surveys of tomato virus diseases done in 1980s and 1990s in Ethiopia in which mosaic causing viruses such as tobamoviruses and potyviruses have been reported as prevalent (Agranovisky and Anisimoff, 1986; Hiskias et al. 1999). However, in 2003, a disease resembling TYLCD was reported first from Melkasssa area in central rift valley and laboratory analysis revealed the association of a begomovirus provisionally identified as *omato yellow leaf curl /ali virus (TYLCMLV) (Shih et al. 2006). A follow up PCR-based survey in 2009 indicated that TYLCD occurred in epidemic proportion on tomato in some parts of the Rift Valley areas with a high incidence of (up to 95%) (Wada et al., 2014). The disease was particularly severe in fields at Upper Awash, Merti, Melkasa and fields along the road from Mojo to Zwai along with high whitefly population. This work thus revealed the emergence of TYLCD as a major tomato virus disease causing serious losses in the fields of Rift Valley areas and that measures for its management are necessary. Further molecular studies of the complete genome of seven TYLCMLV isolates revealed the occurrence of two distinct sequence variants of TYLCMLV that may be considered as two strain groups which differ in 7% nucleotide sequence across the virus genome (Abraham and Winter, unpublished data).

The epidemic of TYLCD in the affected areas is consistently associated with the high population of the whitefly (=emsia ta"aci). It is suggested that the warmer environmental conditions together with more intensive monoculture in the Rift Valley may have provided favorable condition for population increase of its whitefly vector. In other countries, the emergence of TYLCD is believed to be associated with the global expansion of the B biotype of =.ta"aci (Aunpam and Malathi, 2003). Hence, biotyping of whitefly population in affected tomato fields can provide useful information. It should be noted that the whitefly (*B. tabaci*) is also shown to transmit tomato mild mottle virus (Abraham *et al.*, 2012a), an ipomovirus known to be widespread in tomato fields in Ethiopia (Hiskias et al. 1999), arising further concern on the importance of the whitefly in tomato virus diseases epidemiology.

Controlling TYLCD is a demanding task that can only be successful by integrated implementation of several management strategies, including cultural practices like crop rotation, the use of host-free period insecticidal control of the insect vector and obtaining transplants from virus-free areas and when available, along the use of resistant varieties (Anupam and Malathi, 2003). In Mali, for example a host-free period of two months has been reported to be successful for managing begomovirus infections of tomato (Pfeiffer *et al.*, 2011). Whereas practices used elsewhere can be adapted to control TYLCD, local studies on its integrated management based on adequate understanding of the epidemiological parameters including alternate hosts and appropriate planting date are necessary for efficient and sustainable management.

2.4. Tobacco bushy top disease

A new virus-like disease of tobacco (*Nicotiana tabacum*) first observed by the author in 2006 cropping seasons in Bilate commercial farm during a general virus survey rapidly became widespread in the region resulting in drastic reduction (up to 60 %) in harvestable leaf yield. Diseased plants showed symptoms of stunted growth, leaf distortion and curling. Early formation of lateral shoots on which other shoots were produced resulted in infected plants showing the characteristic bushy top appearance. The symptoms resemble what is known to be characteristic of the tobacco bushy top disease (TBTD) first reported in Zimbabwe in 1958 where it caused severe damage (Gates et al. 1962). TBTD was caused by a mixed infection of *Tobacco bushy top virus* (TBTV, genus *Umbravirus*) and *Tobacco vein distorting virus* (TVDV, genus *Polerovirus*, Family *Luteoviridae*). Due to striking similarity in symptoms, it was initially suspected that the same causal agents are involved in bushy top disease of tobacco in Ethiopia. In the contrary however, it was revealed that the disease is caused by a novel combination of a new umbravirus, potato leaf roll virus (PLRV) and a new satellite RNA (Abraham et al., 2014).

In experimental host range study (Abraham et al. 2014), the disease was transmitted to Virginia tobacco causing disease identical to that in the field. In addition, many other solanaceous species including 0. occidentalis, 0 rustica, 0. ta"acum (cv. Xanthi & Samsun), 0. hesperis, 0. clevelendi and ,olanum lycopersicum (tomato) were infected by artificial inoculation. Among the weed samples collected from tobacco fields, the three agents were detected in 0icandra physaloides samples collected in both 2009 and 2011. All the three agents are efficiently transmitted from bushy top-diseased tobacco by field-collected red tobacco aphid (/y%us persicae nicotiane) to healthy tobacco plants including Virginia variety and several other plant species (Abraham et al. 2014). Hence, this aphid which is also the most common insect in tobacco fields in Ethiopia, is very likely responsible for the field spread of the disease. PLRV is required for transmission of all the viral agents by the aphid.

Experiences of tobacco bushy top disease management from countries like China and Zimbabwe shows that no single method can result in complete control of the disease and that integrating the various components is necessary to minimize the loss due to the disease. Since the disease is spread in similar way, the same approach can be adapted to manage the disease. The options include the use of insecticide to control the aphid vectors, employing cultural practices like avoiding planting and seedbed preparation during the time with high aphid pressure, suitable adjustment in crop calendar (intercrop period between the tobacco crops) and safe distance between seedbed and standing crops reducing primary infection sources like weeds and volunteer tobacco crops and early rouging of infected plants, and if available, using disease resistant varieties. In China for example, the use of insecticides alone resulted in 61% control efficiency whereas integrated approach using insecticides and cultural practices increased the efficiency to 86.9%.

Chickpea Stunt disease

Serology-based surveys in late 1990's suggested that =eet western yellows virus (BWYV) is the main cause of stunting and yellowing diseases of chickpea, lentil and faba bean (Abraham et al. 2000, Tadesse et al. 1999). In chickpea in particular, stunt is considered the second most important chickpea disease after fungal wilt and root rot disease and causes a yield loss as high as 30% (Hulluka and Tadesse, 1994). A more detailed molecular investigation on viruses associated with chickpea stunt and faba bean yellows in Ethiopia however revealed that it is predominantly caused by a new polerovirus for which the name <hickpea chlorotic stunt virus (CpCSV) has been coined (Abraham et al. 2006). In the same work, it was shown that the virus naturally infect lentil, grasspea and fenugreek causing similar symptoms. The virus is found to be transmitted by +phis craccivora and its host range and complete genomic sequence have been described (Abraham et al. 2006)

Since its discovery in Ethiopia, CpCSV is reported from many countries including Eritrea, Sudan, Syria, Morocco, Egypt, Tunisia, Azerbajan, Australia, China, Yemen and Iran (Abraham et al. 2009, Makkouk and Kumari, 2009). A study also indicated that there are at least two CpCSV strains that different considerably in their symptomatology, serology, nucleotide sequence and their geographical distribution within East and North Africa and West Asia (Abraham et al. 2009). The existence of serological cross reaction between CpCSV and other legume poleroviruses such as BWYV has been implicated as a possible reason for the previous misidentification of the virus as BWYV (Abraham et al. 2006).

In a legume virus survey conducted in 2007 growing season in northern Ethiopia (Gojam, Gonder, Tigray, Wello and Shewa regions), most of the 128 chickpea and lentil fields had stunt symptoms resembling those caused by viruses with incidence ranging from trace up to 80%. The highest prevalence and incidence of chickpea stunt was recorded in Western Tigray with incidence as high as 80% recorded in Shire area (Adane Abraham and Bedasso Jebessa, unpublished data).This contrasts with earlier reports where incidence of chickpea stunt disease is usually not more than 30% (Hulluka and Tadesse, 1994). CpCSV is the most prevalent virus serologically detected in 105 out of 125 (84%) of the fields. The reported high prevalence, incidence and expansion of geographical distribution of stunt in chickpea and other legumes caused by CpCSV suggests that its economic importance has increased in the last decade. Thus, concerted efforts should be made to manage the disease. In addition to CpCSV, another new virus causing stunting and yellowing in lentil in Ethiopia has been described using molecular methods and a tentative name Lentil stunt virus is given (Abraham et al. 2008). Other viruses rarely associated with legume stunt disease hence of minor economic importance in Ethiopia include Bean leaf roll virus, Chickpea chlorotic dwarf virus and Faba bean necrotic yellows virus and Soybean dwarf virus (Abraham et al. 2000, Abraham et al. 2008. Tadesse et al., 1999).

As a newly discovered virus, little research attention was given in Ethiopia and elsewhere to the management of stunt caused by CpCSV. However, since the virus might have existed as a causal agent of chickpea stunt long before its discovery, previously identified sources of resistance for stunt (Hulluka and Tadesse, 1994) might be useful. In addition, the virus is persistently transmitted by aphids like many other luteoviruses and options used for them such as seed treatment and planting date adjustment (Makkouk and Kumari, 2001; Makkouk and Kumari, 2009) can be adapted. Nevertheless, targeted research to identify sources of resistance and other integrated management in Ethiopian condition is required to stop this expanding disease.

Faba bean necrotic yellows and necrotic stunt disease

Necrotic yellows and necrotic stunt represent faba bean diseases caused by three closely related nanoviruses. Necrotic yellows were first reported in early 1989 from faba bean in Syria (Katul et al.,1993), causing huge losses in affected areas. In Ethiopia, it was reported in lentil and faba bean with the causal agent identified as ;a"a "ean necrotic yellows virus (FBNYV)(Tadesse et al., 1999; Abraham et al. 2000). In faba bean, leaves become thick and brittle and show interveinal chlorotic blotches starting from the leaf margins which becomes necrotic and kills the plants within 5–7 weeks. In other legumes, the nanoviruses cause yellowing and stunting symptoms very similar to luteoviruses with the exception of grasspea on which severe stunting and bunchy top leaves are observed (Abraham and Lencho, 2000).

Earlier serological studies suggested that FBNYV caused necrotic yellow disease of faba bean in Ethiopia (Franz et al. 1996, Tadesse et al. 1999, Abraham et al. 2000). Detailed molecular studies at genome level however later revealed that most faba bean nanovirus isolates from Ethiopia were genetically distinct from typical FBNYV isolates from other countries, by over 25% in total nucleotide sequences difference (Grigoras et al. 2010). Based on molecular criteria, these isolates predominant in Ethiopia were thus considered to belong to a distinct species for which the name ;a"a "ean necrotic stunt virus (FBNSV) has been proposed (Grigoras et al. 2010). Further molecular analysis of large number of Ethiopian nanovirus isolates (Abraham et al. 2012b revealed that in addition to FBNSV, two more distinct nanovirus species, comprising typical FBNYV identical to that found in countries like Syria and a novel species named ;a"a "ean yellow leaf virus (FBYLV) exist in Ethiopia in limited proportion of samples. FBYLV is thus a tentative new nanovirus species so far reported only from Ethiopia. FBNSV, on the other hand is reported from few more countries including Morocco, Azerbajan and Iran (Abraham et al. 2010).

The three nanoviruses have similar mode of spread and thus can be managed in the same way. Thus, the integrated virus management practices found effective for faba bean necrotic yellows virus in Egypt (Makkouk & Kumari, 2009) can be recommended for FBNSV in Ethiopia. These consists of seed treatment with imidacloprid before planting, judicious application of insecticide for vector control, planting at an appropriate time to avoid peak number of viruliferous aphids, planting to provide high-density crop stand, and planting with resistant genotypes, where available. Attempts to obtain faba bean genotypes resistant to FBNSV from local accessions in Ethiopia as well as from international sources by field screening with supplementing artificial inoculation has not been successful as all accessions were highly susceptible (Abraham and Bedasso, unpublished data).

Enset leaf streak disease

Leaf streak disease, also causing severe stunting of enset (Ensete ventricosum) plants, has been reported in different parts of Ethiopia in 1990's. The association of a bacilliform DNA virus has been reported with the disease (Tessera et al. 1995). Preliminary yield loss assessment of two enset clones in natural stands showed that there is very high reduction in the fresh yield (93-98%), pseudostem circumference (74-77%) and height (64-73%) (Tessera et al., 2009). However, apart from suggested badnavirus etiology at genus level (Quimo and Tessera, 1996, Williams and Matile-Ferrero, 1999), the precise identity of the causal virus species remained unknown.

Recently, from enset with leaf streak disease, a virus resembling the badnavirus reported earlier (Tessera et al. 1995) by having bacilliform particles has been isolated and further characterized using molecular tools including rolling circle amplification, inverse PCR and nucleotide sequencing (Abraham et al. 2017). The virus particles decorated at medium level using Banana streak virus OL antibodies indicating their serological relationship. Sequence analysis of its circular dsDNA genome showed that the virus is genetically most closely related to Sugarcane bacilliform Guadaloupe D virus recently reported from sugarcane with 73.6% overall nucleotide identity. Based on molecular criteria, the virus is sufficiently distinct that it should be considered a new species in genus =adnavirus for which the name Enset leaf streak virus (ELSV) is suggested. The virus was also detected in 6 out of 40 randomly collected enset samples using virus specific primers in PCR suggesting that ELSV is fairly widely distributed. Banana streak OL virus (BSOLV), the most common banana virus in Africa, was not detected in any of enset samples while several banana samples were positive.

Mealybugs which are known to be the main vectors of badnaviruses may also contribute to the field spread of the virus from infected to healthy plant. In Ethiopia, two species of mealybugs, <ateanococcus ensete and)lanaococcus ficus are reported to be associated with enset (Williams and Matile-Ferrero, 1999). Hence, the potential of these mealybugs in transmitting ELSV should be investigated.

Since enset is vegetatively propagated, tissue culture in combination with heat and chemotherapy may assist in obtaining virus-free enset to minimize possible loss due to the virus. Similar approach has been successfully implemented for related vegetatively propagated crops like banana and plantain. In recent years, efforts are being made by research institutions in Ethiopia to provide growers with large quantity of tissue culture-derived disease-free enset seedlings of improved varieties to boost production (Abraham, 2009). Badnaviruses however are known to be integrated to host genome and there is evidence of the same in ELSV-enset pathosystem (Abraham et al., 2017). Thus, a reliable virus-testing procedure discriminating integrated and episomal viral sequences is necessary.

Cabbage mosaic disease

About 70% of leafy vegetables consumed in Addis Ababa are supplied by small scale farmers living in the city. Cabbage (=rassica oleracea var. capitata) is the most widely grown leafy vegetable in Addis Ababa. A virus-like disease of cabbage with symptoms including mosaic, leaf distortion, a striking yellowing and veinal chlorosis,stunted growth and leaf deformation severely reducing yield and impair quality of cabbage has been observed by the author in fields in Addis Ababa since 2011. In a survey conducted in 2016 and 2017 in 21 farms, the disease was recorded in nearly all cabbage fields with incidence often reaching 100%. The symptoms were more severe in black stemmed varieties locally called Tikur gomen. When 108 samples collected from suspected cabbage samples were tested by double antibody sandwich ELISA for three viruses, *urnip mosaic virus (TuMV) was observed in all filed while some also had mixed infection of TuMV and <auliflower mosaic virus (CaMV) (Abraham and Guadie, unpublished data). The result was confirmed by reverse transcriptase-PCR and sequencing of TuMV genes product of ca. 1kb with selected cabbage samples which indicated that TuMV is indeed the causal agent the disease. From the results, the Ethiopian TuMV isolate has 97% nucleotide identity with UK1isolates (from United Kingdom). This is the first report of virus disease infecting these crops in Ethiopia. The cabbage aphid (=revicoryne "rassicae) which is known to transmit the disease is also observed in many fields. The high incidence,

the magnitude of losses in yield and marketability of cabbage due to TuMV calls for further information on its distribution and importance in other parts of the country and the need for devising immediate control measures.

TuMV has wide host range and is efficiently transmitted in a nonpersistent manner by several aphid species, most notably the green peach aphid (/ y%us persicae) and the cabbage aphid (=revicoryne "rassicae) non-persistently. Cultural practices like removing TuMV-infected plant debris and eradicating infected plants around fields can help to reduce virus inoculum and hence spread. The application of a straw mulch to seed beds, to deter aphids from landing and feeding, ensuring that individual crop species are grown separately, destroying when possible all weeds, both in the crops and in their immediate vicinity are some of the control methods recommended. As a non-persistently transmitted virus, the use of insecticides is unlikely to completely control TuMV but might help to reduce aphid populations and reduce the rate of virus spread. Sources of resistance for TuMV have been found and used in other countries and could be looked after in Ethiopian cultivars.

To summarize, among the newly emerged virus diseases discussed above, MLND, SPVD and tobacco bushy top are caused by synergistic interaction of two or more unrelated viral agents co-infecting the plants. While the first two are known synergisms described elsewhere, that of bushy top is novel discovered only in Ethiopia. In both single and co-infections, previously known and newly discovered viruses are involved. Accordingly, SCMV, PLRV, TYLCMLV and TuMV are viruses previously known to cause similar disease in Ethiopia and elsewhere. PLRV, although widespread on potato worldwide, has very low incidence in the crop in Ethiopia (Bekele et al. 2011). Most notably, it has never been reported to infect tobacco anywhere before. MCMV which has been established in the Americas long time ago may have been recently introduced to Ethiopia via seeds. On the other hand, five viruses namely CpCSV, ELSV, FBNSV, FBYLV and ETBTV are described for the first time in Ethiopian crops, perhaps with specific adaptation to their respective hosts in the country. Thus, viruses previously known elsewhere and newly discovered have been contributing to new virus disease emergence in

Ethiopia. The unusually high number of new viruses associated with emerging diseases suggests that Ethiopia which is known to be center of origin and/or diversity of cultivated crops is also an important center of origin or diversity for viruses which may have coevolved with the respective hosts.

Factors deriving virus disease emergence

Among the factors deriving the global emergence of plant virus diseases, introduction from other countries makes up 71%, followed by change in vector population (16%), weather (5%), recombination (5%) and farming techniques (3%) (Aronson et al. 2004). Humans are known to be largely responsible for virus introduction directly or indirectly. Directly, humans contribute by introducing 1) a new virus or virus strain often linked to the movement of seeds or vegetative propagated materials due to germplasm movement or seed trade, 2) a new vector species or biotype (e.g. aphids, whiteflies, thrips and whiteflies) along with such materials 3) a new crop or new vulnerable genotype during crop diversification. The weak quarantine system in which virus inspection not done using reliable and sensitive techniques like ELISA and PCR may have contributed to the situation. Humans can also indirectly contribute by inducing changes in agronomic practices due to agricultural modernization by planting monocultures or exotic crops, by introducing agricultural practices like irrigation that enhance virus spread, or by excessively relying on chemical control enhancing vector resistance to insecticide. In addition to humans, viruses can be introduced to a country via aerial vectors across borders as many can fly long distances. Finally, seasonal or long-term changes in climate can enhance virus spread.

It is known that several exotic pathogens and insect pests have gained entry in to the Ethiopia during the past decades (Kumsa et al., 2009) but no information exists on intercepted viruses probably due to the fact that our quarantine system is unable to effectively detect viruses. Thus one can only speculate about the possible origin the specific viruses discussed above. MCMV is probably introduced with maize seeds from the Americas to Eastern Africa including Ethiopia from which further spread within the country is facilitated by ubiquitous aerial vectors and seeds. The finding of limited genetic diversity among isolates of MCMV from different geographic locations and hosts (Fentahun et al. 2016, Mahuku et al. 2015, Guadie et al. unpublished) seems to support this suggestion. The widespread occurrence of SCMV, the presence of susceptible maize cultivars and environmental conditions favoring the vectors may have aggravated the development of MLND. Sweet potato viruses are very likely introduced from Eastern Africa with vegetative planting materials introduced for research purposes, further being disseminated with released varieties. The likely route for the incursion of TYLCMLV is inadvertent introduction of infected tomato seedlings and fruits or seedlings from nearby African countries, as it is the case for the international movement of other TYLCV-like viruses.

Among the viruses newly described in Ethiopia, CpCSV is found to be genetically most closely related to ?roundnut rosette assistor virus (GRAV) (Abraham et al. 2006) while ETBTV is most closely related to ?roundnut rosette virus (GRV) (Abraham 2014). These two groundnut viruses are known to be endemic to Africa causing a devastating groundnut rosette disease. Naidu et al. (1999) suggested that the groundnut rosette disease agents including GRAV and GRV have evolved with indigenous plants in Africa and later infectedgroundnut when it was introduced in the 16th century. CpCSV, ETBTV and the two groundnut viruses have overlapping geographical distributions in Africa. Therefore, it is possible that the CpCSV and GRAV on one hand, and ETBTV and GRV on the other, have common ancestors in Africa, perhaps in Ethiopia, from which they have diverged by adaptation to different hosts. ELSV appears to have specific adaptation to enset and hence may have co-evolved with the host in Ethiopia.

Challenges in Virus Management and Ways Forward

It is clear from the foregoing accounts that considerable progress has been made in recent decades in diagnosis and identification of the causal agents of economically important crop virus diseases in Ethiopia. The ultimate goal of applied virus research is however to generate and adapt technologies to control the diseases and prevent economic losses. Unfortunately, the national agricultural research system is lagging behind in providing suitably large scale virus control measures that are effective and affordable for use by farmers. This can be partly attributed to the challenging nature of research on virus disease management which involves selecting the best measures for each virus–crop combination and production system and sensibly integrating the various options. The basis for this is the knowledge of the epidemiology of the specific virus disease in a given agroecosystem typically generated by field-based research data, an area currently ignored. Such work is demanding and needs committed and well organized research groups with adequate number of trained personnel, facilities andinstitutional set up. Due to lack of such prerequisites, research in virus epidemiology is currently very weak and available information is patchy and fragmented often lacking continuity. Consequently, the overall research effort has been inadequate compared to the magnitude of the virus disease problems the country is facing.

At present, only few researchers are involved in crop virus research on full time basis. In their research, they face a diverse array of challenges ranging from poor system of acquiring the necessary inputs and facilities to technical issues including absence of resistance genes in host plants, lack of expertise to identify and seasonally monitor major insect vectors, and inability to elucidate the contribution of alternate hosts, crop residues or seeds to inadequate information on virus ecosystems with the consequent inability to forecast epidemics. Furthermore, even if effective control package of a disease are developed, it is difficult to ensure their adoption on a sufficiently large scale due to the inability of the farmers to deploy and adopt the research findings due to unaffordable cost and knowledge gaps. This is compounded with the limitation in the capacity and resources available for extension services to implement specific recommendations. This shows that the complex task of managing important virus diseases and preventing the introduction of new ones was not given the attention it deserves and concerted effort of all stakeholders is needed to address the problem. One of the interventions could be to initiate a grand nationally coordinated research program on integrated management of major virus diseases and allocate all the necessary resources for its realization. This will enable the country to prevent crop losses being incurred currently by newly emerged economically important virus diseases at the same time preparing to avoid future damages.

Table 1. Properties of the virus(es) that are the causal agents of emerging diseases

Disease	Causal Virus(es)	Particle shape & size	Genome type & size	Natural transmission
Maize lethal necrosis	/ ai%e chlorotic mottle virus	isometric, 30 nm	ssRNA, ~4.5 kb	thrips, beetle, seed
	,ugarcane mosaic virus	filamentous, 750 nm	ssRNA, ~10 kb	aphids, seed
Chickpea stunt	<hickpea chlorotic stunt virus	isometric, 28 nm	ssRNA, ~5.9 kb	aphids
Faba bean necrotic yellows or stunt	;a"a "ean necrotic stunt virus ;a"a "ean necrotic yellows virus ;a"a "ean yellow leaf virus	isometric, 18 nm	ssDNA, multipartite, ~8 kb	aphids
Tobacco bushy top	Ethiopian to"acco "ush top virus	isometric, 25 nm	ssRNA,~ 4.3 kb	aphids
	)otato leaf roll virus	isometric, 25 nm	ssRNA, ~6 kb	aphids
	sat40+	isometric, 25 nm	ssRNA, ~0.6 kb	aphids
Enset leaf streak	Enset leaf streak virus	bacilliform, 30x150 nm	dsDNA, ~7.2 k b	mealybugs, propagule
Cabbage mosaic	*urnip mosaic virus	filamentous, 750 nm	ssRNA, ~10 kb	aphids
	<auliflower mosaic virus	isometric, 52 nm	dsDNA, ~8 kb	aphids
Sweet potato virus	,weet potato feathery mottle virus	filamentous, 750 nm	ssRNA, ~10 kb	aphids. propagule
	,weet potato chlorotic stunt virus	filamentous, 900 nm	ssRNA, ~17 kb, bipartite,	whitefly, propagule
Tomato yellow leaf curl	*omato yellow leaf curl / ali virus	isometric, twin, 20x38 nm	ssDNA, ~2.7 kb	whitefly

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Overview of Coffee Protection Research in Ethiopia

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Abstract

*he average yield of coffee in the country is generally low (a"out C2B kg Dha) which is half of that achieved in 'atin +merica. *his is partly due to the limited use of improved technologies and "est practices "y most small$holder farmers, the widespread and prevalence of insect pests, diseases and coffee weeds. @owever, coffee suffers from a range of diseases including coffee "erry disease (<=:), coffee wilt disease (<9:) and coffee leaf rust (<'4) caused "y <olletotrichum kahawae, ?i""erella xylarioides and @emileia vastatrix, respectively. =acterial "light of coffee (==<) and coffee thread "light which is caused "y)seudomonas syringae pv garcae van @all and <orticium koleroga respectively "ecomes an emerging constraint in ,idama and ?edeo 8one at ?era, /etu and 'immu @ori%on coffee plantation. <offee insect pests, mainly antestia, leaf miners and coffee thrips, cause damage in most coffee growing regions of the country. *he coffee growing areas of Ethiopia, characteri%ed "y high rainfall and suita"le temperature and edaphic conditions, encourage the growth of diverse weed flora ranging from a"undant seed producing annuals to hardtocontrol rhi%omatous and stoloniferous perennial grasses and sedges. 4esearch experience has shown that)erennial grasses, sedges, and annual weeds with their fast and vigorous growth can easily oppress coffee, and result in extremely low yields and affect the 6uality of the crop. *o date, a"out 1 released <=: resistant cultivars are under production in coffee growing areas of the country, which is one of the ever success stories in coffee research and development that saved the Ethiopian coffee industry from catastrophe. <offee wilt pathogen is known to "e passive in its mode of penetration; strict practices of sanitation and disease prevention are unavoida"le. <offee leaf rust is widely distri"uted all over coffee growing regions of the country with varying intensities and coffee production systems. :etail characteri%ation of pathogen and standard screening protocol is important for coffee leaf rust, coffee "acterial "light and coffee thread "light disease. Emphasis should "e given for the development of appropriate management method for control of important coffee insect pests. =ecause of the diversity of weeds and the environmental conditions in the coffee growing areas #ntegrated 9eed /anagement (#9/) would "e the "est strategy for sustaina"le coffee production.

Key words› <offee, <offee disease, insect pests, weed species

Introduction

Coffee is the most popular soft drink in the world. Over 2.25 billion cups are consumed every day (Ponte 2002). Its popularity and volume of consumption are growing every year, and coffee shops are the fastest growing part of the restaurant business. Economically, coffee is the second most exported commodity after oil, and employs over 100 million people worldwide (Petit 2007; Pedegrast 2010; Gray et al.

2013). According FAO statistics (www.faostat3.fao.org), global coffee production area covered around 10,142,285 ha in 2013.

For Ethiopia, coffee is the most important export commodity, with a share of 20-25% of the total foreign exchange earnings. At least 15 million people also directly or indirectly rely on coffee for their livelihood (Ministry of Trade 2012, Gray *et al.* 2013). As the county of origin for crop, Ethiopia produces premium quality coffee. It is the leading producer in Africa, and the 5th in the world, following Brazil, Vietnam, Colombia and Indonesia. If we consider Arabica alone, Ethiopia is the 3rd largest producer after Brazil and Colombia (ICO 2015).

The average yield in the country is generally low (about 748 kg /ha) which is half of that achieved in Latin America and Asia. This is partly due to the limited use of improved technologies and best practices by most small-holder farmers, the widespread prevalence of insect pests, diseases and coffee weeds (Girma *et al.*, 2009, Phiri *et al.*, 2009, Esayas *et al.*, 2008, Tadesse E and Tesfu, 2015, Kifle *et al.*, 2015, Demelash and Ashenafi, 2017 ,Tamiru *et al.*, 2017). However, coffee suffers from a range of diseases including coffee berry disease (CBD), coffee wilt disease (CWD) and coffee leaf rust (CLR) caused by *<olletotrichum kahawae*, *?i""erella xylarioides* and *@emileia vastatrix*, respectively. Bacterial blight of coffee (BBC) and coffee thread blight which is caused by *)seudomonas syringae pv garcae van @all* and *<orticium koleroga* respectively becomes a major concern in Sidama and Gedeo Zone at Gera, Metu and Limmu Horizon coffee plantation.

Coffee insect pests, mainly antestia, leaf miners and coffee berry borer, cause damage in most coffee growing regions of the country. The coffee growing areas of Ethiopia, characterized by high rainfall and suitable temperature and edaphic conditions, encourage the growth of diverse weed flora ranging from abundant seed producing annuals to hard-to-control rhizomatous and stoloniferous perennial grasses and sedges. Research experience has shown that Perennial grasses, sedges, and annual weeds with their fast and vigorous growth can easily oppress coffee, and result in extremely low yields and affect the quality of the crop (Tadesse E. 1998).

Therefore, this paper attempts to review research findings on coffee diseases, insect pests and weeds and their control methods in major coffee growing areas of Ethiopia.

Research Findings

Coffee Berry Disease /CBD/

Coffee berry disease was first reported in Kenya, close to the border with Uganda in 1922 (McDonald, 1926). Mogk (1971) confirmed the occurrence of coffee berry disease for the first time in Ethiopia in 1971; The prevalence of coffee berry disease was assessed in different regions of Ethiopia in various times and coffee production systems with different scholars IAR (1997), Melaku and Samuel (2000), Tesfaye and Sinedu (2000) and Arega (2006). Recently Kumulachew et al, 2016 reported 29.9% of national average crop losses to total harvestable coffee yield every year due to CBD and then the increased intensity were associated with disease management and altitude.

Occurrence of *Colletotrichum spp.* on Coffee and Pathogenic Variability among CBD Isolates

<olletotrichum kahawae is the only species, which is pathogenic to green coffee berries, which also colonizes berries of other stages, leaves and maturing bark of the branches. (Hindorf, 1975; Rodrigues et al., 1992; Tefestewold, 1995). The results of three independent studies evidenced no host specialization (physiologic races) in the CBD pathogen populations in Ethiopia (Tefestewold, 1995; Eshetu and Waller, 2003; Arega, 2006). Tefesetewold (1995) tested six isolates sampled in Keffa, Sidamo, and Hararghe on three CBD resistant cultivars (741, 744, and 74110) and a landrace from Sidamo (Kurme) and found significant variations in aggressiveness among the isolates . Similarly, twelve <. kahawae isolates sampled from four montane rainforest coffee areas in Harenna, Bonga, Sheko, and Yayu; and inoculated with seedlings of three widely grown CBD resistant cultivars and a susceptible check. The isolates were pathogenic and varied in aggressiveness (Table 1) (Arega, 2006). These results emphasize that horizontal resistance in the host populations practically advantageous to deploy resistant coffee varieties in CBD management.

Epidemiology

The occurrence and intensity of CBD varies from place to place and from one season to the other, depending largely on pooled effect of host susceptibility, pathogen aggressiveness, and favourable climatic conditions. The disease is initiated mainly from diseased berries (green, ripen and mummified) and infected plant parts (flowers, barks, twigs and leaves) and appears every year again on previously infected coffee trees (Gassert, 1979; Tefestewold, 1995). Conidia are the asexual spores and major inoculums that can be dispersed easily by rain splash and winds over short distances such as dispersal within tree canopy and from tree to the other (Griffiths et al., 1991). Therefore, tree tops are extremely important as sources of inoculum while longer distance dispersal of CBD inoculum has apparently been by passive vectors such as man, vehicles, birds, and insects that may carry viable spores or through the movement of diseased coffee materials such as unshelled coffee or young plants and other vegetative materials (Tefestewold, 1995).

Table 1. Pathogenecity of 12 <.khawae isolates collected from afromontane forest coffee areas inoculated with seedlings of 3 CBD resistant and susceptible cultivars in growth room.

Isolate [1]	Coffee cultivar [2]				Mean [3]
	741	754	74110	370	
H40	14.0 gh	20.3 g	88.7 b-d	100 a	55.8 AB
H41	12.7 gh	17.8 gh	85.3 b-e	100 a	54.0 A-C
H43	14.2 gh	15.4 gh	78.3 d-f	98.0 a	51.5 CD
B52	20.2 g	17.9 gh	89.5 bc	100 a	56.9 A
B53	16.5 gh	13.8 gh	86.6 b-e	100 a	54.2 A-C
B55	17.7 gh	18.9 gh	77.8 d-f	98.3 a	53.2 B-D
S60	12.3 gh	13.7 gh	80.3 c-f	100 a	51.6 B-D
S61	10.7 gh	14.3 gh	76.9 ef	97.6 a	49.9 D
Y70	9.0 h	15.0 gh	79.0 d-f	100 a	50.8 CD
Y73	14.6 gh	18.5 gh	92.7 b	98.3 a	56.0 AB
Y75	16.0 gh	10.8 gh	21.0 g	70.3 f	29.5 E
G81	21.8 g	9.3 h	79.3 d-f	98.3 a	52.2 B-D
	15.0 L	15.5 L	78.0 K	96.7 J	

[1] <olletotrichumkahawae isolates coded with E@, =, ,, F and ?were collected from @arenna (=ale), =onga, ,heko, Fayu and ?era, respectively. [2] <offee cultivar C21, C2G2 and C211. are <=: resistant cultivars, C. was highly suscepti"le check. / eans followed with the same letter(s) are not significantly different according to : / 4*. ', : values () H ...G) for the cultivars, the isolates and the interactions comparisons are 2.1, .C and C. , respectively.

,ource> +rega, 2..7.

Soon after the outbreak of CBD, a crash CBD resistant selection program is designed and effectively implemented in a multidisciplinary approach. The selection program basically consisted of four major steps; vis.; selection and testing of coffee mother trees, screening of their progenies and at the same time multiplication in large blocks (up to 1000 trees) (Van der Graaff, 1981). In both mother trees and progenies testing procedures visual assessment and berry count in the field, detached berry test (DBT) and hypocotyls seedling test in the laboratory have been employed. Finally, the ever-successful crash program resulted in the release of 15 highly resistant coffee cultivars possessing high yield and acceptable commercial quality traits within a short period of time (Van der Graaff, 1981; Merdassa 1986).

Since 1985, great efforts have been made adopting similar selection scheme and testing procedures in search for more resistant cultivars within the heterogeneous populations in various coffee growing areas of the country. The refined CBD resistance selection involves selection of coffee mother trees without or with very low CBD infection among trees showing high CBD pressure in the field. These selected trees are artificially tested by inoculating berries on three representative branches (top, middle and bottom canopy layers) with active pathogenic form of CBD inoculum. Rapid visual estimation of percent infection of berries per tree is also made for CBD and other diseases like leaf rust and blight. During harvesting, ample seeds are harvested from each selected mother trees for seedling inoculation tests; and half of the seed lots are used for raising seedlings to establish their progenies in the field where the improved varieties intended to be released. The progenies are intensively evaluated for their resistance to CBD (following both attached berry and hypocotyls inoculation tests) and to other major diseases for at least 2 years. In general, as coffee is a perennial tree crop, the selection program needs at least 5 to 6 years. This thorough appraisal of resistance of mature trees to CBD is essential for the detection of field resistance and proof the resistance identified in seedling tests or vis$versa (Van der Graaff, 1981; Merdassa, 1986; Tefesetewold, 1995; Jefuka et al., 2013 kifle et al., 2015). To date, about 31 released CBD resistant cultivars are in production in coffee growing areas of the country of which 10 of them were restricted mid altitude (<1700 masl) where CBD pressure is low.

Coffee Wilt Disease

The production of coffee in East and Central Africa is severely affected by tracheomycosis caused by *?i""erella xylarioides* Heim &Saccas(*;usarium xylarioides* Steyaert). Ethiopia, it is more prevalent in plantation and garden coffee systems (Adugna *et al.*, 2005, Adugna *et al.*, 2009). The national incidence and severity of the disease were 29.9 and 3 percent, respectively, and in monetary terms it caused loss of more than 3.7 million USD (CABI, 2003., Adugna *et al.*, 2009). Unlike coffee berry disease, coffee trees infected by coffee wilt pathogen cannot be saved anymore and this makes CWD management more difficult.

Epidemiology, Pathogenic diversity and host specificity

The epidemiology of CWD and life cycle of the fungus is not fully understood, however, the pathogen is supposed to be soil borne and infect coffee trees through wounds. Girma (2004) reported that some tree predisposing factors such as close spacing, wounding, replanting of susceptible coffee trees at the same spot found to aggravate CWD incidence and prevalence. Preliminary observations made during the regional survey indicated that temperature, rainfall, topography, coffee tree age, shade, soil type, and weeding methods had significant effects on the disease incidence. The incidence of CWD was higher on coffee trees that are planted on shaded, older and weeded by slashing (CABI, 2003).

The result of serious inoculation experiments carried out revealed that highly significant ($p < 0.01$) differences among coffee cultivars and *?.xylarioides* isolates; and significant ($p < 0.05$) cultivars-isolate interactions both in percentage seedling death and incubation period (Girma and Mengistu, 2000; Girma and Hindorf, 2001). These implied existence of horizontal resistance in the host and variation in aggressiveness in the fungus population but a significant interaction between the cultivars and the isolates (i.e., a differential effect) in both disease parameters means vertical resistance in the host and virulence in the pathogen (Girma and Mengistu, 2000; Girma and Hindorf, 2001).

The comparison of host specificity of <offea ara"ica and <. canephora of fungal isolate also revealed Coffea canephora appeared to be very susceptible and was severely attacked by its isolate , However, no death rates were observed when <. canephora seedlings were inoculated with any Arabica isolates. In contrast, <. ara"ica isolates were compatible with seedlings of all the Arabica cultivars and caused varying percentages of death, but non-pathogenic to <. canephora seedlings. (Girma, 2004; Girma et al., 2005).

Disease management

A range of cultural practices can be used in managing CWD. The commonest of all and a well-known method are uprooting of infected coffee trees and burning in situ. Other cultural methods include quarantine, use of disease free planting materials, prevention of coffee tree wounding and disinfecting farm implements. Massive communication and information dissemination efforts were made by JARC to reach farmers, extension workers, commercial agents, and policy makers with information related to CWD helped to equip farmers and extension workers with detailed knowledge and skills regarding CWD management.

Use of resistant varieties is the most appropriate, efficient and economical method for the management of CWD. Jefuka et al., (2012), Kifle et al., (2014) and Demelash and Kifle (2015) reported performance of coffee varities such as Fayate and Odicha for their resistance to coffee wilt disease. On the other hand majority of released coffee varities were found susceptible to CWD. Demelash (2013) and Kifle et al., (2014) also described the genetic variability against coffee wilt disease on Arabica coffee germplasm collections conserved at Jimma, southwest Ethiopia. Among testing coffee accessions 279/71 and 3/70 of fewer Bale 2004 collection showed good performance of resistance to coffee wilt disease (tracheomycosis) at seedling stage. In order to get promising coffee accessions that can be further proved with repeated inoculation and/or field observations in wilt disease infested hotspot areas like Gera and Yirgachefe is in progress.

Coffee leaf rust

Coffee leaf rust was first reported in 1934 in Ethiopia (Sylvain, 1955) but it has never reached to epidemic level to cause eradication of Arabica coffee in the country. This may be as a consequence of long term coexistence of rust and coffee which created a balanced pathosystem and high level of horizontal (race non specific) resistance (Van der Graaff, 1981; Meseret et al., 1987;). CLR is widely distributed all over coffee growing regions of the country with varying intensities (Chala, 2009; Chala et al., 2010; Girma et al., 2016).

The average national infected trees were estimated to 12.9% in 1980 and increased by three fold (36.3%) after ten years in 1990 (Meseret, 1991; Chala, 2009; Chala et al., 2010; Girma et al., 2016). Eshetu et al. (2000), reported as high as 27% CLR severity in Hararghe and this might be attributed to the distribution of susceptible host, occurrence of virulent races and the type of coffee production systems. Current CLR survey study with JARC coffee team indicate that the severity of coffee leaf rust was 5.04% (Goma) and 3.54 %(Gera) of Jimma Zones while in Illubabor zone the severity was 6.97% (JARC, 2017).

Epidemiology: In Ethiopia, onset of rust in monomodial rainfall at high altitude is October to January with peak period in November to December while in lower altitudes rust increase from August to November with peak in September (Chala, 2009; Chala et al., 2010). Other workers reported the occurrence of maximum rust incidence in November to December (Eshetu et al., 2000). These peak epidemics appeared to occur after heavy rainfall (in amount and distribution) months but just before onset of the dry season. This slight variation over seasons may be due to variation in onset of rainfall that initiates epidemics and early removal of infected leaves eliminating inoculum source.

Altitude influence local climatic conditions, which in turn affect the development of the disease. CLR intensity was reported to decrease with altitude in Ethiopia (Meseret, 1996; Chala, 2009; Chala et al., 2010). High altitudes are associated with lower night temperature and a cooler day temperature that result in lowered disease severity (Weyesa et al, 2015).

Resistance study of Coffee genotypes for CLR

The reactions of 56 coffee collections/released varieties including five introductions were evaluated by artificial inoculation with @. *vastatrix* urediniospores in the growth room at Jimma. Occurrence of CLR significantly varied with locations and seasons. Mean incidence of 31.1%, 21.4% and 7.9% and sporulation leaf density of 2.7, 1.8 and 0.86 were occurred in Yayu, Berhane-Kontir and Bonga forest coffee populations, respectively (Chala *et al*., 2009). Seedling inoculation test discerned significant variations among the coffee populations in Ethiopia. Introduced cultivars except Catimor lines and Geisha, showed higher susceptibility (RT 6 - 8) than the indigenous collections. However, Catimor lines manifested more than 60% incidence in the field at Tepi but showed moderate reaction type (RT 3 -, 4.25) in the growth room. Coffee accessions, P24, P27, P315 and P411 had showed consistent resistance reaction while P215, P44 and P48 showed susceptibility under both field and growth room conditions. The observed heterogeneity of forest coffees to rust in the field under the same agro-ecology and in the growth room provide an opportunity to develop resistant varieties among the enormous forest coffee genetic resources in Ethiopia (Chala, 2009).

Bacterial Blight of Coffee (BBC)

Bacterial blight of coffee also known as Elgon or Solai dieback, caused by)*seudomonas syringae* pv *garcae* van Hall, is reported as a serious disease of Arabica coffee in Kenya and Brazil (Mugiira *et al*., 2011). Outbreak of bacterial blight of coffee was reported in three districts in southern Ethiopia where the famous Sidama specialty coffees is produced (Girma *et al*., 2012). The results of three years data showed that the disease syndrome on young, mature and older coffee plants were similar with bacterial blight of coffee documented elsewhere. The disease invariably attacks coffee leaves, branches and shoots with characteristic blight symptoms. The infected branches and shoots start die-back from the point of infection towards the tip while coffee berries on infected branches are also completely destroyed leading to total crop failure.

Currently the spread of the disease was reported at Gedeo, Sidama, Wolita and Kembata-Tembaro Zone of SNNP regional state. The survey result conducted on released and local coffee in six and three district of Sidama and Gedeo Zones respectively revealed the disease is observed in all released coffee cultivars at different locations at various levels of disease severities. The highest disease severity value of 12% was observed on Angefa at Aletawondo. Less than 3% disease severity was observed at Sidama Zone on coffee cultivars 74110, 74112 and 74158. On the other hand at Gedeo Zone severity value of 10.8, 15 and 15.6 % was observed on coffee cultivars of Odicha, Koti and Angefa. Conversely coffee bacterial blight infection was not observed or negligible on compact released cultivars (74110, 741140). On local coffee land race disease severity varied between 12-42 and 12-25 % for Sidama and Gedeo respectively (Demelash and Ashenafi, 2017).

Coffee Thread Blight

Thread blight diseases on Ethiopian coffee for first time seen at Gera and Metu agricultural research sub-stations in 1978 and it may be exists before (Eshetu et.al., 2000; Demelash et.al., 2008). However this disease sporadically occur every five to six year between June and September, but increaslly becoming important around Gera, Metu and Limmu coffee plantation "?umer" (JARC back to office report, 2016). Thread blight of coffee out break seen for first time in 2008 at Limmu coffee plantation farm of "Gumer" with mean diseases incidence and severity of 49.2 amd 9.8, respectively. Assessment result on four commercial varieties of coffee (741, 74110, 75227 and 744) affected with diseases severity percent of 14.42, 21.08, 2.48 and 1.17 respectively (JARC back to office report, 2010, unpublished). The second reported outbreak of the diseases was from Bebeka coffee estate of ":isadis" farm on which 34 hectares of coffee (JARC back to office report, 2012, unpublished). Area wide outbreak of thread blight of coffee seen in 2014 and coffee farms like Duwina of Agricefit PLC, Limmu coffee Plantation of Horizen PLC and Gera and Awada coffee research sub centers reported that they have noticed similar symptoms in the same season of a year. At Agriceft coffee plantation of :uwina farm disease incidence ranged from 32.08 to 92.0 percent per sample plot with average severity was about 55.71 percent (Kifle et al., 2015).

Identification and characterization of fungal isolates of CTB

Almost all the specimens of leaves, branches, twigs and berries collected from infected coffee trees in all sample fields of affected localities namely, :uwina, 'immu sintu and ?umer, consistently produced fungal colony similar in color and morphology on potato dextrose agar media after 7 days incubation at 22^{0}C. The fungal isolates were characterized with conventional procedures like colony morphology, color, uniformity and pathogenecity test on the host plant parts and show characteristics of <orticium koleroga (Causative agent of CTB) (Kifle et al., 2015). However, detailed mycological study and molecular characterization of the pathogen was needed in future for correct identification and classification.

Coffee Insect Pests

Insect pests are one of the biotic factors that affect yield and quality of coffee. Over 47 species of insect pests are known to attack coffee in Ethiopia. Antestia bug, +ntestiopsis intricata,+. facetoides and coffee blotch miner, 'eucoptera caffeinia are the major insect pests of coffee, which inflict considerable damage. On the other hand, coffee berry borer, @ypothenemus hampei, Coffee thrips, :iarthrothrips coffeae, green scale, <occus alpinus and coffee cushion scale, ,tictococcus formicarius are potentially important pests which need research attention (Esayaset. al., 2008).

Survey was conducted in 2015/16 to study the current status of major coffee insect pests in south western and western parts of the country indicated maximum mean number of Antestia bug was recorded at Mettu (0.92) followed by Hurumu (0.85) as compared to other surveyed localities. While the lowest mean number of antestia was recorded at Gimbo (0.03) woredas. In western part the maximum mean number of antestia was recorded at Ayira (0.76) followed by Haru (0.26). The mean infestation of antestia bug at Anfilo , Homa, Manasibu , Mendi , Mugi and Sayo were 0.16, 0.02, 0.03, 0.02, 0.13 and 0.076 respectively . The highest mean infestation 0.92 , 0.85, 0.76, 0.75, 0.65 and 0.56 of antsita bug per sampled trees were recorded at Mettu , Hurumu , Ayira ,Dambigabana , Haro and Gore respectively , which was almost more than economic injury level was recorded at those locations per single tree (Tamiru et al., 2017). The status of 'eucoptera caffiana was assessed at different locations including intensive coffee production system (Goma II, and Bebeka). From the survey result the average infestation of coffee blotch leaf miner at Bebeka , Goma II, Agaro, Haru ,Haro, Melko and Tepi 22.50%-35.7% and at Ayira , Yayo, Gera and at Mettu 11.40% -18.28 whereas at Gore, Gera ,Chora, Beshasha and Nedjo the average infestation of 1.99%-6.94% was recorded.The higher mean percent infestation was observed at Bebeka estate farm which ranged from 2.25%-86.26% with average infestation of 35.11% in different coffee genotypes and agronomic practices. They also indicated the status coffee thrips, : iarthrothrips coffeae. Coffee thrips become a challenging pest of coffee which damaged coffee farms badly in different coffee growing areas of the Ethiopia. At Jimma Zone Limu coffee plantations and Gomma woreda the infestation of coffee thrips 4-28 per leaf was recorded (Tamiru et. al., 2017).

Coffee weeds

The coffee growing areas of Ethiopia, characterized by high rainfall and suitable temperature and edaphic conditions, encourage the growth of diverse weed flora ranging from abundant seed producing annuals to hard-to-control rhizomatous and stoloniferous perennial grasses and sedges. Research experience has shown that weeds can be serious competitors. Perennial grasses, sedges, and annual weeds with their fast and vigorous growth can easily oppress coffee, and result in extremely low yields and affect the quality of the crop (Tadesse E. 1998.) So far over 63 species from 23 families were identified by Getachew (1991).

For successful management of weeds integrated strategies are more useful and safe. While in some production systems, herbicides may provide the main means of control; these alone are unlikely to be successful unless combined with slashing and hand weeding around coffee trees and good land preparation. No one weed control method is likely to control all weeds, and in the long term this can lead to a build-up of certain species. The combination of direct weed control methods, such as herbicides or slashing and hand weeding around coffee trees, with indirect methods such as cover cropping, mulching and intercropping (competitive crops) will help prevent this situation. The use of cover crop like desmodium is also recommended for the management of coffee wilt disease as it is very efficient in suppressing weeds. (Tadesse and Tesfu, 2015, Demelash T., 2017).

Conclusion and Recommendations

CBD still cause significant crop losses on susceptible landraces although the magnitudes vary from place to place and from time to time. There has been no physiologic race recorded so far reported within <ollototrichum kahawae populations that enables to develop durably resistant coffee cultivars. Currently the use of fungicide is not advisable as the national coffee research program has released 31 CBD resistant varieties which can serve different coffee agro ecologies. Prevent wounding of any part of coffee trees that serve as avenue for infection, cultural weed control practices such as slashing and digging of coffee fields should be avoided or be practiced with great care, phytosanitary measures should be taken seriously in to account (strict surveillances of fields, uprooting and burning of infected coffee trees with typical wilting symptoms, i.e., before the fungus produce perithecia and (ascospores) Strictly recommended for management of CWD. Use of tolerant cultivars; provision of balanced crop nutrition; Effective quarantine and use of cultural practices like pruning or cutoff and burning of affected branches just few centimeters below the infection is recommended for managing BBC. For pest management, indigenous natural enemies be conserved and any farm activities which can affect the biological balance of natural enemies be avoided; Cultural practices such as shade tree regulation and pruning of coffee tree can reduce antestia bug and coffee blotch leaf miner population. Because of the diversity of weeds and the environmental conditions in the coffee growing areas however, dependence on single weed management practices is not advisable. Under such circumstance, Integrated Weed Management (IWM) would be the best strategy for sustainable coffee production.

Gaps and Challenges

CBD, CWD and CLR is still the leading disease of Arabica coffee significantly affecting yield in all coffee growing regions of the country. Bacterial blight of coffeeandcoffee thread "light becomes a major concern in some parts of the country. CBD is a challenging disease of high altitude areas, but also occurs in mid land places where the weather becomes favorable; Growers are advised to strictly adhere variety utilization manual as some of released coffee varieties are moderately resistant restricted to mid altitudes.Like any other soil borne diseases, disease management of CWD is troublesome by virtue of being vascular nature of the pathogen and the difficulties of conventional control approach (uproot and burn infected trees at the spot). The disease epidemiology and fungus biology are still less understood. Agronomic/ cultural practices such as slashing and/or hoeing, pruning and stumping activities aggravate the disease situation in various ways. Strong efforts should continue to aware and sensitize and intensively train coffee farmers and extension workers about CWD and its management through practical training. Coffee leaf rust severity become very high and moving to higher altitude area where it was not present before which requires equal attention as major coffee diseases.

It is recommended to conduct successive year's field observations to look for the dynamics of BBC and coffee thread blight disease in the areas in order to understand and factors associated which favors the disease epidemics. Studies on current status of insect pests of coffee and their natural enemies under different ecology and production systems; The need for re-identification of natural enemies, proper studies on biology, rearing and ecological requirements of the identified potential natural enemies, Appropriate insecticides for the control of nursery insect pests and Identifying suitable mulch materials and cover crops for the different agro ecologies were some of the gaps in coffee Entomology and weed science.

1. **Prospects**

The continuous development of resistant coffee cultivars for each ecological niche in the major coffee growing regions of the country should get the highest priority. The prospects of successful control of coffee wilt rely principally upon adopting strict prophylactic measures (prevention and sanitation) and deploying resistant coffee cultivars. In this regard, monitoring and supervision of established sick plot should get due attention to identify CWD resistant varieties. Study CWD inheritance mechanism is of paramount importance to continue further with successful breeding program. In addition, biocontrol agents including *richoderma spp. should be worked. There has been limited research in characterization and genetic diversity analysis of coffee leaf rust pathogen using standard differentials and DNA-based molecular markers, which has been identified and researchable gap to be addressed for designing efficient disease management strategy. Biological control ought to be very promising for coffee insect pest management because coffee trees provide ideal condition for natural enemies. At present, although the advantages of integrated weed management /IWM/ are well known, it is not widely practiced in the coffee growing areas. Hence, IWM would be the best weed management strategy for sustainable coffee production.

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Advances in Potato Bacterial wilt Research and its Relevance to Defining the way forward for the Potato Sector in Ethiopia.

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Abstract

#n addition to "eing intellectually interesting and scientifically !ustified, the awareness of the symptoms, causes, and mechanisms of development of plant diseases has an extremely practical purpose and it allows ac6uiring knowledge to com"at "acterial wilt disease. #n this regard, a technology development and dissemination activity was undertaken "y using the ;armers 4esearch Extension ?roup supported "y sessions (;4E?$session) harmoni%ed with crop phenology to develop potato technologies suita"le to local conditions and to address the causes, sources and management of "acterial wilt and assist farmers in developing healthy potato farms. 3sing this approach, experiments on soil amendment with effective micro$ organism (E/), fre6uency of hilling, potato tu"er seed cycle, and one, and two season crop rotation were studied with the full involvement of farmersL research groups. <oncurrently, plant extracts (<ym"opoogon citratus, <ym"opogon nardus and +llium sativum), anti"iotics (4ifampicin followed "y Erythromycin) and "io$agents (*richderma viride, *richderma har%anum) were tested in$vitro. *he ;4E?$session approach was found to "e effective in stimulating farmer participation "y considering their goals in the targeting and design of innovations. ,oil amended with M E/ $fortified compost, M fertili%er of the recommended rate for the area and M E/ sprayed had the lowest disease incidence and latent infection and highest tu"er weight.)lant extracts (<ym"opoogon citratus, <ym"opogon nardus and +llium sativum), anti"iotics (4ifampicin followed "y Erythromycin) and "io$agents (*richderma viride, *richderma har%anum, *richderma hamantum and)seudomonas flourenscens) significantly inhi"ited the growth of the pathogen in$ vitro and reduced percent incidence of the disease in tu"ers harvested from cold frame. 'osses in tu"er yield attri"uted to potato seed cycle significantly ()N....1) increased the progress of the disease and reduced tu"er yield. 3nder wear potato production scenario, in the first cycle in local and improved potato varieties, the tu"er yield loss was increased from 2O to 2O and from C O to 21O in 2th cycle respectively. #n the second scenario, when potato was produced for seed purpose, correspondingly the loss was increased G. 2 O to 2B.7 O and 2..CB O to 7C. 2 O.)receding crop had an effect on "acterial wilt incidence. ,uscepti"le potato variety planted after wheat and mai%e exhi"ited low wilt incidence and two seasonLs rotation potato with "eans and ca""age significantly reduced the wilt incidence and significantly (pH...G) increased marketa"le tu"er yields. ,eed tu"ers should not "e used as a seed more than two cycles. 9heat, /ai%e, =eans and <a""age can "e good rotation crops in a potato rotation scheme where "acterial wilt is the ma!or threat to potato production.

Key words> 4alstonia solanascearum, ;4E?$session, Effective microorganism, =io$agent,, potato seed cycle, "acterial wilt, potato tu"er yield loss, dissemination, rotation

Introduction

There is no dependable population census in Ethiopia before the year 1970. It is estimated, however, that there were about 30 million people living in the country. During 2012, there has been a dramatic explosion in population estimated to be about 50 million people (CSA, 2012). Despite recent efforts to reduce the rate of population growth, the number of new humans added to the population each year and the additional demands for food, energy, and other resources from our planet are frightening. Thus, the population in 2015 was close to 100 milion, and, at the present rate of 3.5 % annual growth, it was expected to be 120 million by the year 2020 and will be 150 million by the year 2025. Paradoxically, the country, in which 80% of the population is engaged in agriculture, has the lowest agricultural output, the people are living on a substandard diet, and they have the highest population growth rates. Because of the current distribution of usable land and population, of educational and technical levels for food production, and of general economy, it is estimated that even today some 8 million people suffer from hunger, malnutrition, or both. To feed these people and the additional millions to come in the next few years, all possible methods of increasing the food supply are currently being pursued, including (1) expansion of crop acreages, (2) improved methods of cultivation, (3) increased fertilization, (4) use of improved varieties and reducingcrop losses to diseases, Insects, and Weeds.

Tremendous growths over last decade in area planted to potato in Ethiopia have been documented and the area under potato increased from 50,000 hectares to 163,000 hectares (Bekele and Eshetu, 2008). Despite the area coverage increase, yield at farm level is still far below the international average, which is 10 t ha^{-1}. The major constraints to increased production include poor growing practices low use of inputs, poor control of diseases, and insect pests and poor quality seed (lung'aho et al., 2007). Late blight and bacterial wilt of potato are two of the most important diseases of potato in tropical Africa (CIP, 1995). These diseases are seriously threatening the crop in Ethiopia (Bekele and Eshetu, 2008). Substantial economic losses often result from devastation of diseased potato fields (FAO-CIP, 1995 and Bekele and Abebe, 2013). Despite the economic losses attributed to these diseases, research and extension efforts have realized limited achievements. This is partly due to the extension approach used which limit farmers' from access to knowledge intensive technologies such as bacterial wilt management. To address these concerns, it was considered that training of farmers and participatory technology development are important elements. According to Bekele et al. (2002) promoting participatory research coupled with crop phenology based sessions and conducting training at field level helped farmers to make decision on control measures. The "Farmers Research Extension Group supported by sessions" (FREG-session) may contribute as did Farmers Field School approach which has been used in integrated pest management (Ortizet al.,1999 and Van de Fliert, & Braun, 1999) compared to Farmers Research Group (FRG) without session. Preliminary impact study on the Farmers Field Schools (FFS) approach suggested that famers who participated in the school become independent in making effective control decisions and as a result improved tuber yield (unpublished data) compared to none participating farmers.

Bacterial wilt caused by 4alstonia solanacearum (Smith) in many tropical and subtropical regions has been widely distributed and associated with a wide range of hosts (Agrios, 2004). 4alstonia solanacearum (4,) is grouped in to five races based on the difference in host ranges and geographic distributions; those races principally attacking Bananas (race 1), ornamental plants (race 2), potato (race 3), Ginger (race 4) and mulberries (race 5) (Kelman, 1997). Race 3, of the pathogen limits the production of potato in the country (Yaynu 1990) and relatively has a narrow host range (Berga, et al.,2005).

The destructiveness of this pathogen and its exceptional ability to survive in soil (Hayward 1986) , plant debris and root parts of plant hosts (Graham, and LIoyd, 1979; Granada & Sequeira,1983) as well as its broad host spectrum, stemmed to massive crop losses (Kelman, 1997), make difficult to control bacterial wilt pathogen in the soil (Jones, 1997). Control of bacterial wilt has so far only been moderately effective, and is based on sanitation, cultural practice (Shekhawatet al., 1990) and crop rotation. Due to some biotic and abiotic factors, breeding for host resistance is not successful for all host species (Hayward, 1986). The use of chemicals as fumigant is partially successful (Melton, 1991). Crop rotation with non-host crops is preferred control strategy worldwide for bacterial wilt caused by *4. solanacearum*(Akiew & Trevorrow, 1994; Hayward 1991; Melton, 1991). The extended host range, which also includes latent and / or symptomless hosts of *4. solanacearum*, makes it difficult to find suitable, rotational crops for the control of the disease (Hayward, 1986). Bekele *et al.*(2006) based on results of *in$vitro* and greenhouse studies, reported the inhibition effect of crude extract of *+llium sativum* on the causative agent of wilt caused by *4. solanacearum*. The antibacterial activity of *I lea africana* and *'antana camara* have been demonstrated (Cheruiyot*et al.*, 2009). Paret *et al.* (2010) reported the effectiveness of *<ym"opoogon citratus* oil in reducing bacterial wilt pathogen. Some plant species which are grown in the country such as *<ym"opogon martinii*, *<ym"opogon nardus*, *E6ualeptus glo"ules*, *+ngustifolia sp*, *=rassica carinata*, *<urcuma longa*, and *+llium sativum* have antimicrobial component and potentially inhibit the growth and development of the pathogens that cause wilt in potato. Biological control of crop disease is receiving increased attention as an environmentally sound alternative to chemical pesticides. Some species of **richderma* and *)seudomonas* are among the major microorganisms that have shown great potential for biological control of several plant pathogens including the causal organism of potato wilt (Jones and Stwart, 1997; Dolatabadi *et al*,. 2011 and Bekele and Habteweld, 2.1C).

According toHiga (1994), the use of effective microorganisms improved soil health and plant health there by improving the quality and productivity of crops. Various control strategies were developed to control and suppress this disease including biological control (Dolatabadi, *et al.*, 2011). Lemessa and Zeller (2007) reported that some strains of *4hi%o"acteria* inhibit the pathogen and reduced the incidence of the disease. Attempts also made to control *4. solanacearum* using **richoderma* spp. and *)seudomonas flourencens* and some naturally occurring antagonistic rhizobacteria such as *=acillus* spp., *)seudomonas* spp. were found effective (Guo *et al.*, 2001).

In the south east of Ethiopia, a diversity of crops: pulses, cereals, vegetables, root crops and sugarcane are grown. However these crops are sometimes rotated with potato but often potato comes successively for two three seasons. But several research reports indicate that crop rotation helps to significantly reduce the disease (Kloos *et al.*, 1991; Lloyd, 1976; Van der Zaag, 1986; Bekele and Berga, 2001;Berga *et al.*,2005).Verma and Shekhawat (1991) and Gunadi *et al.* (1998) also reported that a two season rotation with pulses, cereals, and root crops reduced wilt incidence but after three seasons incidence started to increase. Bekele and Berga (2001) from the study conducted on artificially developed sick plot, reported that rotating potato with maize and wheat reduced the incidence of bacterial wilt in the subsequent potato crop. According to Verma and Shekhawat (1991) a five-year rotation that included wheat, lupin and maize reduced wilt and increased yield. Higher potato yields were also obtained under crop rotation in the presence of bacterial wilt in Kenya (Barton *et al.*,1997). Therefore, it is important to increase farmers knowledge on bacterial wilt management; to determine the effects of one- and two-season rotations with some pulses, root crops and vegetables on BW incidence and tuber yields; to identify appropriate rotation crops and planting sequences to reduce BW incidence and determine the effects of seed cycle in progeny tubers on bacterial wilt incidence and estimate tuber yield losses after every cycle and gradually to enable them make better disease management decisions. This paper therefore attempt to summarize advances in potato bacterial wilt research and its relevance to defining the way forward for the potato sector in Ethiopia. The review also focuses on studies that were set up to empower potato farmers and adopt the FREG-session approach to the conditions of Ethiopian.

Materials and Methods

Extension approach

Seventeen farmers research extension groups (FREGs) with an average of 26 farmers in each group were organized in year 2010 based on voluntarily bases and the high initial level of enthusiasm on bacterial wilt control. The activity was conducted in four districts namely Tulubolo, Welmera, Weliso, and Shashemene with 10, 2, 2, and 3 groups respectively. A total of 442 farmers were involved of which 33 % females and 77 % men farmers from year 2010 - 2013. The methodology for implementation of modified FREG-session are problem oriented, participatory activity based approach with sessions. The field sessions were typically based on crop phenology. The sessions consisted of field assessment, diagnosis and discussion. However, experiments on seed cycle effect on disease and rotation were undertaken with three FRGEs organized in Shashemene district but farmers from the rest of the districts had an opportunity to visit and exchange ideas during field days.

Table 1 type of sessions, their objectives and activities made by the group

Session No.	Type	Objectives	Activity
1	Introduction to FREG-session	Introduce the mode of operation of FREG	Introduction & discussion
2	Potato seed quality & selection planting supplementary experiments,	Differentiate & select diseased and healthy tubers	Seed sorting, planting and hands on learning
3	Knowledge & practices of farmers	Base line information	Questioner / Discussion
4	Potato seed quality (seed size, physiological stage and , physical and pest damage) sorting	To assist farmers to recognize symptom related to pest damage and proper stage of seeds	Discussion and diagnosis
5	Crop management (Field preparation, fertility management, planting and hilling)	To assist farmers to adopt improved practices	Field exercise, observations hand on learning
6	Symptom and diagnosis of bacterial wilt, late blight and viral diseases	Diagnosis and Identification of pests	Discussion and diagnosis
7	Wilt and late blight development / bacterial wilt life cycle, supplementary experiment	Learn the cause and life cycle of the pathogen	Group discussion, learning exercise, observation
8	Mode of transmission and supplementary experiments	How it transmit and disseminate	Group discussion, learning exercise, observation
9	Bacterial wilt and late blight management (Removal of infected plants, clean seed and rotation	Demonstrate sanitation and create awareness	Discussion, learning exercise, and observation
10	Harvest and storage considerations	Demonstrate and create awareness on pre harvest and	Discussion, learning Exercise and DLS visit

Plant extracts and antibiotics

Extracts of <ym"opogon citratus, <ym"opogon martinii,<ym"opogon nardus, Eucalyptusglo"us,+ngustifolia and +llium sativum were obtained from Wondo Genet Agricultural Research Center. In the case of aromatic plants, the extraction was made from leaves, whereas seeds and bulb cells were used for <urcuma longa and =rassica carinata and +llium sativum respectively (Table 1). Method of extraction used for all above mentioned plants was water whereas; =rassica carinata (seed) and <urcuma longa (rhizomes) were extracted using methanol and acetone, respectively. The extract was evaporated at reduced pressure to remove residual solvent and moisture. In the second set of test, five antibiotics namely Gentamycin, Erythromycin, Streptomycin, Chloramphenicol and Rifampicin were bought from the local drug stores. Before poring to the wells, 4ml crude extract of each tested material were dissolved in 4ml of dimethyl sulfoxide (DMSO) to yield 8ml but, for antibiotic test 250mg of each antibiotic were dissolved in 5ml of DMSO as a solvent.

Microbial culture and Inoculum preparation

4alstonia solanacearume that causes bacterial wilt of Ginger and Potato were isolated from each of the host plants at Holetta Agricultural Research Center plant pathology laboratory, Ethiopia. Pathogen isolation for the test was performed from diseased ginger samples obtained from Teppi Agricultural Research Center and diseased potato tubers collected from fields in the vicinity of Shashemene, Ethiopia. Nutrient agar was used for culturing the bacteria and performing antibacterial testing. Both test bacteria were inoculated in to liquid nutrient broth medium and incubated at 37 ^{0}C for 8 hrs and the suspensions were checked to provide approximately 10^5 colony forming unit (CFU)/ml. One of the most sensitive well variant method (Cleidson et al., 2007) was used for plant extract and antibiotic tests. For both tests, 20ml of nutrient agar medium was poured in the sterilized petridish and allowed to solidify. One drop of bacterial strain was spread over the medium by L-rod and incubated at 32 ± 2 ˚C for 6 hrs. Wells (6nm in diameter) was punctured in the culture medium using sterile well borer and 1000µl of each extract were added to wells. Each extract and antibiotics were tested in triplicate considering one replicate of wells filled with streptomycin as a positive control and the other replicate with water as a negative control treatment. Plates were incubated at 37 °C for 24 hrs. Antibiotic activities were evaluated by measuring inhibition zone (cm) produced by the antibiotics and /or plant extracts.

Bio-agents

In the year 2013, three bio agents of *richoderma spp. namely T. viride, *. har%ianum, and*. hamatum, and)seudomonas flourenscens at 4 concentrations (100 %, 75%, 50% and 25%) were evaluated in$vitro against 4alstonia solanacearum isolated from potato using dual plate method (Dennis and Webster, 1971) and those which had shown the best inhibitory performance to the test namely *richoderma viride, *. har%ianum, ,*. hamatum, and)seudomonas flourenscens at the concentration of 100 % were farther subjected to pot trial in the green house in the year 2014. For this test, pots were filled with sterilized soil to avoid any confounded factor due to any other microorganisms so that each treatment will have equal chance to express the potential to inhibit the causative agent. Prior to inoculation with the pathogen, bio-agents were applied 2 weeks ahead of the pathogen. The reason is that antagonists should occupy the site earlier than the pathogens' arrival (Baker and Cook, 1974) . The trial was replicated four times and the design was Completely Randomized Design (CRD). The effectiveness of the bio-agents was evaluated by examining latent infection in percent.

Table 2 Natural products, Antibiotics and Bio-agents evaluated for their antibacterial activity in the current study.

Natural products	Part used	Source
Extracts		
Cymbopogon citratus	Leaves	Wendo Genet Agricultural Research Center (WGARC)
<ym"opogon martinii	Leaves	WGARC
<ym"opogon nardus	Leaves	WGARC
Eucalyptus glo"us	Leaves	WGARC
+ngustifolia sp	Leaves	WGARC
+llium sativum	Bulb cells	Holetta Agricultural Research Center

<urcuma longa	Rhizomes	Ethiopian Spice Extraction Factory
=rassica carinata	Seeds	Ethiopian Spice Extraction Factory
,treptomycin (<ontrol)	Powder	Jimma Agricultural Research Center
Bio-agents		
*richoderma viride	Culture	Ambo Plant Protection Research Center
*richoderma har%anum,	Culture	APPRC
*richoderma hamatum	Culture	APPRC
)seudomonas flourenscens	Powder	
Antibiotics		
?entamycin	Tablet	Local Drug Shop
Erythromycin	Tablet	LDS
Rifampicin	Tablet	LDS
Chloramphenicol	Tablet	LDS
Streptomycin (Control)	Powder	Jimma Agricultural Research Center

Field trials

All field trials discussed under were conducted on-farm in the vicinity of Shashemene-East Arsi, hot spot to the disease, using a participatory approach.Shashemene is located at latitudes 7 °12′ N latitude and 38° 30′ S, longitude 36 ° East and having an elevation of 1700-2600 masl. With annual rainfall of 1200 mm. It has an annual minimum and maximum of 12-27 °Crespectivelly. This site is suitable for both the crop and pathogen. The selection of participating farmers and communities was based on the presence of bacterial wilt in the field plots to be used and perform recommended cultural practices for potato production.

Soil amendment with effective Microorganisms (EM)

The field experiment was conducted from June 2009 until January 2011 on–farm in shashemen district where the bacterial wilt infestation is very high. The locations were in three kabeles namely Faje sole, Hurso simbo and Idela burka. The treatments were: Improved management package (full fertilizer rate, recommended spacing and improver variety (Jalene); soil amended with full rate of EM - fortified compost, recommended spacing and improver variety (Jalene); Soil amended with ½ EM- fortified compost and ½ fertilizer of the recommended rate for the area and recommended spacing and improver variety (Jalene); Soil amended with ½ EM - fortified compost and ½ fertilizer of the recommended rate for the area plus ½ EM spray on the foliage weekly using the recommended spacing and improver variety

(Jalene); Farmers practice (1/2 fertilizer using the local variety); and seed tube treated/socked in EM at a dilution of 1: 1000 v/vl for 30minutes. The design was RCBD in 2 X 6 factorial arrangements where variety being factor A and the six treatments were considered as factor B. The data were subjected to analysis of variances using SAS soft ware.

Potato seed cycle effect

Concurrently, in the above indicated sites, effect of seed retained from previous harvest and planted as a seed and wilt intensity and tuber yield were studied for four successive seasons (200B, 2011A, 2012 A and 2013A) using a participatory approach with farmers. An improved potato variety, Gudene (CIP-386423.13) and the local (Nech abeba), were used. The experiment was laid out in a randomized complete block design. Within a season, each farmer's field (farm) was considered as a replication and the number of fields per season was 6 but, one of the experimental fields was not handled properly by the farmers group hence, it was excluded from the report.

Disease assessment

Plots were assessed at weekly intervals to determine days to onset of first wilt symptoms. Subsequent counts of wilted plants were made at two-week intervals from the onset of the disease. At each assessment, all plants that showed either complete or partial wilting were considered wilted. These were staked to avoid double counting in subsequent assessments and also to avoid the possibility of missing those that died completely during the growth period. The counts of symptomatic plants were expressed as a percent of the total number of plants that emerged. Late blight was controlled with one spray of fungicide Ridomil MZ for the improved varieties but the local variety received additional two sprays of the fungicide Dithane M-45 starting from the first visible symptoms. At harvest, data were recorded on yield, including total and marketable yields, as well as rotten tubers due to BW. In order to build farmers confidence and trust on the outcome of the technology, member farmers were involved in collecting data on the incidence of the disease, data on yield parameters and evaluate the treatments at field level through discussions. Data on BW incidence were subjected to square root transformation before analysis using SPSS soft ware. The relationship of mean tuber yield over disease incidence in the field was used to estimate tuber loss attributed by the disease to wear potato production scenario. In seed potato production scenario, the loss was determined based on the relationship of mean tuber yield over mean latent infection for the improved and the local varieties independently. Percent latent infection was calculated based on 1000 randomly sampled potato tubers which look healthy from each treatment and were diagnosed for the presence of latent infection in the laboratory after the tubers were incubated at 2 ± 32 °C that help to promote symptoms in the latently infected tubers (Rueda, 1990).

One and two seasons crop rotation

In the seasons preceding the experiments, the fields were planted with a BW susceptible local variety "Nech Abeba" to uniformly increase the inoculum pressure. Both rotation trials were planted in mildly infested five fields with an initial mean incidence of 37.8 % with uniform distribution. The local variety «Nech Abeba» was planted before and after rotational crops. The one season rotation experiment was carried out in 2011B, 2012A and 2012B and the two season rotation experiment was done in 2011B, 2012A, 2012B and 2013 A seasons.

Experimental design

The design was randomized complete block with 4 replications with the plot size of 6m X 6m. The local variety «Nech Abeba» was planted before and after rotational crop. Potato was planted in 75 cm X 30 cm between rows and plants before and after the rotation crops. Crops that are commonly grown in the area were included in the treatments. All the crops were planted at recommended spacing's, which for potatoes, beans, cabbage and carrot was 75 x 30 cm 30 cm x 10 cm, 50 cm x 30 cm and 20 cm x 10 cm respectively. Late blight was controlled with Dithane-M45 and Ridomil-MZ, based on need application, each of which was sprayed at a rate of 3 kg ha $^{-1}$ and 2.5 kg ha $^{-1}$ respectively. Fertilizers in the form of Diammonium sulfate (DAP) and Urea was side dressed in the rows at a rate of 195kg and 165kg ha $^{-1}$ base respectivelly.

Treatments

Table 3. Crop spp. considered in one and two season rotation, Shashemene, Ethiopia

Treatment	
One season	**Two seasons**
potato - Beans – Potato	Potato - Beans – Carrot - Potato
Potato - Cabbage – Potato	Potato - Beans – Cabbage – Potato
Potato - Carrot – Potato	Potato - Beans – Beans – Potato
Potato – Potato – Potato	Potato - Carrot – Carrot - Potato
	Potato - Cabbage – Carrot – Potato
	Potato - Cabbage – Cabbage – Potato
	Potato – potato – potato - potato

Disease assessment

Assessment of the wilt disease started with the onset of wilt symptoms and was done on a weekly basis. Plants that showed either complete or partial wilting were all considered wilted and staked to avoid double counting in subsequent assessments. Wilt incidence for each treatment was then calculated as percentage of total number of plants emerged. Percent latent infection was calculated based on 75 randomly sampled tubers which are looking healthy from each treatment and were diagnosed for the presence of latent infection in the laboratory after the tubers were incubated at 2 ± 32 ^{o}C that help to promote symptoms in the latently infected tubers converted in to percentage (Rueda , 1990) .

Yield parameters

Tubers were harvested after 95 days when it reached senescence. At harvest, total and marketable yields were separately determined.

Statistical analysis

For statistical comparisons, percent wilt incidences were transformed into square roots before analysis. The relationship of mean tuber yield over disease incidence recorded at field level was used to estimate tuber loss attributed by the disease to wear potato production scenario. In seed potato production scenario, the loss was determined based on the relationship of mean tuber yield over mean latent infection of the improved and the local varieties independently.

Tuber yield loss was estimated under wear and seed potato production scenarios independently using local and improved varieties. The loss was determined based on the relationship of mean tuber yield over mean disease incidence recorded at field level and percent latent infection after incubation respectively. Data were statistically analyzed using Genstat 4.23 release.

Result and discussion

Extension system

Despite the economic losses attributed to these diseases, research and extension efforts have realized limited achievements. This is partly due to the extension approach used which limit farmers' to knowledge intensive technologies. To address these concerns, as reported by Ortizet al.(1999), it was considered that training of farmers and participatory technology development are important elements (Bnekele et al., 2002 and Ortiz, et al.,1999). Appraisal of farmers revealed that late blight as the first major constraint followed by bacterial wilt, scab and viruses as descending order (Figure 2). However, though late blight ranked first, farmers recognized the availability of technologies to control the disease while for wilt farmers do not exercise any control strategy hence, they considered wilt as the most important potato production threat in the area.

Other problems such as aphids, potato tuber moth (PTM) mole rat, cut worm and termites were also mentioned and prioritized (Figure1). According to the farmers, aphids are the number one insect past followed by potato tuber moth. Whereas, of all diseases attacking potatoes in the area, late blight followed by bacterial wilt were considered the first and second most important potato disease (figure 1 and 2).

Before the inception of the project, more than 90 % of the farmers in the group did not know the causes of potato diseases and the basic knowledge to differentiate symptoms between insect damage and infection by pathogens. Most of the farmers (95%) in the group believe disease can be caused by rain and frog whereas, others don't even guess the causes. After subsequent discussions and demonstration at field level, they were able to change their views and understood about the causes of diseases in general and knew the causative agent of bacterial wilt and late blight.

Figure 1 Farmers when diagnose symptoms and identify diseases symptom diagnosis session

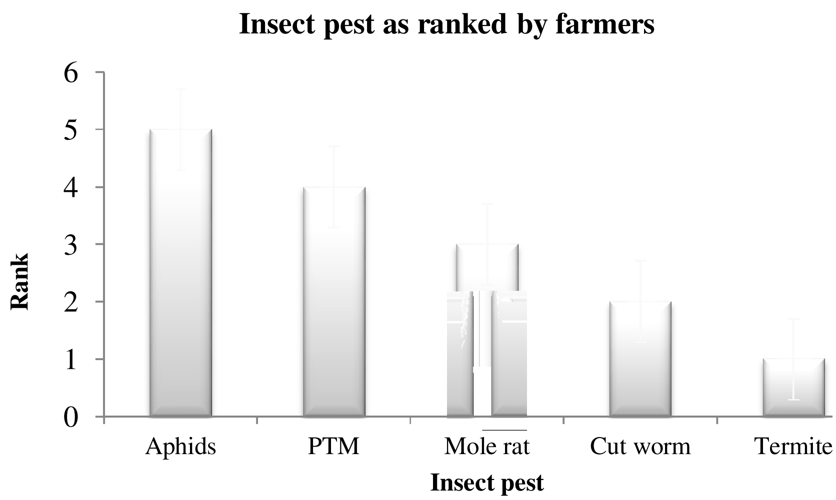

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Figure 2 Ptato production insect pest problems identified by group members in Shashemene. 4ank G refers as first priority and . as no priority .

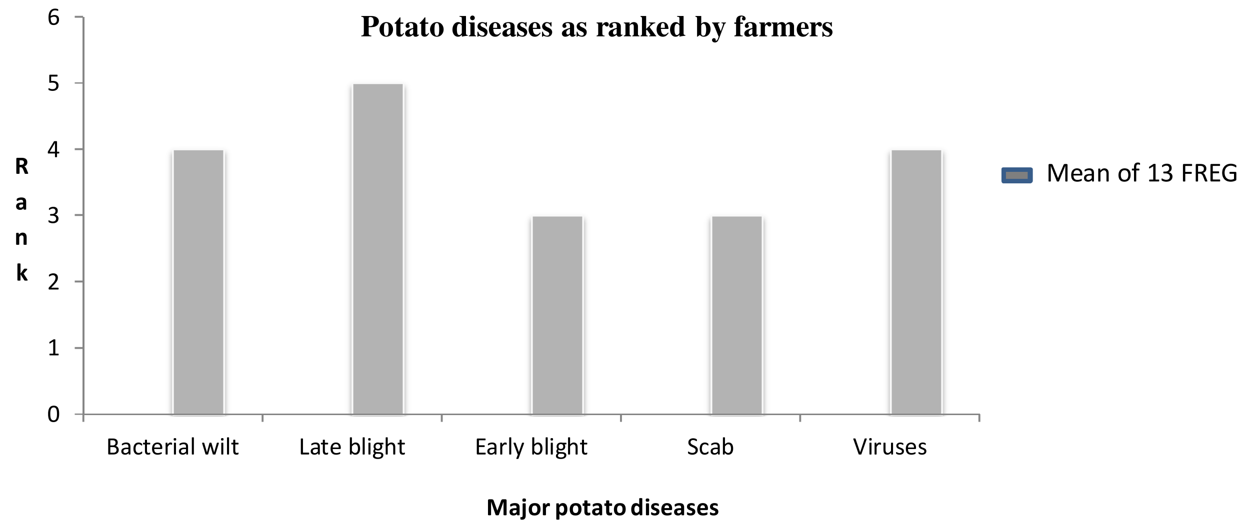


Figure 3 Ptato production disease problems identified by group members in Shashemene.

Rank 5 refers as first priority and 0 as no priority

Soil amendment with EM

Fortified compost amendment at different rates was studied on on-farm in permanent plot for four consecutive seasons. The result exemplify no statistical significant ($P<0.05$) differences among varieties however, there was a slight difference in common scab (,treptomyces sp), and BW incidence and latent infection in tubers (Table 3). The highest mean percent disease incidence (24.9 %) was recorded on local variety as opposed to the improved variety which had 24.9 %. Among treatments, soil amended with ½ EM - fortified compost and ½ fertilizer of the recommended rate and ½ EM spray had the lowest incidence of the disease compared to the treatment that represent farmers practice. The trend was observed when tubers were examined for latent infection. In both varieties, significantly ($p<0.05$) highest incidence of latently infected tubers in percent was recorded of the farmers practice treatment the lowest being recorded from tubers harvested from the treatment that had ½ EM - fortified compost , ½ fertilizer of the recommended rate for the area plus ½ EM spray on the foliage weekly. Our results agreed with the findings of APNAN,1995 and Higa, (1994) who reported that the use of Effective Microorganisms (EM) can improved soil health and plant health there by improving the quality and productivity of crops.

Table 4. Effect of effective micro organism on pathogens associated with potato tubers, 2009 (Combined over four locations)

Variety	Treatment *	CSs (1-5 scale)	BWI (%)	Latent infection (%)
Jalene	IMP	1.33	22.75	53.33
	FEM	1.50	25.00	56.66
	1/2EMFS	1.30	18.84	26.73
	EMFS	1.97	19.64	50.00
	FP	1.93	25.47	63.33
	STEM	3.33	19.55	33.40
Mean		1.89	20.84	47.24
Local	IMP	3.63	27.00	53.33
	FEM	3.33	31.22	50.00
	1/2EMFS	2.50	19.20	30.00
	EMFS	3.93	21.00	73.33
	FP	3.67	33.00	76.77
	STEM	3.53	19.48	46.67
Mean		3.43	24.98	53.33
CV %		14.92	17.23	22.37
F- test Variety		NS	NS	NS
	Treatment	NS	S	S
	V X T	S	NS	NS

Source: Holetta Research Center progress report for the period 2012

*IMP= improved management package (full fertilizer rate and recommended spacing); FEM= soil amended with full rate of EM - fortified compost, recommended spacing; 1/2EFFS Soil amended with ½ EM- fortified compost and ½ fertilizer of the recommended rate for the area, ½ EM spray and recommended spacing; EMFS =

Soil amended with full rate EM - fortified compost and fertilizer of the recommended rate for the area plus EM spray on the foliage weekly using the recommended spacing; FP= Farmers practice (1/2 fertilizer); and STEM= seed tuber treated/socked in EM at a dilution of 1: 1000 for 30 minutes and with recommended fertilizer rates.

Table 5. Effect of effective microorganism on potato tuber yield components, 2009 (Combined results over three locations)

Variety	Treatment.	MTNo	TTNo	MTwt (kg)	TTwt(Kg)/5 pants
Improved	IMP	146	181	16.4	21.1
	FEM	143	182	12.6	14.6
	1/2EMFS	193	216	18. 7	24.4
	EMFS	150	195	17.4	18.3
	FP	151	184	15.67	17.1
	STEM 6	127	222	18.13	18.5
	Mean	152.1	186.1	16.2	17.75
Local	IMP	137	182	20.7	17. 6
	FEM	161	248	16.1	13.4
	1/2EMFS	213	221	20.5	19.5
	EMFS	188	218	12.7	16.4
	FP	177	216	16.6	15.9
	STEM	181	233	15.9	13.4
Mean		176.7	216.5	17.1	17. 30
CV %		16.32	21.86	15.44	22.13
LSD 0.05		43.8			
T		S	NS	NS	S
V		NS	NS	NS	NS
T XV		NS	NS	NS	NS

Source: Holetta Research Center progress report for the period 2012

*1= improved management package (full fertilizer rate and recommended spacing); 2= soil amended with full rate of EM - fortified compost, recommended spacing; 3= Soil amended with ½ EM- fortified compost and ½ fertilizer of the recommended rate for the area, ½ EM spray and recommended spacing; 4= Soil amended with full rate EM - fortified compost and fertilizer of the recommended rate for the area plus EM spray on the foliage weekly using the recommended spacing; 5= Farmers practice (1/2 fertilizer); and 6= seed tuber treated/socked in EM at a dilution of 1: 1000for 30 minutes and with fertilizer rates. MT No.= marketable tuber No., TTNo. = Total tuber number, MTwt (Kg)= Marketable tuber weight, TTwt = Total tuber weight .

Screening of Natural Products and Antibiotics

Plants may provide natural sources of antimicrobial compounds that may be employed in controlling economically important diseases like 4alstonia ,olanaearum. Extracts from eight plant species namely <ym"opoogon citratus, <ym"opogon martinii, <ym"opogon nardus, E6uaeptus glo"us, +ngustifolia sp, +llium sativum,<urcuma longa and =rassica carinata and four antibiotics (Gentamycin,Erythromycin,Rifampicin andChloramphenicol) were evaluated at Holetta Agricultural Research Center in year 2014 for in$vitro antibacterial activity against 4alstonia solanacearum using agar well diffusion method. Concurrently, four bio-agents (*richderma viride, *richderma har%anum, *richderma hamatum and)seudomonas flourenscens) were also evaluated against the causative agent under controlled environment in cold frame. The results revealed that extracts from <ym"opoogon citratus, <ym"opogon nardus and +llium sativum had maximum inhibition effect followed by =rassica carinata and <ym"opogon martinii (Table 2 and Figure1).<ym"opogon nardus and +llium sativum) showed statistically significant inhibition zone compared to the standard antibiotic streptomycin. These results were in agreement with the research findings of Paret et al. (2010) who reported the effectiveness of <ym"opogon citratus to suppress 4. solanacearum in the soil when it was applied as bio fumigant in the polluted soil. The rest were found inferior however, had better performance than the negative control.

Among antibiotics, Rifampicin followed by Erythromycin showed the highest inhibitory activity compared to the standard control antibiotic Streptomycin (Table 6.).Rifampicin showed more activity and the greatest inhibition zone compared to the remaining tested antibiotics followed by Erythromycin which had more and above 266 % and 166 % effect than the standard control, respectively.

From the tested bio-agents *richderma viride, *richderma har%anum, *richderma hamantum and)seudomonas flourenscens reduced "y 72.G, G2. , G .2 and 2 .2 % tuber latent infection compared to the control which had 88 % percent incidence (Table 4). This study was substantiated by Akhtar and Siddiqui (2008) and Ephrem et al. (2011) who reported that *. viride followed "y *. har%anum, *. hamantum and). flourenscens have been found to reduce latent infection of 4. solancearum in potato. Other relative research findings also suggested to use bio-agents against 4. solansearum (Myint and a Mukhaarachchi., 2006; Naseby, et al., 2000; Halos and Zorrilla, 1979; Wall and Sanchez, 1992 and Chutrakul et al., 2008.). Barbosaet al.(2001) also reported the antagonistic nature of trichoderma on cladosporium her"arium. 1n generally, these research results suggested that antagonistic microorganisms, plant extracts and antibiotics can contribute and warrant to be considered as a control component in integrate management of bacterial wilt of potato.

Table 6. Antibacterial activity of crude extracts (w/v) from nine plant spp. against 4alstonia solanacearum

No.	Plant species	Ginger Inhibition zone (Cm)				Potato			
		Replication				Replication			
		After 24 hr incubation							
		I	II	III	Mean	I	II	III	Mean
1	Cymbopoogon citratus	2.5	3.4	3.2	3.0 ±0.2a	2.9	3.8	3.6	3.4±0.2a
2	<ym"opogon martinii	2.0	1.5	1.3	1.6±0.1c	2.4	1.8	1.7	2.0±0.12b
3	Cymbopogon nardus	2.5	1.8	2.2	2.2±0.1b	3.1	1.9	2.5	2.5±0.15b
4	E6uaeptus glo"us	1.1	1.1	1.0	1.1±0.07d	1.2	1.1	1.0	1.1±0.06d
5	lavenden +ngustifolia	1.2	1.0	1.0	1.1±0.07d	1.3	1.1	1.0	1.1±0.06d
6	<urcuma longa	1.2	1.3	1.4	1.3±0.08::				

No	Antibiotics	Inhibition zone (Cm) Replication				Replication			Mean
		After 24 hr incubation							
		I	II	III	Mean	I	II	III	
1	Gentamycin	1.5	1.2	1.2	1.3±0.15	1.8	1.4	1.3	1.5±0.16
2	Erythromycin	2.1	2.1	1.7	2.0±0.23	2.2	2.3	1.7	2.1±0.22
3	Rifampicin	3.4	3.0	3.2	3.2±0.36	3.8	3.2	3.5	3.5±0.37
4	Chloramphenicol	1.1	1.1	1.0	1.1±0.13	1.2	1.1	1.1	1.1±0.11
5	Streptomycin (Control)	1.2	1.2	1.3	1.2±0.14	1.1	1.1	1.1	1.1±0.11
6	Water (control)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
	CV %				6.6				4.2

Source: Bekele and Habtewelde , 2017

Table 7. Effect of bio - agents on the incidence of 4. solanacearum in potato seed cycle under pot trials (latent infection)

*reatment	% latent infection	% over the control
*richoderma viride	31.13 ± 0.13	55
*richoderma har%anum	35.75 ± 0.15	46.4
*richoderma hamatum	34.69 ± 0.14	46.8
)seudomonas flourenscens	44.64 ± 0.19	38.06
Control	88.8 ± 0.37	-
Mean	42.5	53.42

Source: Bekele and Habtewelde, 2017

Seed cycle effect

The progress of the disease was signifcantly ($P<0.05$) increased as seed cycle repeated in both types of varieties, significantly higher mean disease incidence was recorded in the fourth tuber seed cycle compared to the third and the second sycle (Figure 4). In the first year of the experiment the progress of the disease on the local variety was slow and the on set of the diseases incidence was recorded 54 days after planting (DAP) and reached around 9 % after 96 DAP (Figure 4 A). Whearas in the second, thired and fourth cycle the incidence was 3 %, 7% and 13% respectively at 54 DAP and after 96 DAP the incidence reached to 30%, 43% and 52% respectively. The progress of the disease in the improuved varity was followed the same trend as to the local variety. However on the improuved variety the progress was slightly lower and not exceded 41 % in the fourth cycle (Figure 4 B).

In the first season, the improved varieties gave the highest mean tuber yield compared to the mean yield of the local variety (Table 5). Use of tuber seeds from previous harvest for subsquent wear potato production reflected in drastic declination of marketable tuber yield in the folowing harvest. Mean marketable tuber yield reduced by 17.1 %, 28.6 % and 40 % on the improved varieties in the 2nd 3rd and 4th seed cycle, while the crosponding percentage figure of mean yield on the local varieties were 12 %, 29 % and 45%. However over all mean yield have been rduced by 20 %, 37 % and 49 % respectively.

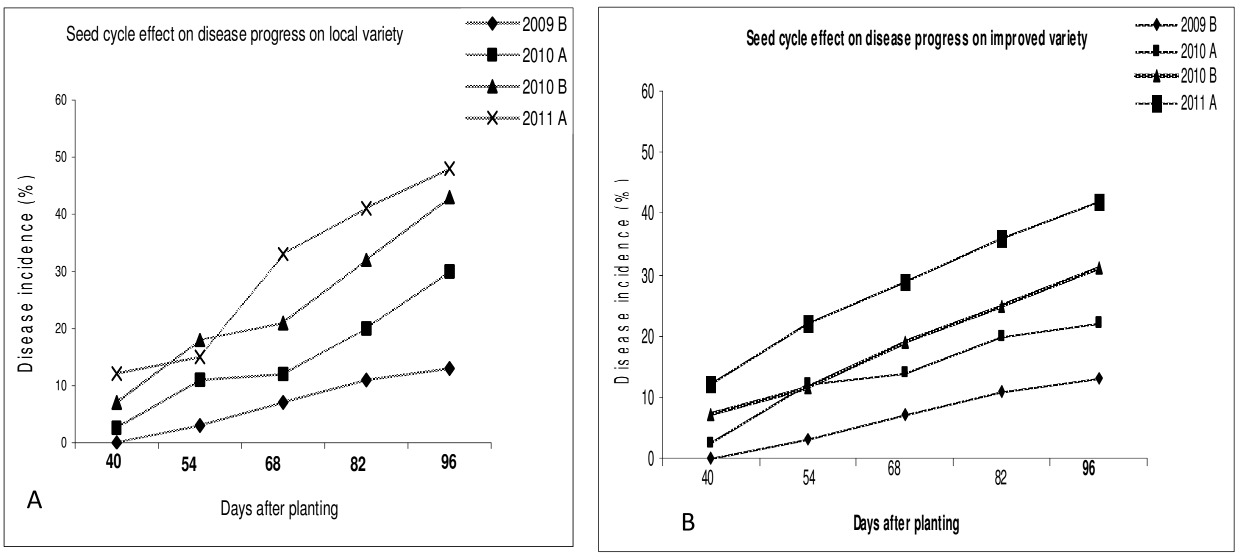


Figure 4. Disease progress with time on local (A) and improved (B) varieties from 2009B to 2011A seasons in Shashemene.

The results obtained from this experiment indicated that the fair uniformity of the pathogen distribiution in the field, as it is belived to be the hotspot for the disease (Bekele, 1996), which inabels to investigate the role of varietal differences in response to the disease to the high land race 3 biovar 2-A strain of bacterial wilt. As to the previous reports (Rueda, 1990 and French, 1994) the two groups of potato varieties showed their difference in reaction to the disease, wich also reflected in latent infection in the progeny tubers and total and marketable tuber yield. In line with this study (Bekele, and Abebe., 2013) found that latent infection of BW was one way for disease dissmination, sugessted tha need to consider srict uarentine measure and restrict the free muvment of seed tubers. Moreover Begum et al.(2012) found that due to soil borne nature of the pathogen, the diseas out break occurs on the same arteas even when susceptible varieties were re–grown after gap of 2-3 years of crop rotation with non-host crops.   .

Significatly (P<0.05) higher mean yield differences was recorded between the improved and local variety (Table 1). The imroved and local varieties gave a mean tuber yield of 33 t/ha and 24 t/ha respectively. Even though, there was significant (P<0.05) diferences in the yield of progeny tubers among varieties, tuber yield in both catagory (improved and local) of varieties dicreasead as the progeny tubers was used as a seed for the subsiquent seasons. However, the tuber yield of local varieties were more affected compared to the improved varieties by the tuber seed cycle.

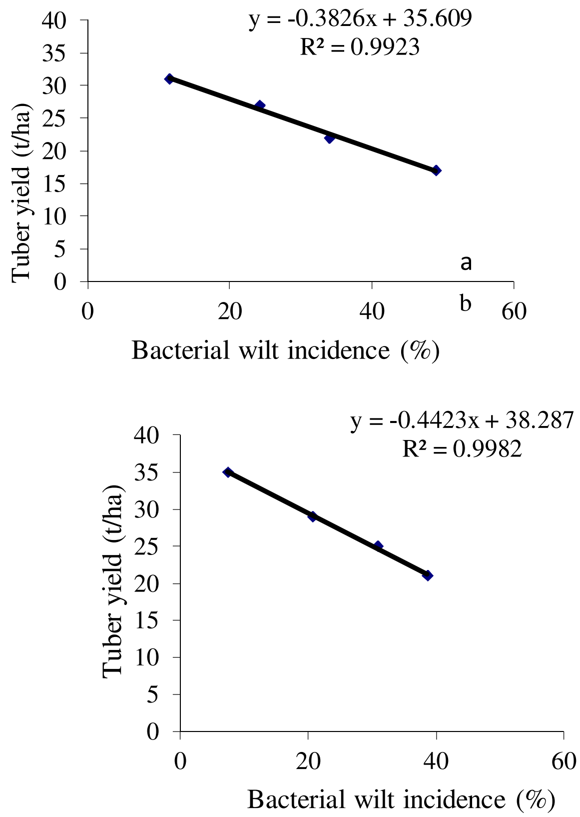
Table 8. mean marketable tuber yield of three improved varieties and two local varieties in 2009B to 2011A, in the vacinity of shashmene (yield data pooled from five farmer fields)

	Variety					
	Yield t/ha					
Season	Improved	Yield reduction (%)	Local	Yield reduction (%)	Mean	Yield reduction (%)
2009 B	39.1	-	31.2	-	35.15	-
2010 A	35.3	10.2	27.0	12.0	31.2	11.2
2010 B	31.6	19.2	22.4	29.1	27.0	23.2
2011 A	24.0	38.4	17.3	45.1	20.6	41.4
Mean	32.5		24.5			
Cv %			13.5			

Source: Bekele and Abebe, 2013.

As indicated in Table 8, percent latent infection in progeny tubers of local varieties was also significantly (P<0.05) higher comared to in improved varieties. In the highlands of Ethiopia, crop scenecence is not the criteria for harvest. Rather the field serve as a store for their produce and harvesting could ofthen extended from

June to December. During the last harvest, farmers callect tubers remained in the field and used as a tuber seed for following planting. In agreement with this study, Begum et al. (2012) indicated that, cropping sequence farther infered that BW is prevalent during high temperature and humidity with in the month of June-July when most of solanaceous crops are near to the harvesting stage.The largest proportion of tubers in the harvest are small sized with inferior quality and are sources of disease causing patogens for the coming season (Amsal and Bekele, 1997). But farmers donot realize that, progeny of such tubers are low in productivity due to the accumilation of pathogens in the tubers. As a result of this type of seed system, the potato tuber yield per unit area declined year after year due to degeneration. In th esame maner farmrs in the mid atitude are often keep tubers from their harvest for the next planting in different ways, in some are they store in peats and some spread in flour in their leving house and some acquire from the market. In all cases, farmers do cycle their tubers from season to season with out any inspection for the health of the seed. Results of this study in which the tubers are cycled for four seasons showed that, the yield significantly reduced as the progeny tuber cycle repeated. In the first progeny the marketable mean yield redused by 10 % and 12 % on improved and local variety respectively. Whereas in the 2nd and 3rd cycle percent reduction increased to 19% and 38% in improved variety, crospondingly 23 % and 41 % on the local variety. Mean tuber yield of the two group of varieties reduced by 11 %, 23 % and 41 %. In the 1st , 2nd and 3rd seed cycle respectively. The relationship between mean tuber yield over incidence of bacterial wilt in the four season seed cycle (2009B to 2011A) had negative and strong relationship $y = -0.3826x + 35.609$ (R2 = 0.9923) and $y = -0.4423x + 38.287$ (R2 = 0.9982) over local and improved varieties (Figure 2 and 3). The mean yield loss was in the range of 7 % to 32 % on the local varieties and 4% to 21 % on improved varieties under the senario of wear potato production. Tuber yield loss of local variety In the first progeny was estimated to 7 % and incresed by 50 % loss in each cycle. The same ttrend of loss increament was also recorded in an improved variety.

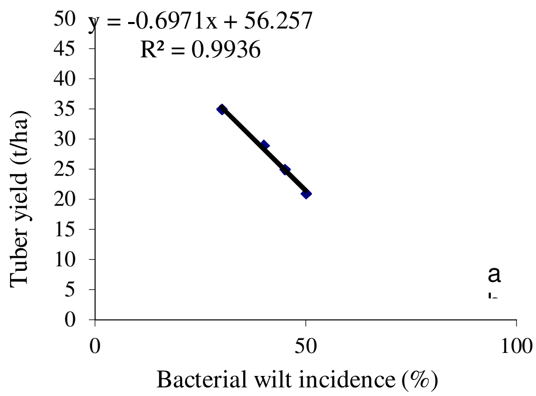


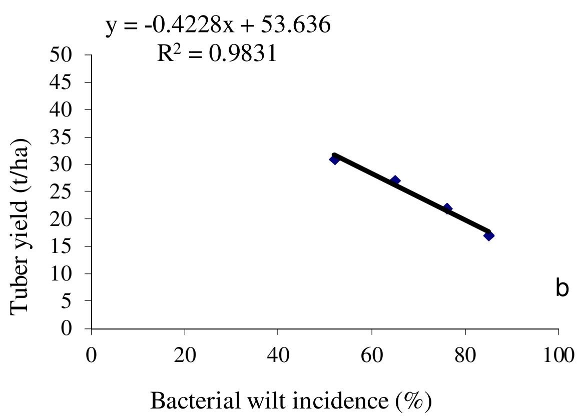
Source: Bekele and Abebe ,2013

Figure 4. Relationship between potato mean tuber yields over incidence of bacterial wilt in four cycles of progeny seed tubers (2009B to 2011A) of five locations using local varieties (a) and improved variety (b) in Shashmene

The relationship mean seed tuber over percent latent infection in tuber is presnted in Figure 4 and 5. The relationship of mean tuber yield of varieties over latent infection demonstrated strong and significant ($P<0.001$) relationship, $y = -0.4228x + 53.636$ ($R2 = 0.9831$) and $y = -0.6971x + 56.257$ ($R2 = 0.9936$) with local and improved varieties respectively. Mean tuber yield loss, on the local varieties, in the 1st seed cycle was 20.4 % where as in the 4th cycle it increased to 67.34 %. The same increment trend was also observed on the improved variety and the tuber loss of 5.34 % was recorded in the 1st cycle where as in the 4th cycle it was as high as 5 fold from the 1st cycle.

According to the research findings of Hayward (1991) seed-borne wilt or latent infection has long been recognized as the principal method of dissemination of the potato strain, race 3, biovar 2-A. The movement of tuber seed from infected fields at worm location like Shashmene to cooler areas has apparently been reported to have high incidence of the disease in healthy appearing fields Such infected seed has often resulted in serious outbreaks of the disease appearing fields of north western and central Ethiopian highlands (Bekele, 1996, Bekele and Eshetu, 2008). This study revealed that use of previous harvest as a seed for subsequent potato planting contributed to a serious tuber yield loss in terms of seed health and over all potato production as well as help for the dissemination of the pathogen. Our results agreed with the findings of French, 1994, in which latent infection in progeny tubers are the main vehicle for the spread of the disease. Hence, seed tubers should be checked for their health from the source so that latent infection could be monitored. That would result in good wilt control, higher yields, and reduced wilt spread.





Source: Bekele and Abebe, 2013

Figure 5 Relationship between potato mean tuber yield over percent latent infection of bacterial wilt in four cycles of progeny seed tubers (2009A to 2011A) of five locations using local (a) and improved (b) varieties

The use of subsequent harvest as seed from season to season had negative and significant.

Relationship between disease incidence, latent infection and tuber yield indicated that tuber loss increased as cycles in progeny tuber seed increased. Use of previous harvest as a seed for wear potato production attributed to a mean tuber yield loss of 21 % & 32 % in improved and local variety respectively at the 4th cycle. Whereas, tuber yield loss in seed potato production scenario at the 4th seed cycle reached to 67.3 % and 28.6 % in local and improved varieties respectively. These study results directly indicate how seed could be degenerate through time and attribute to huge tuber yield loss. Generally the study strongly suggested that, farmers in low and mid altitude areas and having similar agro-ecologies with Shashemene should be used potato seeds produced in the high elevation potato fields where the weather condition is not conducive for the development of the pathogen so that the dissemination of the pathogen could be reduced and at the same time can minimize the yield loss what they are exercising. The research result of this work call for an immediate need to develop and materialize seed conspiracy at national and regional level. No single control measure is effective to prevent loss caused by the disease (Lemessa and Zeller , 2017; French, 1997). Barton et al., (1997) reported that most farmers cycle their own seed potato or purchase from nearby markets or neighbors. Hence, yield losses due to BW average about 50 % with occasional losses of 75% on seed potato whereas in traditional production system and areas the loss reached to 100 % (Ajanga, 1993). Moreover, the pathogen rout for dissemination is seed, the most effective way to control the disease is the use of BW free seed as seed source (Adipala et al., 2001) .

Whereas, tuber yield loss in seed potato production scenario at the 4th seed cycle reached to 67.3 % and 28.6 % in local and improved varieties respectively. These research results directly indicate how seed could be degenerate through time and attribute to huge tuber yield loss. Generally the study strongly suggested that, farmers in low and mid altitude areas and having similar agro-ecologies with shashemene should be used potato seeds produced in the high elevation potato fields where the weather condition is not conducive for the development of the pathogen so that the dissemination of the pathogen could be reduced and at the same time can minimize the yield loss what they are exercising. The research result of this work call for an immediate need to develop and materialize seed conspiracy at national and regional level.

Rotation with none host crops

To determine the effect of preceding crops (maize, beans, wheat, and potato), an experiment was conducted in 1996-97 at Ambo in sick plot using two potato varieties having some degree of difference in tolerance to BW. The result showed that wilt incidence was influenced by type of the preceding crop. Susceptible potato variety planted after wheat and maize exhibited mean wilt incidence of 8.3 and 9.3 % as compared to the susceptible variety followed by the susceptible variety which had 25.6 % incidence(Table 9). Wilt incidence on the susceptible variety was 23 % as opposed to 0% on tolerant variety. Percent tuber rot at harvest differed with variety but not with type of preceding crops and frequency of hilling. Incidence of tuber rot after 3 weeks in diffuse light storage was affected by type of preceding crop and variety and there was a negative correlation (r=-0.86) and a coefficient of determination of R^2 = 0.74 between tuber wilt and wilt incidence. This research result was agree with the findings Berga et al., (2001a) who stated that in heavily infested fields wheat and maize did not reduce wilt . However, in mildly infested fields a one season rotation with wheat and maize significantly reduced and increased yield as compare to the control. Therefore use of maize and wheat as preceding crop and relatively tolerant varieties are important to manage wilt.

Table 9. Effect of preceding crop and post emergence cultivation on bacterial wilt incidence and yield of potato.

	One times hilling			Two times hilling		
Preceding crop	Incidence (%)	Rotten tubers (DLS) %	Yield t/ha	Incidence (%)	Rotten tubers (DLS) %	Yield t/ha
Awash (tolerant variety)						
Wheat	0.0	24.9	24.33	0.0	3.6	31.67
Beans	0.0	8.9	31.67	0.0	7.1	31.33
CIP_384321.3	0.0	15.4	30.33	0.0	20.5	35.67

Awash	0.0	3.7	31.00	0.0	3.2	32.00
Maize	0.0	9.0	34.00	0.0	7.1	32.67
CIP_384321.3 (Susceptible variety)						
Wheat	7.2	6.1	31.67	9.4	7.3	34.00
Beans	31.0	3.5	31.33	29.9	1.7	29.33
CIP_384321.3	18.8	4.1	35.67	31.9	1.2	24.33
Awash	40.9	1.9	32.00	42.9	1.8	25.33
Maize	14.1	3.6	32.67	4.5	0.0	44.33

Source : Bekele and Berga, 2001

One season rotation: rotation had not significant effect on the onset of the disease and the symptom of the disease was recorded with in the same week in all treatment however on the control treatment, the disease was appeared three days earlier. Unlike the onset of the disease, the progress of the disease became relatively faster on mono cropped potato compared to the other three treatments and reached maximum 62.1 % as oppose to 18.4 % - 32.0 % range at 82 days after planting (Figure 1). Bacterial wilt incidence in all the one season rotations with beans and vegetables although not different from one another, significantly ($P < 0.05$) decreased BW incidence but reduction in latent infection was not significant compared to the mono crop potato (Table 10). The highest wilt (63.2 %) was recorded when potato was planted for three consecutive years. whereas, potato –beans -potato, potato – cabbage- potato and Potato- carrot-potato were not vary significantly however, cabbage in the system reduced BW incidence slightly compared to beans and carrot and had in the range of 18.4 - 32.3 (Table 10). Total and marketable tuber yields significantly ($P < 0.01$) increased when compared to the control. This agrees the findings of Verma and Shekhawat (1991), who reported that in a five-year rotation, wilt incidence was reduced to 6.3%, compared 80.1% under a mono crop. The lowest incidence of BW 18.4% and 23.1% and the highest marketable potato yields 24.8 and 26.4 t/ha was recorded after rotations with cabbage and beans respectively (Table 3). In contrast, the lowest (21.3 t/ha) yield were obtained following rotations with carrots, which allowed slightly highest incidence (32.3 %). Rotation with beans Carrot and Cabbage helped to get 33%-77 % yield advantage.

Figure 6. One season rotation with Cabbage, Carrot and Beans effect on the progress of disease

This could be that these crops do not exploit soil nutrients at the lower soil depths of 15-30 cm, where the potato is most active hence the high yields after relatively shallow rooted crops is expected. Gunadi *et al.* (1998) also reported that potato yields following rotations with crops that have longer roots, such as maize, and tomatoes may perform better. This suggests that the nutrient exploitation of crops selected for rotation with potatoes should be considered. The cabbage, which is the second most important horticultural crop in Shashemene (Bekele Kassa, unpublished data) can be very suitable for rotation where BW is an important disease.

Table 10. Effect of one-season rotation with vegetables and beans on incidence of bacterial wilt and potato yields

Treatment	Bacterial wilt (%)	Latent infection (%)	Total yield t ha-1	Marketable yield t ha-1	Increase in marketable Yield (%)
P - B – P*	23.1b**	19.4a	26.4a	25.5a	77.1
P - Cab -P	18.4b	23.2a	24.8b	21.3b	47.9
P - Car - P	32.3b	25.9a	21.3c	19.1b	32.6
P - P - P	63.2a	16.3a	18.1d	14.4c	-
Means	34.25	21.2	22.65	20.07	

crop to fix free nitrogen from the air which increases the availability of the element to the plant and improve soil fertility.

Figure 7. Two seasons rotation with Cabbage, Carrot and Beans effect on the progress of the disease

The performance of rotations that included beans followed by cabbage is important because both are cash crops as well as are major source of plant protein and vitamins in the district (Bekele kassa, unpublished data). However, using beans alone for rotation is not recommended, as beans are potential hosts of **4**. solanacearum (Gunadi et al.,1998 and Abd El-Ghafar, 1998). Though, none of the rotation treatments was good enough to either decrease the incidence of BW and increase tuber yields. Though not quantified in our study, according to French (1996), Intercropping potato with beans resulted in less spread of **4**alstonia solanacearum.

The studies reported here demonstrated that bacterial wilt incidence can be satisfactorily reduced and potato yields increased by exercising one and / or two seasons retaliations with cabbage or beans. Cabbage and beans which are among the major cash and food vegetables and food crops for resource poor farmers can be good rotation crops if used either alone or cabbage after beans. In general, good control of BW can be achieved in Shashemene through the combined use of clean seed, crop rotation, uncontaminated soil, a less-susceptible variety, and rouging. Latent infection should be monitored with mores sensitive methods like NCM-ELISA to ensure that seed lots are free from BW. This would result in good wilt control, higher yields, and reduced wilt spread.

Table 11. Effect of two-season rotation on bacterial wilt incidence and potato yields at Shashemene, 2009 - 12 seasons

Treatment	BW incidence	% Latent infection	Marketable tuber yield (t ha-1)	% increase Marketable
Potato - Beans - Beans - potato	36.4 (5.81 bcd)*	25.0	29.27a **	154.52
Potato - Cabbage - Cabbage - Potato	14.0 (3.28 bc)	23.0	20.73bc	80.27
Potato - Carrot - Carrot - Potato	40.3 (6.32bc)	53.3	18.92bcde	64.57
Potato - Carrot– Beans - Potato	49.4 (7.01b)	36.7	20.15bc	75.21
Potato – Cabbage - Beans – Potato	25.2 (4.89cd)	30.0	20.7bcd	80.00
Potato – Cabbage - Carrot – Potato	21.9 (4.52 d)	48,3	27.37ab	138.00
Potato - Potato - Potato - Potato	81.1 (8.96 a)	77.3	11.5f	-
Mean	40.26	38.74	20.97	98.76
LSD(0.05)	(1.47)	9.43	2.72	2.41
CV %	14.1	8.4	12.6	

,ource> =ekele, 2.1C

* Square root values. **Means followed by same letters in columns are not significantly different at 5% probability level.

The way for ward

There are no effective bacterial wilt management means because chemichals are not available and/or complex in their applicabelity and no host resistance exists.Although some research findings have shown the effect of some bioagents and plant extracts on BW, still they are on an infant stage and need more research work in termes of its applicebility to use as control in the production system. In aditoin, sanitation and regulatory control are either not inplace or not strengthened. The other option, soil amendment, as opposed to chemical control to leaf diseases that showed effect within the season, needs relatively long seaons to show an effect after application. As a result farmers do not show interest to use the techniology. Since the pathogen is also soil borne, one of the stratagies to control the disease is the use of rotating potato with identified none host crop species to the pathogen in addition to the use of halthy seed tubers. Overall the knowlage of farmers thorugh partcipatory BW management techiniology development extension system which enables them to convince themselves about the advantage of sanitation of farm tools, roguing of diseased plants, the use of healthy seeds and crop rotation. especialy for seed producers is sought. Generally efficient disease free seed system should be developed and materialized thorugh out the country to mange BM.

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The causal pathogen, inoculums sources and alternative hosts studies of the newly emerged gall forming faba bean (*Vicia faba*) disease in Ethiopia

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Abstract

*he fa"a "ean gall disease was first reported in I cto"er of 2.1. from Ethiopia. : uring its assessment the farmersL responded, it was "efore two years prior to the report. *he disease covers the northern ma!or fa"a "ean growing areas of the country. Ecologically it was more sever with the increasing altitude and on poor soil fertile land. ; a"a "ean gall caused "y the fungal pathogen Olipidium viciae was identified "ased on field symptom, plant symptom and morphometricD / orpholgical means using light microscopy and found to "e similar to previously identified pathogen from 1apan. #t has different alternative hosts and the innoculum sources were mainly contaminated soils and crop residues. 0 either , eed from diseased plant, nor air (opened micro plot) were not showed disease symptom on experimental fields for three consecutive years. #ts rapid dissemination and severity makes it the ma!or fa"a "ean disease in Ethiopia. : ifferent management options were deployed since it was reported. +gro chemicals like; / anco%e", 4idomil (foliar spray) and "eylaton (seed dressing) were reduced the severity level. *he improved varieties ? achena and ? ora were reported with lower incidence than the local at : e"re"irhan.

Key words: Ethiopia, Faba bean, Faba bean Diseases, Faba bean Gall

Introduction

Faba bean is believed to be originated in the Near East and is one of the earliest domesticated legumes after chickpea and pea. Ethiopia is considered as the secondary center of diversity and also one of the nine major agro-geographical production regions of faba bean. According to Central Statistics Agency of Ethiopia 2013/14, Faba bean takes over 30% (nearly half a million hectares) of cultivated land with an average national productivity of 1.5 tons ha^{-1}. It is the first among pulse crops cultivated in Ethiopia and leading protein source for Ethiopian's and used to make various traditional dishes. Feeding value of faba bean is high and this legume has been considered as a meat extender or substitute due to its high protein content of 20-41 % (Crépona et al., 2010). From the economic standpoint, faba bean is a source of cash to the farmers and foreign currency to the country. Ethiopian farmers are also cognizant of the role of legumes in general and faba bean in reticular in improving soil health by fixing atmospheric nitrogen, and widely use them in rotation with cereals (Sahile et al., 2008). It occupies close to 574,060 ha of land with annual production about 943,964.2 tone (CSA., 2013). Even though Ethiopia is the world's second largest producer of faba bean next to China, its share is only 6.96 % of world production and 40.5 % within Africa (Chopra et al., 1989). In Ethiopia, the average yield of faba bean under small-holder farmers is not more than 1.6 t ha^{-1} (CSA, 2013), despite the availability of high yielding varieties (> 2 t/ha) (MoA, 2011). The low productivity of the crop is attributed to susceptibility to biotic and a biotic stresses (Sahile et al., 2008 and Mussa et al., 2008). Of the biotic category, diseases are important factors limiting the production of food-legume crops as a whole and faba bean specifically in Ethiopia (Negussie et al., 2008; Berhanu et al., 2003). Diseases such as chocolate spot (=otrytis fa"ae Sard.), rust [3romyces 5icia fa"ae(pers.) de Bery], Ascochyta Blight (+scochyta fa"ae Speg.), black root rot (;usarium solani Mart), and foot rot (;usarium avenaceum) are among fungal groups that contributes to the low productivity of the crop (Negussie et al., 2008; Berhanu et al., 2003). Furthermore, a new emerging disease which cause up to complete crop failure over wide areas within short period of time and aggravates the diminution of yield to maximum nationwide (Dereje et al., 2012).

The disease is shortly covering areas of previously not observed. Yet, the disease is not well studied and its causal pathogen, spread mechanisms, and alternative hosts are not well identified. Thus, the aim of this study was to identify faba bean gall disease causal pathogen, inoculum sources and alternative hosts.

Materials and Methods

Study area

The experiment was carried out in North shoaat the Addis Ababa University's, Salale campus where the disease was first reported (Dereje et al., 2010) and in faba bean gall disease hot spot areas for three consecutive years.

Causal agent (pathogen) study

According to Dereje et al. (2010) the disease was first reported from North Shoa of Oromia region in 2010 and depending on its field symptom they suggest as it is "faba bean gall" incited by the pathogen (I lpidium viciae Kusano) Xing (1984) which was first reported as new species in 1912 in Japan.

Faba bean gall infested fields around hot spot areas (highlands of North Shoa of Amhara and Oromia regions) and diseased individual plants were observed thoroughly to diagnose with its symptom. The formed gall were measured and recorded. Diseased leaves were crushed and set under light microscope for cellular examinations. All results were recorded and compared with previously documented characterization features of the pathogen.

Inoculums source study

Experimental setup: Micro plots with the volume of 1m*1m*20cm were prepared on the wooden bench 1m high above ground to avoid surface contamination. Each plot was filled with sterile soil. Infected faba bean residue (plant debris) from previously known field and seed from different sources disease free seed and seed from previously infested faba bean field) were used to check for their potential inoculums sources. Ten plants were planted per plot and recommended fertilizer rate and weeding practices were done on time. The raised plots were partitioned by polyethene sheet to protect the contamination from side plot by rain splash or wind current. Disease free seeds from Holetta research center were used (the place where the disease not observed). A total of four treatments were used in completely randomized block design and replicated trice. The seeds were planted following farmers planting time in the main season. Finally, faba bean gall disease incidence and severity were recorded.

Alternative host study

Experimental setup: Two meter long double experimental lines with 30 cm of intra line were prepared on precursor of diseased faba bean field with all its agronomic practices. The planting time follow farmers' season for faba bean.

1. 'otus corniculatus
2. :olichos la"la"
3. 5icia sativa (Vetch)
2. *rifolium 6uartinianum
5. /edicago sativa var 5929
6. 5icia 5illose 2441
7. 5icia das6carpa var lana (vetch)
B. /edicago scutellata
9. Field pea ()issum sativum)
10. Faba bean (5iciae fa"ae)
11. Fenugreek (*rignollela sp.)
12. Rape seed (=rassica sp.)
13. Lentil (sp.)
14. Chickpea

Seeds of all pulse crops were collected from disease free area (Holetta research center). Data was collected based on the presence and absence of faba bean gall disease symptom and under light microscopy.

Results and discussions

Causal agent (pathogen) study

Identification of the causal agent study was largely depending on symptom descriptions and microscopic examination.

Field and plant Symptoms of the disease

The infested fields were observed easily detected depending on their severity and stage of the plant. The disease observed soon after crop emergence and reaches its maximum in mid rainy season and gradually reduces as the season gone. In this moment the plants rejuvenate with new leaves and highly infected leaves were senescence. Severely infested field show highly stunted crops and the field turned dark brown (Fig1. C.). Seriously infected plants are often stunted with few pods.

Fig. 1. Faba bean gall disease symptoms A. gall on faba bean leaf B. gall on field pea C. highly infested faba bean field

Faba bean gall disease symptom mainly observed on the leaf and stalk, sometimes also on petiole but not on pod. Its early appearance detected on the back (or sometimes front) side of leaves was light green nearly round bulge spots, the surfaces of the spots appeared rough with development, proliferated gradually to form chlorotic galls gall finally (Fig.1). The small tumors like galls are formed, 2-8mm in diameter and 1-4 mm high before coalesced (Fig. 1) which is comparable with Xing (1984). The individual gall was rolling up able to fuse into irregular shapes (abnormal growth of leaves) caused brown stain and necrosis of infected cells. Complete contraction and dysmorphosis of the leaves were observed in its severe condition. At the later stage, the galls turn black or brown, the tissues decay and a few galls break to form necrotic areas. Leaves with more galls usually die earlier. These are considered as characteristic symptoms for the broad bean blister, which are the important basis for the diagnosis (Yan and Hua, 2012; Xing, 1984).

Table1. The diameter and depth of galls on leaves in (mm)

Observations	Gall diameter (mm)	Gall depth (mm)
1	3	2
2	3	2
3	4	3
4	5	3
5	2	2
6	6	4
7	8	3
8	7	2
9	8	3
10	5	1
x	5.1	2.5

The outbreak and distribution of faba bean gall were limited in ecological zone above 1800m and above in Ethiopia the altitude suitable for faba bean growth.

Yan and Hua (2012) reported that, zoosporangiums were constantly reproduced after the disease occurred in field, liberated zoospores with the presence of rain or dew for secondary infection which cause highly repeated secondary infection. The disease spread quickly in the field and reached peak outbreak around flowering and pod formation stages and then stopped gradually after pod stage.

Light microscopy of the disease

The pathogen infected and parasitized in the epidermal cells of leaf and stem. The host responded quickly to the invasion and then it induce symptom. The anatomy of epidermal tissues and cross sections of leaf and stem of broad bean, and the growth of the fungus in host cells were observed with light microscope. The pathogen of faba bean gall inhibited the epidermal cells of faba bean leaf, petioles and stalk. The fungus was unicellular and has one posterior tail (flagellum), with round protoplast. It was observed that the zoospores were able to function as motile isogamete and fused together or conjugates to form zygote with two cilia.

According to Yan and Hua (2012) the biological studies on I. viciae indicated, the mature zoosporangium in epidermal cells of disease spots was able to liberate zoospores once in the presence of rain water with germination temperature range of zoosporangium was from 0 to18°C, it will be significantly inhibited below18°C, and was unable to germinate at 20°C, 25°Cand30°C. It was indicated as the zoospores were able to swim for 72h between 0 and 5°C; for24, 10, and3h below10, 20 and 25°C, respectively; for only 5min when temperature raised to30°C (Yan and Hua, 2012).The disease depended largely upon the temperature, gradually shortened with temperature increase with the optimum temperature for infection and morbidity was between 10 and 25°C.

From this diagnosis the pathogen is typical to the previously suggest pathogen by Dr Dereje and his team (Dereje et al., 2010). The field symptom and laboratory examination also confirms the causal agent with that of I. viciae which was described from Japan and China (Xing 1984; Yan and Hua, 2012).

Inoculum source study

The faba bean gall disease incidence and severity were recorded for eleven consecutive weeks from the date of seedling emergence. The disease symptom was observed on the second weeks after germination on disease infested soil and residues plots. The progress of the disease incidence gradually became sever as the rain increase (Fig. 1). The incidence of each diseased plot was gradually increased and almost 81% for infested soil and 87% for crop residue at around the end of rainy season.

Fig. 2: Faba bean gall disease incidence

Healthy seed planted on faba bean crop residue and soil from the previously faba bean gall disease infested fields shown symptom starting from the first month and more sever in the middle of rainy season (in August). Eventually, as the rainy season end, the disease severity becomes less and the plant growth continues with relatively healthy looking shoots. In this phenomenon, the total healthy leaf area was higher while disease progress curve goes down from the pick point (fig. 2). Seed from the same field (the field on which the test soil samples and residue were collected) didn't show faba bean gall symptom until the end of rainy season or crop maturity and also similar with that of control (pure seed planted on sterile soil).

Series 3. Residue; Series 2. Infested soil; Series 3. Infested seed 4. Healthy seed; w1-w11 = week 1 to week 11

Fig. 2: Faba bean gall disease severity

This disease was reported to be able to spread in short distance by wind and rain. Continuous cropping and application of animal manure in which sick plant residue existed could cause this disease seriously (Yan and Hua, 2012).

Alternative host study

The faba bean gall caused by I lpidium viciae is known to infect some other crops in addition to faba bean. In Japan S. Kusano confirmed that the small galls cause the same disease which had a wide host range, including faba bean and pea. By artificial inoculation, Xing (1984) found that the pathogen can also infect rapeseed, cabbage, cucumber, spinach and buckwheat but not soybean, kidney bean and other legume crops. On the faba bean disease survey, Hailu et al., 2014, found that field pea with gall symptom in Ethiopia. The current study includes the most commonly cultivated highland pulses in Ethiopia. As a result the prior information on rape seed didn't observed in the growing season over all the studied period (three years). Field pea, lentil, vetch (forage crop) and grass pea shown gall symptom at lower severity (Table 2). Other tested pulse crops didn't develop observed gall disease symptom. Field pea was the next highly infested pulse crop next to the control plot plant of faba bean and this crop is the most potential alternative host which the rotation avoid this crop. Or the field pea residue and field can be significant source of inoculums for the subsequent susceptible crop. Lentil and grass pea, even though the gall is observed at mild, their planting time in Ethiopia is late in the rainy season. While the late rainy season is unfavorable for this disease development, most likely, these crops may not be potential source for faba bean gall disease. Also, the disease may not a threat for these crops. Vetch the forage crop can be the potential inoculums source or alternative on which the disease can survive longer until it obtain its major host. The other study in china, faba bean gall disease resistance variety or cultivar didn't find (Yan and Hua, 2012). Due to high soil moisture, three of the tested pulse forage plants and chickpea were not established including

Table 2. Tested pulse crops against faba bean gall disease

	Legumes	Incidence	severity %
1	Dolichos lablab	-	-
2	5icia sativa (Vetch)	+	2
3	*rifolium 6uartinianum	-	-
4	/edicago sativa var 5929	-	-
5	Field pea	+	10
6	Faba bean	+	40
7	Fenugreek	-	-
8	Rape seed	-	-
9	Lentil	+	2
10	Grass pea	+	1

(+) Presence and (-) absence

Conclusion and recommendation

According to the morphology, the organism was identified as I. viciae which is the disease agent of faba bean gall. It belongs to the genus Olpidium of the family Olpidiaceae, Chytridiales, Mastigomycotina in taxonomy.

Generally, from the result indicated, it is believed that the faba bean gall disease pathogen more survives in soil and crop debris/residues. Crop debris of the infested faba bean gall and soil of the previously year were found the most inoculums source of faba bean gall pathogen to transmit the disease to the subsequent season crop. As the control plot or disease free seed which was only on sterile soil and the seed collected from infested field didn't show any disease symptom, so far we have no information on its seed transmission and from our experiment the disease is believed to be neither air nor seed transmitted. But high current wind can transport with soil and crop debris particles (Yan and Hua, 2012; Xing 1984). Symptomless latent infection should be tested further.

From this experiment, faba bean gall disease cause a disease on faba bean as major host but still there are other pulse crops can be infected by this pathogen. Commonly cultivated highland pulse, field pea, is the most important alternative host. Field pea is mostly grown at similar time of planting season with faba bean and mostly around side field. More over all the farm machinery, farm animals and crop residue have higher chance of contamination with faba bean field. So, survival rate of the pathogen on crop debris and in the soil should be studied for proper crop rotation. Crop debris of these the diseased pulse crops should avoided and rotation should be done with cereal or other vegetable (potato) crops given enough time based on the study results.

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Overview of wheat rust epidemiology and management in Ethiopia

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Abstract:

5arious pu"lished and unpu"lished documents consulted have revealed that wheat rusts caused "y)uccinia graminis)ers. f. sp. tritici Eriks and E. @enn, and)uccinia striiformis f.sp tritici are serious threats to wheat production due to creation of several races in these pathogens over the years. Epidemics in Ethiopia resulted from virulent races resulted in countrywide and locali%ed epidemics in various mega varieties, caused yield losses as high as 1..O in meherDmain wheat production season. ?rowing seasonsL effect on stem and stripe rusts intensityDepidemics was noted, high in meherD main season and while "oth rusts are not a risk in "elg season at all. :iseases surveys carried out for the last B years (2..C$2.1G) in meher seasons revealed that rusts regularly occur in wheat producing highlands of I romia, +mahara, ,00)4 and *igray regional states. Fellow rust is e6ually important in all highland areas of the regions while high incidence fre6uency of stem rust is inclined to southern parts of Ethiopia, mainly in I romia, as indicated "y over$years cumulative high incidence fre6uencies. 'ikewise, rusts pressure varied "y altitude and season although epidemiological factors such as weather elements influencing epidemics within and "etween altitude ranges have not "een studied. *he aforementioned surveys also confirmed the presence of alternate host plant that serves for new stem rust race evolution and sexual spore production. ,tudies conducted on spore traps confirmed that rust urediospores are consistently present in the air, almost thoughout the year and seasons. *he main reason for this fact could "e the presence of continuous interconnected components of wheat rust$ pathosystem such as green "ridges consisting of volunteer crops, alternative hosts, "elg season, irrigated wheat crops and spore excursion from a"road. *hese factors contri"ute to rust spores loaded in the air, source of continuous inoculum sources for main season crops regularly affected "y one or other rust. Ethiopia is a large country and spores of rust races hardily disseminate to all wheat producing areas in a single year; spores of new rust race move step "y step as was demonstrated "y the *-**; stem rust epidemics that spread from south part of the country, =ale %one, in 2.1 to +rsi, 9est +rsi %ones and various ,hewa %ones and *igray region in 2.12 and 2.1G seasons. 4ust management options in Ethiopia were developed, of which management of rusts only "y growing resistant wheat cultivars in non$rust risk "elg season and "oth host resistance and application of fungicide options in meher season are the principal options in practice in Ethiopia. @owever, germplasm evaluations at adult and seedling plant stage against rusts are regularly and occasionally treated, respectively. 3nfortunately, genotyping and gene postulation activities have "een occasionally exercised in foreign la"s. /ore interestingly, recent literatures on rusts indicate that current resistance "reeding is inclined toward stem rust rather than to yellow rust.

*here was time when rust race analysis was routinely conducted in Ethiopia at +m"o. *his activity was later weakened. <urrently stem rust race analysis strengthened and is fully functioning at +m"o since 2.1 P. 3nfortunately, yellow rust race analysis is hardily conducted and if done dependent on foreign la"oratories. /oreover, yellow rust races identified so far from Ethiopian samples are not availa"le in the country for anticipatory resistance "reeding, resistance source identification, resistance gene postulation and pathogen related genetics studies, strengthening rusts race analysis, pathogen and host genotyping activities at country level along with physical capacities, especially for yellow rust is relevant for Ethiopia.

Key words: wheat, wheat rust, races, disease outbreaks, epidemiology, disease management

Introduction

Ethiopia's agricultural system constitutes 46% of gross national production, employs 85% of its population, and creates 75% of export commodity values (FDRE, 2013). Wheat is cultivated in bimodal and unimodal rainfall patterns and areas having an altitude of 700 to 2800 masl by 5 million farmers, largely smallholder subsistent farmers (Michael and James, 2017). Produces of 4.5 million tons of wheat produced on 1.7 million hectares under rain-fed conditions in Ethiopia (CSA, 2017; Minotet al., 2015). The national average productivity is 2.6 t/ha, which is lower than the world average of 3.07 t/ha. Several multifaceted biotic, abiotic and socio-economic factors contribute for low wheat productivity. Rusts are the major biotic factors limiting wheat productivity and production (Stewart and Yirgu, 1967; Bekele, 1986). Research has been conducted on rusts, re-emerging wheat diseases, for years in Ethiopia. This paper presents an overview of wheat rust research in Ethiopia. Themes related to integrated rust management: including epidemiology, resistance, cultural and chemical management options are discussed, along with directions for future wheat rust research.

2. Rust causing Pathogens

Of the three rusts infecting wheat crops in Ethiopia, stem rust caused by)uccinia graminis Pers. f. sp. tritici Eriks and E. Henn, and stripe rust caused by)uccinia striiformis f.sp tritici are the most feared and destructive. Pathogens of the rusts have a complex life cycle and five spore types and have distinct two hosts worldwide. Likewise, in Ethiopia, two stem rust spore stages, uredinial and telial are produced on cereal hosts and the sexual spores on =er"eris holitii (Lim et al., 2015; Getaneh, et al., 2016). Rust causing pathogens acquire virulence either through sexual recombination on alienate host or mutation (Singh et al., 2002), the latter mechanism being the most important.

2.1. Emerged races of P*uccinia graminis*: Stem rust race monitoring started in late 1950s and early 1960s by sending rust samples to foreign rust laboratories(Eshetu, 1986, Mengistu et al, 1991 and Ayele et al., 2008b). Fifteen to 39 races, named by specific numbers assigned to them, were known between 1963 and 1982 (Mesresha, 1996). Of the races detected, race 17, 122 and 5 were most frequent during 1963 to 1969, while races 40, 53 and 117 were most frequent from 1974 to 1978. Later on, between 1987 and 1990, 41 races with four letter nomenclature were reported including race JCC/L being the most frequently and races RRT/T, RRTP, RRKT being the most virulent (SPL, 1988). By 2001 to 2004, 44 races were reported, of which races such as TTT and TTR were the most virulent. Most recently, 15 stem rust races named by five letters nomenclature were detected (Endale et al, 2015a and Endale and Getaneh, 2015b), of which races TTKSK, RRTTF TRTTF, JRCQC, TKTTF and TTTTF were the most frequent. The frequency of stem rust races did fluctuate over the last decade. Race TTKSK (Ug99) dominated from 2005 to 2013; however race TKTTF (Digalu race) has become prominent since 2014. The stem rust situation remains very dynamic; recently there is an indication that a new race group may be increasing (Clade III-B, typed race TTTTF/TTRTF). As indicated, stem rust is a re-emerging disease in Ethiopia. Moreover, race naming lacked consistency and thus, created difficulty in grasping similarities or dissimilarities of the races evolved over years, at least, from the literatures. Historical races identified have not been stored locally, however recent ones such as TKTTF, RRTTF, TTKSK, TRTTF, JRCQC and TTTTF are now being stored by Ambo PPRC and isolate collection is being developed. The most important recently detected races are now starting to be used in anticipatory stem rust resistance breeding. However, lack of any historical isolate collection limits investigation of relations among races evolved over time, although modern genotyping tools may shed light on evolutionary mechanisms if samples have been preserved in international isolate collections.

2.2. **Emerged races of P*uccinia striiformis*: Y**ellow rust race study was started in Ethiopia in the early 1973 through collaboration with CIMMYT and the Institute of Plant Protection (IPO, the Netherlands (Eshetu, 1986 and Mengistu et al., 1991). Races named as 20A, 25A and 11/29 was detected. Using the European system of nomenclature (Johnson et al., 1974). a total of nine different stripe rust races were identified from samples collected from various parts of the country within the period of 1977-90 and the most frequent races were 6E16, 82E0, 82E16,134 (166E)150 and 1666E158 (Ayele and Stubbs 1995). The Scientific Phytopathology Laboratory(SPL) established in 1974 at Ambo identified 90 races of stripe rust (SPL, 1988; Masresha.1996) of which races 2EO, 6EO, 14E26, 14E158, 14E138 and 127E225 were reported as most virulent (Mengistu et al, 1991). From 1988 to 2003, 10 races were reported in Ethiopia (Ayele et al., 2008a), of which races 166E150 (Dashen race), 230E150 (Galema race) and 230E158 (Kubsa race) were being isolated from popular varieties , Dashen, Galema and Kubsa, respectively. Of these, the Dashen race occupied more than 50% of races populations during 1987-1989 (Ayele and Stubbs 1995). Races 230E158, 198E158 and 206E158 showed virulence to most resistance genes except to YrCV, Yrsp, Yr4, Yr5, Yr10, Yr15 and Yr17. Wubit(2008), 39 races from 107 samples collected from different regions in Ethiopia and Yr1, Yr5, Yr15, and YrSP genes were effective to all races. Recently in 2013 and 2014, 18)uccinia striiformis races (Wan et al. 2016) were extracted from samples collected from Southeast and central Ethiopia, of which the most predominant ones are shown in Table 1. More than 80% of 18 races in 2013 and 2014 in Ethiopia were virulent to Yr-gens Yr 6, Yr 7, Yr9, Fr2, Yr17, Fr2G, Fr2C, Fr2B, Fr 1, Fr2 , FrExp2, and Fr+, while 40-80% were virulent to Fr1, FrB, and Fr22(Wan et al., (2016). Virulence to Yr10, Fr22, Fr 2, Fr*r1, Hybrid 46 (Fr2", Fr@27), and Vilmorin 23 (Fr2a, Fr52) was low (Wan et al., 2016). Recently work by Ali et al., (2017), has identified genetic lineage of stripe rust defined by molecular tools. Stripe rust samples from Ethiopia during the period 2010-

2015(Global Rust Reference Center Wheatrust.org) showed the prevalence of lineages PstS6,(virulence on Yr2,3,6,7,8,9,1025,27, AvS and the predominant race in the 2010 epidemic) and PstS2(virulent on Yr23678910, 25,27,AvS) also presence of PstS4(detected on Triticale with virulence to: Yr2,6,7,8,10.24). In 2016, a new stripe rust race lineage PstS11 (formerly termed named as AF2012 due to first detection in Afghanistan in 2012 with virulence on Yr2,4 (het),6.7,8,17,27,32,AvS) was detected in Arsi on variety Digalu. Digalu and several other previously resistant varieties e.g. mw, Hulluka were severely hit by stripe rust epidemic both in 2016 and 2017 meher (main) season. Over years data revealed that virulent races to Yr-genes Yr5, Yr 15, YrCV, YrSP and Fr*ye are not common or not found in east Africa (Wan et al. 2016; Ayele and Stubbs, 1995).

Table 1. Yellow rust races and virulence for Yr-genes, 2013 and 2014 crop season in Ethiopia.

Race name	Virulent to Yr-genes
PSTv-105	Yr 1, Yr 6, Yr 7, Yr 9, Yr 17, Yr 27, Yr 43 and Yr Exp2
PSTv-106	Yr 1, Yr 6, Yr 7, Yr 9, Yr 17, Yr 27, Yr 43, Yr 44 and Yr Exp2
PSTv-107	Yr 1, Yr 6, Yr 7, Yr 8, Yr 9, Yr 17, Yr 27, Yr 43 and Yr Exp2
PSTv-76	Yr1, Yr 6, Yr 7, Yr 8, Yr 9, Yr 17, Yr 27, Yr 43, Yr 44 and Yr Exp2
PSTv-41	Fr7, FrC, FrB, FrA, Fr1., Fr1C, Fr22, Fr2C, Fr 2, Fr2 , Fr22, Fr*r1 and FrExp2

Source: Wan et al., (2016).

Results of stripe rust race analysis show that similar to stem rust, stripe rust is a re-emerging destructive disease for Ethiopia. stripe rust races identified in foreign and local labs have not been maintained in local labs and hardily used in anticipatory resistance breeding, and investigating the historical relations among preceding and currently reported races of stripe rust in Ethiopia.

Leaf rust races: No recent race information regarding leaf rust. However, presence of five races of). reconditaDtritici was reportedin the early 1930s by Sibilia (1939) in foreign laboratory (Ayele et al., 2008b; Eshetu, 1986). Subsequently, Scientific Phytopathological

Laboratory conducted leaf rust race surveys since 1974, and identified 60 rust races coded in numbers. From 1988 to 1990, a total of 33 different races were identified from 282 samples collected from Ethiopia in the Cereal Rust Laboratory, USDA (Ayele et al., 2008b). Among the the leaf rust races, EEE/E was the most frequent.most recently, Klmer and Acevedo(2016) reported the detection of 8 races from 193 isolates collected in central Ethiopia during 2011-20013. Using the five letters of North American nomenclature (Long and Kolmer, 1989) the races identified were BBBQ1, CCMSS, CCPSSCBMSS, MBDSS and EEEEE. The isolates from race EEEEE were collected exclusively from the durum wheat, but were avirulent on susceptible on hexaploid wheat cultivars. Despite virulent leaf rust isolates detection in previous years in Ethiopia, there was no nationwide leaf rust epidemics which challenged wheat production so far.

Genotyping of rust pathogens:

Stem rust: Although genetics studies of isolates of). graminis races have not been started in Ethiopian labs, considerable progress has been made through the international collaboration – especially with USDA-ARS Cereal Disease Lab in Minnesota. Olivera, et al., (2015) genotyped 47 Ethiopian isolates belonging to Ug99 group (TTKSK, TTKST, TTTSK, and TTKSF) and TRTTF, JRCQC and TKTTF. During, this study, PgtSNP Chip identified 16 multilocus genotypes (MLGs), and divided them into four clades containing Ug99 group (clade I), JRCQC (clade II), TRTTF or RRTTF (clade III) and TKTTF (clade IV) using bootstrap values using phylogenetic analysis. This study clearly indicated that isolates of TKTTF race is not only belonged to a genetic lineage ofUg99 race group, but also composed of two distinct genetic types (Olivera, et al., 2015; Singh and Jin, 2015??).

2.4.2. Stripe rust: Recent work by Ali et al., (2017), identified genetic lineages). striiformis defined by molecular genotype. This work is being expanded by the Global Rust Reference Center as new lineages are identified. Current genetic lineages and associated races are described on wheatrust.org(seehttp://wheatrust.org/stripe-rust-tools-maps-and-charts/definitions-of-races-and-genetic-lineages/). Stripe rust samples from Ethiopia during the period 2010-2015 show the prevalence of lineages PstS2, PstS2 and also presence of PstS4. In 2016, a new stripe lineage PstS11 (formerly termed AF2012) was detected for the first time in Ethiopia.

Rust Epidemiology

Epidemics in rainfed Meher and Belg seasons: Wheat is produced under rainfed and irrigation conditions in Ethiopia. Rain fed wheat is produced in meher and belg seasons. The former is the major wheat producing season in terms of both cultivated area and the amount of wheat production.Wheat rust diseases remained endemic in all wheat producing highlands of Ethiopia although they vary by years and seasons; and within the season in disease prevalence and frequency of high disease incidence recorded by regular wheat diseases surveys. Studies have confirmed that diseases in general and rusts in particular affect wheat production significantly in the meher seasons rather than in the belg seasons as has been demonstrated by the data generated since 1996 by series of mobile and stationary rust surveys carried out in Bale and Arsi zones (Bekele et al., 2010; Bekele et al., 2002; Bekele. 2003). Stem and yellow rusts epidemic parameters such as prevalence and intensity have been very low or absent in belg season and high in meher season (Tables 2 and3). Currently commercial and smallholder farmers grow susceptible varieties in rainfed "elg season on several hectares in Bale zone in south-eastern Ethiopia without any stem rust and yellow rust risks, as opposed to meher season which often suffers from rust epidemics.

Wheat disease surveys conducted for the last 8 years, 2007-2015, in meher season in Oromia, Amara, SNNPR and Tigray regional states (Figures1-3) clearly indicated that the risk of stripe rust, in relative terms, is equal in all highland areas while high stem rust risk prevails in areas toward south-eastern parts of Ethiopia, being most prevalent and frequent in Oromia. Leaf rust has exhibits a more patchy distribution with generally a low level of intensity. Leaf rust was most frequent in Oromia and Tigray than in other regions in 2015 as presented in figure 3 and Table 7. The frequency of rust severity detected has shown a clear trend corresponding to the appearance or incursion of the new rust races in Ethiopia (Figure 4). High severity of stripe rust observed in 2010 and 2011 corresponding to the emergence of races virulent on Yr27. Similarly, high severity of stripe rust was observed in 2016 and 2017(virulent to Fr 2, Fr(2), Fr7, FrC, FrB,Fr1C, Fr2C, Fr 2) (Hovmøller et al., 2017). (Tables 4 and 5) corresponding to the detection of PstS11 in Ethiopia. Likewise the emergence of stem rust race TKTTF in 2013 resulted in high severity of stem rust in 2014 and 2015. Like in 2010, these epidemics have enforced farmers to spray fungicides up to three to four times on susceptible varieties such as Kubsa and Digalu in Arsi , West Arsi and Bale zones where the yield loss of up to 100% would have been occurred under no fungicide applications (communication with farmers). Most interestingly, variety Digalu that has been hit by stem rust race TKTTF during 2013-2015, also become vulnerable to stripe rust during 2016 and 2017 seasons. If farmers keep on growing this variety they must have be prepared to use fungicides if either stem rust or stripe rust appears.

Moreover, all virulent yellow and stem rust races have been evolved (Masresha, 1996; Wan, et al., 2016) and devastated resistance genes deployed to several rust resistant popular commercial varieties identified from samples collected from meher season, indicating that this season is also most conducive for new rust race creation. This clearly indicated that belg and meher season have their own sets of environmental conditions that significantly affect the aforementioned rusts differently, most probably difference in moisture and cloudiness. According to McDonald and Linde, (2002), moisture is one of the factors affecting the rust epidemic which agrees with findings of Tamene (2015) which demonstrated that stems rust epidemics are significantly affected by rainfall.

Figure 1. Stem rust distribution and importance in Ethiopia, 2007-2015

Figure 2. Yellow rust distribution and importance in Ethiopia, 2007-2015

Figure 3. Leaf rust distribution and importance in Ethiopia, 2007-2015

Figure 4. Frequency of rust severity classes over the period 2007-2017, based on field surveys. Appearance of significant stripe and stem rust races indicated.

Rust epidemics in irrigated wheat: The three rusts which usually occur in meher season(Eshetu,1986; Mengistu, 1991) and "elg season (Bekele, 2003;Bekele et al.,2010) were also identified in irrigated wheat areas, stem and yellow rusts being more pronounced in mid-altitude irrigated wheat in West Gojam zone in Koga farm(Adet RC, wheat disease surveys, 2013 and 2014, unpublished data). In 2015 and 2018, stem and stripe rusts were observed in lowland irrigated wheat in Fantale district and Werer, respectively, (personal observation at a Field-day organized by Were ARC, 2015, Tsegab, 2018). These preliminary survey data have indicated that stem and yellow rusts may potentially affect irrigated wheat production in Ethiopia, depending on which agroecologies the production area is belonged to. Studies conducted elsewhere overseas also have revealed that rusts are important in irrigated wheat areas along with other diseases such as powdery mildew, loose smut, eye spot, tan spot, head blight and alternaria leaf blight (Etienne et al., 2007). However, in order to provide the detail picture of rust intensity and race composition in irrigated wheat production areas in Ethiopia, more surveys need to be conducted in all irrigated wheat agroecologies of the country.

Table 2. Stem rust severity by wheat cultivars at Sinana during =elg and / eher seasons (EWRTN, 1996-2000).

Cultivar	Year of release	Stem rust severity (%) by season and year									
		Belgbelg season					**Meherseason**				
		1996	**1997**	**1998**	**1999**	**2000**	**1996**	**1997**	**1998**	**1999**	**2000**
K6290-Bulk	-	**0**	**0**	**0**	**0**	**0**	**5**	**40**	**30**	**30**	**50**
Dereselign	1974	**0**	**0**	**0**	**0**	**0**	**30**	**60**	**35**	**40**	**60**
Batu	1984	**0**	**0**	**0**	**0**	**0**	**5**	**60**	**40**	**40**	**40**
Dashen	1984	**0**	**0**	**0**	**0**	**0**	**20**	**60**	**40**	**70**	**40**
Gara	1984	**0**	**0**	**1**	**0**	**0**	**10**	**80**	**40**	**40**	**50**
Lakech	1970	**0**	**0**	**0**	**0**	**0**	**50**	**60**	**50**	**50**	**60**
Pavon-76	1982	**0**	**0**	**1**	**1**	**1**	**15**	**30**	**30**	**60**	**40**
Galema	1995	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**1**
Wabe	1994	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**60**	**60**	**40**
Kubsa	1995	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**10**	**20**	**40**
Tusie	1997	**0**	**0**	**0**	**0**	**0**	**1**	**5**	**30**	**15**	**15**
Abola	1997	**-**	**0**	**0**	**0**	**0**	**0**	**5**	**40**	**40**	**30**
Mitikie	1994	**-**	**0**	**0**	**0**	**0**	**1**	**5**	**10**	**10**	**15**
Megal	1997	**-**	**0**	**0**	**0**	**0**	**0**	**5**	**15**	**15**	**40**
K6295-4A	1981	**0**	**0**	**1**	**0**	**0**	**5**	**10**	**20**	**20**	**25**
ET13A2	1981	**0**	**0**	**1**	**0**	**0**	**1**	**10**	**10**	**15**	**50**
Katar	1999	**-**	**-**	**0**	**0**	**0**	**-**	**0**	**40**	**30**	**50**
Morocco	-	**0**	**0**	**10**	**40**	**0**	**90**	**80**	**90**	**90**	**100**

Source: Bekele (unpublished) and Bekele et al., 2010

Table 3. Yellow rust percentage by number of genotypes infected at Sinana during genna/belg and bona/meher seasons, 1996-2000

Season	**Year**	**No. of genotypes tested**	**% infected genotypes**	**No. of genotypes in severity classes**				
				1-10	**11-20**	**21-30**	**31-40**	**41-100**
Belg	**1996**	**55**	**0**	**0**	**0**	**0**	**0**	**0**
	1997	**178**	**0**	**0**	**0**	**0**	**0**	**0**
	1998	**184**	**36.4**	**61**	**5**	**0**	**1**	**0**
	1999	**186**	**60.0**	**74**	**21**	**6**	**2**	**1**
	2000	**184**	**0**	**0**	**0**	**0**	**0**	**0**
Meher	**19996**	**187**	**89.3**	**43**	**24**	**43**	**29**	**28**
	1997	**185**	**89.2**	**46**	**7**	**14**	**61**	**37**
	1998	**188**	**92.0**	**31**	**23**	**19**	**44**	**56**
	1999	**186**	**95.2**	**28**	**24**	**28**	**28**	**69**

	2000	**193**	**94.3**	**24**	**21**	**22**	**79**	**36**

Source: Bekele et al., 2002.

3.3. Rust Epidemics by altitudes: Generally, temperature and amount of rainfall vary with altitudes and thus influence disease occurrence and epidemics. Studies have revealed that stem rust, leaf rust and yellow rust development is favoured with altitudinal range of 1600-2500 m, 1800-2600 m and 2150-2850 m, respectively (Kuzmichew et al., 1985). Stem rust was observed destructive at altitude below 2300 masl while yellow rust was most important at altitudes above 2100 masl (Mengistu et al., 1991) and at 2144 to 2497 masl (Worku, 2014) while it was low at 2000 masl (Worku, 2014) and high both in east Gojam (2100-2600 masl) and North Shewa (2674-3036 masl) (Landuber et al. 2016) although showed variability both in terms of incidence and severity. Stripe rust incidence was observed to be 100% both at Sinana with an altitude of 2400 masl and temperature of up to 21^{o}C and rainfall of 531mm and at Ginner with an altitude of 1972 masl and temperature of up 26^{o}C and rainfall of 562-842 mm, although, however, the disease was more severe (55.5%) at Sinana on susceptible variety Kubsa invariably with records taken on all leaves, flag leaves and F-1 leaves (Wubishet et al., 2015). Almost all these observations are in line with Kuzmichew et al., (1985) except the Ginner case for yellow rust. Rusts' variability by altitude could be explained mainly with two important elevation based epidemiological factors, temperature and rainfall patterns. These two parameters are pre-requisite elements for the rust spore germination, infection, growth, survival and development (Chen, 2005).

Stripe rust highly and positively affected with minimum temperature, relative humidity and rainfall, sunshine radiation and negatively affected with maximum temperature (Salman et al., 2006; Ahmad et al. 2010). Over years stem rust intensity and weather data analysis based at Sinana and Kulumsa research centers has revealed that rainfall affects stem rust epidemics (Tamene, 2015). Our understanding of altitude effect on rust epidemics, most probably, has become a basis for altitude based variety release and registration for lowland to highland altitude ranges (Crop Variety Register, Issue

Numbers from 4-19, 2001-2016; NSIA, 1988). Nevertheless deploying varieties on the basis of altitude ranges has been hardly put into practice in wheat production.

Sometimes unexpectedly stem rust was found in very highland areas such as Meraro with an altitude of 3000masl. Likewise, stripe rust epidemics outbreaks experienced in warmer areas such as countries closer to the equator due to high temperature tolerant aggressive strains moved to the area (ICARDA, 2011; Hovmoller et al., 2008; Milus et al., 2009).). Observation of stem rust and yellow rust at extremely highland and lowland areas, respectively, in Ethiopia, thus, is an indicative fact that these rusts are extending their adaptation to cooler higher and warmer lower altitudes, respectively. The assumption that yellow rust and stem rust are the disease of cooler and warmer environments, respectively, has been challenged globally. To date bread wheat production occupies diverse altitudes, lowland to highland managed under rainfed and irrigation and altitude wise three rusts epidemic reported to be reworked in detail through thorough surveys along with prevailing weather conditions and clearly demarked.

4. Alternative host, green bridge and airborne inoculum: Survival of the rusts and the inoculum disseminating from one season to another or between crops is implicated to the presence of continuous supply of living host plants such as grasses (alternative host) and volunteer wheat plants (main hosts). Grasses are important in the epidemiology of rusts. Studies conducted during 1985-87 revealed that urediospores from 'olium multiflorum infect wheat seedlings and produced stem rust infection within 10 to 12days and stem rust spores from @ordiem spp. and Setaria spp infected susceptible wheat varieties Ashahan and Morocco (Mengistu et al., 1991). Also it has been confirmed that stem rust spores collected from grasses such as 'olium temulentum, ,etaria pupila, +vena fatua, ,nowdenia polystachahya, <ynodon dactylon, =romus pictinatus and Euphor"ia shiperiana in Shewa, Arsi and Bale zones and inoculated to susceptible wheat varieties and reciprocally to grasses gave positive infection although rust spores were produced

only in pustules produced on 'olium temulentum and ,etaria pupila (Zerihun and Abdella, 2000).

Stripe rust urediospores collected from)halaris spp in 2016 at Agarfa Research Station, produced infection on the seedlings of susceptible variety Morocco with few spores on the pustules. Also, diverse farmers planting dates within a season potentially harbours rust spores and thereby extending time of spore production and survival. For example, wheat is planted early in June to early July, in most of Arsi and West Arsi zones, while it is done latter in Bale Zone from August to September. Spore emanating from rust susceptible wheat varieties of the earlier planting dates in Arsi and West Arsi could be a potential inoculum sources for the late planted crops in Bale zones and similar areas although urediospores exist in atmosphere across the years as revealed by spore trap studies conducted at Ambo, Adet, Holeta, Sinana and Kulumsa research centers in ordet to detect airborne spore load (Kebede and Bekele, 2009; Paul, et al., 1994; Bekele, 2003; Eshetu, 2003; Getaneh and Temesgen, 1995). Yellow rust urediospores are present throughout the year, peaking in November at Kuluma and in Feb at Holetta. At Sinana, stem and yellow rusts spores caught throughout belg and meher seasons, being low in belg season and showed peak in November to December. At Ambo, stem rust and leaf rust spores were caught throughout the year except in July, a peak reaching in January. These rust spores picked from hosts by winds remain airborne till they are scrubbed down by rain on susceptible host crops for inoculation and infection. A study conducted by Tamene, (2015) also proved that rainfall has positively influenced stem rust infection process and disease development.

It has been reported that rust spores of virulent either evolved in the country or migrate to the country. The question is that whether these spores once reached Ethiopia immediately disperse to all wheat production. According to Singh et al., (2004), four worldwide principal spore dispersal modes: single event (unassisted and assisted), stepwise expansion (assisted), and extinction and re-colonization are known. Although we do not have clear picture of how virulent races disperse from their origin to other areas, lessons leant from 2013-2015 and other years in Ethiopia suggested that stepwise spore dispersal modes could be most possible. Stem rust race TKTTF destroyed Digalu variety in 2013 in Bale, and yellow rust race virulent to Yr 27 (Kubsa), observed in West Arsi at Heraro state farm in 1997, south-eastern Ethiopia and then disseminated to the rest wheat producing regions and destroyed popular varieties Kubsa and Galema in 2010.

Another example for stepwise spore movement is that dispersal of Yr9-virulent yellow rust race evolved in East Africa Kenya to South-eastern Ethiopia and migrated across other parts of the country and beyond to Middle East, West Asia, South Asia in over about 10 years, and caused severe epidemics along its path (Singh et al., 2004). Likewise, race Ug99 which evolved in Uganda in 1998, has moved in stepwise manner to Kenya then within Ethiopia since 2003 and beyond Ethiopia to Yemen. Furthermore, recently, a virulent yellow rust race temporarily named as A2012 (Hodson, personal communication) was detected in Arsi Zone in 2016 and migrated to other wheat growing areas of the country destroyed Digalu variety both in 2016 and 2017. This information indicates that epidemics from virulent races could be avoided easily by timely detection of virulent race/s and replacing susceptible variety by resistant variety. Alternate host (=er"eris holstii) has been found to be susceptible to)uccinia graminis, and). striiformis (Jin et al. 2010). The host was identified by Addis Ababa University and registeredin 1950 in a book of the Ethiopian flora. Currently at least seven barberry sites are marked in North Shewa, South Wello and South Tigray zones being located at 2488 to 2979 masl (Getaneh et al., 2016; Lim et al., 2015; Figure 5). Aeciospores inoculated to 28 small cereal lines in 1978 failed to produce stem rust infection (SPL, 1978). Recently, however, of 13 aeciospores samples, five, eleven, eight, four and one sample gave stem rust infection on two wheat, barley and oat lines, respectively (Getaneh et al., 2016). Likewise, 69 and 26 aeciospores samples gave positive and weak positive infection in DNA assays, and thereby revealed that =. holstii is an alternate host for). graminis in Ethiopia. Urediospores with aeciospores backgrounds resulted in races such as BBBBB, avirulent to ,r21) and GBBBB and DBBBB, virulent to ,rAe genes (Getaneh et al, 2016), indicating that sexual recombination could result in virulent stem rust race although wheat rust epidemics have not been reported from areas with barberry sites so far.

Figure.5. Distribution of =er"eris holstii as alternate host of)uccinia graminis, (Getaneh et al, 2016)

Impact of periodically emerged virulent rust races on wheat production

Stripe rust: Stripe rust causing pathogen changes in Ethiopia (Wan et al., 2016) and at worldwide level (Burdon, 1993), and adapting to resistance genes deployed to varieties and thus resulting in catastrophic epidemics in Ethiopia (Bekele, 2010; Mengistu et al., 1991; Ayele et al., 2008b) and in other countries (ICARDA, 2011, Saari and Prescott 1985). Epidemics of yellow rust have been noticed in Ethiopia since 1977. Destructive epidemics associated with virulent yellow rust race have been repeating at different intervals ranging from 6 to 22 years (Table 4). Yellow rust (Table 4) and stem rust (Table 5) epidemic occurrences have clearly indicated that yellow rust epidemic is more frequent and problematic in Ethiopia. Yellow rust epidemic continues occurring per annum at limited farmers' fields, localities or nationwide after its initial outbreak, and presence of epidemiological factors virulent race, favourable environmental conditions and susceptible mega varieties. Stripe rust periodically has resulted in financial losses exceeding several million Ethiopian birr for wheat farmers due to failure to replace susceptible variety by resistant variety. Of all yellow rust epidemics which occurred in Ethiopia, the epidemic caused by Yr 27 virulent race in 2010 has more widespread and most damaging. This epidemic wipedout the popular varieties Kubsa and Galema were planted on about 600,000 hectares. This epidemic has enforced the country to purchase and distribute fungicides of worth about 60 million Ethiopian Birr (Table5) for spraying fields planted to the aforementioned yellow rust susceptible cultivars and thus partially sustaining wheat production.

In 2013, popular triticale varieties locally known as ogashibo and Gondare were damaged by yellow rust epidemic which occurred in South Wello, North Wello and South Gonder zones (Bekele et al, 2013 unpublished)that could be due the race extracted from infected triticale sample collected from this epidemic region(Wan et al., 2016). During 2016 and 2017 seasons, yellow rust epidemics were high as shown in Table7 and Table8. Yellow rust epidemic onset was very early; the most earliest was noted in early August in Arsi zone in 2017. Assuming that yellow rust symptoms appear about 1 week after infection under optimum temperature conditions (Chen, 2005), the onset of this rust could be dates lapsed between the end of July and early August. Like the epidemic of 2010, yellow rust epidemics of 2017 season have forced the farmers to purchase fungicide to spray the affected fields and preventing the rust and avoiding crop losses.

In the wheat belt zones of Arsi, West Arsi and Bale, farmers applied fungicide up to three to four times on susceptible varieties such as Kubsa and Digalu where loss of 100% would have been occurred under no fungicide applications. Studies conducted in Ethiopia have also revealed that thousand kernel weight losses from spike and whole plant infection in plots varied from <5-56% (Landuber et al. 2016, Kebede et al., 2010; Ayele and Temesgen., 1996, Ayele and Wondimu, 1992). The actual grain yield losses determined through experiments over years have ranged from 20 to 96% (Landuber et al. 2016, Kebede et al., 2010;Ayele et al., 2008b; Bekele.2003; Dereje, 2003 ; Hailu and Fininsa, 2009, Eshetu, 1986; Mozgovoy, 1987; Ayele and Wondimu, 1992) depending on the resistance levels of varieties and locations. The lowest loss of 20% was recorded on bread wheat variety ET 13 (Bekele, 2003).

Table4 Expert estimation of yield losses from major yellow rust epidemics in meher season, 1988-2016

Year	Variety	Virulence	Loss (%)
1977	Lakech	?	?
1988	Dashen	yr9	58
2010	Kubsa/Galema	Yr27	Up to 100
2010	Galema	Yr27	Upto 100
2013	Triticale	?	Up to 100
2016	Digalu*	?	Upto 100
2017	Digalu		Up to 100

Table 5. Yellow rust infested regions, zones, districts and area and area sprayed with fungicide, meher season, 2010.

Region	Zone	District	Area infested (ha)	Area sprayed (ha)	% sprayed
Oromia	13	118	292,866	123,357	42.1
Amhara	8	77	161,348	26,579	16.5
SNNP	15	94	137,376	32,089	23.4
Total	36	289	591,590	182,025	30.8

,ource> / o+, unpu"lished data 2.1.

Stem rust: Wheat production has periodically faced stem rust threats from virulent races that breakdown Sr-genes of major effects deployed to varieties and thereby caused catastrophic yield losses under no fungicide management innervations (Eshetu, 1986, Olivera,et al., 2015). The period at which new virulent stem rust evolving and initial epidemic outbreak seem somewhat longer, 19 to 22 years compared to that of stripe rust as measured by times elapsed among the epidemics outbreaks so far registered (Table 6). However, similar to the yellow rust epidemics, stem rust epidemic also has continued to threat wheat production annually once it had been started to occur in these cases where susceptible mega variety remained in production, favourable weather conditions and virulent race exist. Of stem rusts epidemics occurred so far in Ethiopia, the recent epidemics caused by race TKTTF in Bale in 2013 and further spread to Arsi, and West Shewa zones in 2014 and 2015 were the most destructive epidemics so farexperienced in Ethiopia affecting about 20,000 to 40,000 hectares and resulted in financial losses of several million of Ethiopian Birr.

On other hand, however, virulent stem rust race Ug99 (TTKSK) immigrated to Ethiopia from Kenya in 2003 has not resulted in any known stem rust epidemics under natural conditions in the country so far (Singh et al., 2004), although this race stem rust population from 2005-uptodate, and most of the bread wheat varieties showed high vulnerability under artificial inoculation. Stem rust is more destructive in dense fields applied high nitrogen fertilizer (Bale zone, 2013, Personal observation). This observation is in line with findings of McDonald and Linde (2002) suggesting that foliar diseases caused by obligate or semi-biotrophic pathogens having high evolutionary rate are significantly constraining yield in dense stand crops with high tillering.

Yield losses figures estimated by experienced experts or actual yield losses determined by experiments are given in Table 6. The other severe effects of the rust is that wheat straws severely infected are not even preferred by animals and thus, left in the field or burned down (Bale farmers observation, 2013), significant animal feed loss.

Table 6 Major stem rust epidemics in meher season and expert-estimated yield losses, Ethiopia, 1974-2014

Year	Variety	Virulence	Loss (%)
1994	Enkoy	Sr36	67-100
2013	Digalu	SrTmp	Up to 92
2014	Digalu	SrTmp	Up to 100

5.3 Leaf rust: Leaf rust is less important in Ethiopia than stem rust and stripe rust in terms of disease distribution and intensity pressure. It is predominantly specific to landraces of emmer wheat and durum wheat types although it also is severe on bread wheat at limited agro-ecologies such as Gololcha, Gindhir, Meda Wallabu districts in Bale zone. Yield reduction as high as 75 % was reported on bread wheat at Holetta due to leaf rust (Eshetu, 1986) although this data seems old to represent the present Ethiopian wheat production system.

Table7. Comparative wheat rusts status in prevalence (%), incidence (%) and severity (%), Meher season, 2015 and 2016

		Yellow rust		stem rust		leaf rust	
Zone	Disease parameter	2015	2016	2015	2016	2015	2016
Bale	prevalence	49	69	93.9	47.6	20.4	2.4
	average incidence	20.7	43.1	67.6	12.3	14.3	2.4
	average severity	3.1	10.2	18	2.1	1.1	0.2
ARSI	prevalence	22	85	57.6	15	3.4	0
	average incidence	8.6	60	33	5.5	0.4	0
	average severity	3.3	28.6	10.4	1.3	0.2	0
West.Arsi	prevalence	48.4	100	58.1	28.6	22.6	14.3
	average incidence	30.2	50	44.4	8.7	8.9	5.7
	average severity	10.5	23.4	12.9	5.7	5.6	4.3
North Shewa	prevalence	15.5	90.9	38.2	13.6	1.1	9.1
	average incidence	6	78.8	9.7	6.1	1.2	6.2
	average severity	2.6	24.8	2.6	1.1	0.6	1.1
East Shewa	prevalence	0	28.9	72.7	88.9	18.2	24.4
	average incidence	0	15.7	23.8	30.6	9.2	16.5
	average severity	0	7.7	11.6	14.5	2.8	6.6
West Shewa	prevalence	0	92.3	63	61.5	19.8	7.7
	average incidence	0	76.3	20.3	19.3	9.9	1.9
	average severity	0	49.7	10.2	9.4	7.7	1
South West Shewa	prevalence	0	81.3	75	75	25	37.5
	average incidence	0	42.5	75	27.8	25	8.8
	average	0	32.2	46.9	18.1	15	5.3

	severity						
East Wolega	prevalence	9.1	100	63.6	40	27.3	0
	average incidence	-	86	-	11	-	0
	average severity	2.7	46.3	3.9	3	3.7	0
Horo Guduru	prevalence	4.3	100	59.6	84.6	12.8	0
	average incidence	-	79.2	-	30.3	-	0
	average severity	0.1	42.3	4.9	12.9	0.4	0
South Tigray	prevalence	2.8	0	1.4	0	2.8	11.1
	average incidence	2.8	0	0.7	0	1.6	0.7
	average severity	2.3	0	0.4	0	1.3	0.9
East Tigray	prevalence	5.3	25.7	7	6.9	47.4	43.1
	average incidence	0.3	8	0.5	3.8	24.2	31.4
	average severity	0.6	5	0.4	0.9	8.6	11.8
South East Tigray	prevalence	54.3	8.8	19	0	40.5	41.2
	average incidence	34.9	4.7	14.2	0	12.3	31.5
	average severity	23.4	1.8	4.6	0	3.2	13
Guragie	prevalence	58.3	70.6	41.7	64.7	66.7	47.1
	average incidence	34.2	60.6	30	26	24.3	15.9
	average severity	10	26.6	14.3	11.5	5.1	5
Silte	prevalence	81.3	61.5	62.5	69.2	87.5	15.4
	average incidence	48.8	38.5	31.4	36.2	35.3	2.7
	average severity	12.2	19.2	9.3	19.6	9.2	0.8
Hadya	prevalence	30	75	70	75	100	14.3
	average	7.1	43.8	55	38.6	42.6	3.4

	incidence						
	average severity	1.1	15.2	17.5	8.1	11.6	2

Table 8. Status of wheat rusts comparative weight in terms of overall prevalence, incidence and severity mean (%) in Arsi and West Arsi zones, Meher season, 2017

		Yellow rust			Stem rust			Leaf rust		
Zone	Total field	prevalence	Incidence	severity	Prevalence	Incidence	Severity	Prevalence	Incidence	Severity
Arsi	79	73.4	42.5	13.3	0	0	0	0.03	1.9	0.3
West Arsi	51	51	23.9	23.9	11.8	1	0.12	0	0	0

Components of rusts management

Cultural practices. Cultural practices such as under ploughing and grazing alternative hosts and volunteer cereal crops, destruction of alternate hosts, optimum plant density and nitrogen application, planting date and crop rotation are effective for rust management being used in integration in Ethiopia. Growing wheat no rust risk agro-ecologies has proved to highly effective

Barberry destruction: In Ethiopia, Barberry bush (=er"eris holstii) has been recognized as an alternate host for). graminis (Getaneh et al.,2016; Lim et al.,2015), a plant on which the fungus sexual cycle is completed and new races are formed through sexual recombination (,ingh et al. 2..2; 'eonard and ,%a"o, 2..G) and broke resistance genes through infecting aeciospores coming to the host (Zhao et al., 2013). In Ethiopia, thisbarberry bush is found in patches in very limited localities in northern parts of the country (Getaneh, et al., 2016) and thus, could be easily eliminated from vicinities of wheat–Puccinia pathosystem. Observations of more severe rust epidemics in the cereal crops near barberry bushes in France led the country to 1660 Barberry Laws demanding the destruction of barberry plants near grain fields (Rubiales and Niks.2000) and likewise, extensive reduction of =er"eris vulgaris resulted in successful stem rust control inNorth America, (Leonard and Szabo, 2005).

6.1.2. **Growing wheat in no rust risk season:**Data generated from over years mobile and immobile(rust trap nursery) wheat diseases surveys in belg and meher seasons revealed that wheat escapes stripe and stem rusts epidemics in belg season (Bekele et al., 2002 and Table- in this document). Commercial and subsistent farmers have been successfully growing both rust susceptible and resistant wheat varieties without any need for application of fungicides in Bale zone in the belg belg Dgannaseason with average rainfall and temperature of – and- respectively.

Variety deployment by altitude: Studies indicated that agro ecologies located in the altitude range of 1600-2500 m, 1800-2600 m and 2150-2850 m enhances stem rust, leaf rust and stripe rust development, respectively. Growers who deploy varieties on the basis of rust resistance backgrounds and recommended altitude ranges as indicated in Crop Variety Register (Crop Variety Register, Issue Numbers,4 to 19, 2001-2016) are in a better position to contain the rust epidemics.

Planting date: Planting date has an effect on disease development as studied in various research centers. For instance, early to mid August planting reduces stripe rust incidence and give high yield at Sinana whereas early-mid July planting at Debre-Zeit increased stem rust severity and decreased the yield as well compared to late plantings. Planting wheat at the mid June and early July at Ambo reduced stem rust incidence and increased wheat yield.

Sanitation: Wheat crops grow sequentially one after another in Ethiopia under three conditions, rainfed belg and meher seasons, and to some extent under irrigation on which rusts live on wheat plants all over the year and form green bridge on which rusts perpetuate and survive. In addition to normal crop sequences, self sown volunteer wheat related grass weeds such as Lolium multforum, @ordeum spp and ,etaria spp harbour stem rust and carryover the inoculum to next wheat crop.)halaris sppharbouring stripe rust was observed and recorded in Agarfa district in Bale zone (personal observation, 2016). Moreover green bridges are increasing the population size of virulent strains arising from low frequency events such as mutation (Elliset al., 2014).Reduction/ prevention of inter-seasonal survival of the rust inoculum by destroying the volunteer wheat and cereals, and grasses from the vicinity of wheat crops by tillage/ grazing are seen as part of an integrated disease management component that reduces rusts pressure and subsequently avoid risks of rusts epidemics

Host resistance. Host plant resistance is an important method for disease control in wheat. The use of resistant varieties is very much welcomed by resource poor Ethiopian wheat farmers because it is the most environmentally friendly and economically affordable approach. Major and adult plant resistance genes are the two resistance groups deployed to wheat for rusts management in Ethiopia and worldwide. Several germplasm were screened against rusts over years at adult plant and recently at both seedling and adult plant stages (Wan et al., 2016; Alemayehu et al., 2015; Netsanet Hei, et al., 2015; Tolessa et al., 2014; Worku, 2014; Bekele, 2010; Eshetu, 1986; Mengistu et al., 1991; Ayele et al., 2008a; Ayele et al., 2008b) and many cultivars were released/registered for combating the rust menace and sustaining wheat yield (Crop Variety Register, Issue No. 4-19, 2001-2016; Tesfaye and Jamal, 1982). Unfortunately resistance governed solely with individual major resistance genes has proven to be non-durable against newly emerging races, as experienced with popular wheat varieties such as Lakech, Dashen, Galema, Kubsa and Digalu which succumbed to different stem and yellow rust races (Olivera et al., 2015 ; Bekele, 2010). Farmers sometimes continue to stick to grow some varieties in various agroecologies through integrating fungicide option rather than replacing them with resistant varieties. Wheat resistance breeding has continued to release high yielding resistant bread wheat varieties since 2000 and bread wheat varieties having better resistance to current stem and stripe rusts populations were released (Table-). Old varieties ET13, Enkoy and K6295-4A have been considered to be durably resistant to Ethiopian stem and stripe rusts populations for a long in wheat Puccinia pathosystems, although stripe pressure has been increased on latter variety starting 2016 season onwards.

Genotyping works on Ethiopian elite commercial cultivars are limited. Recently molecular characterization of some Ethiopian commercial bread wheat cultivars and advanced lines was conducted at CDL-USDA (Table-) in order to diagnose the nature of Sr-genes (Table 9) inherent the genotypes whereas conventional gene postulation was by Ayele et al.,(1990); Table 10) and then by Wubit Dawit (2008) in order to discover the nature of Yr- genes 9). Knowledge of disease reaction (both at seedling and adult) and of resistance genes contained in elite lines and commercial cultivars are very essential for breeding programs and gene deployment strategies. According to recent results (Table9) indicated that Sr24 could be quite common in commercial cultivars and elite lines. The prevalence of Sr24 in released varieties and advanced breeding lines highlight the need to diversity the resistance genes used by breeding programs. Virulence to Sr24 is common stem rust races present neighbouring East African countries, while this virulence was detected in Ethiopia in 2016. Cultivars such as Kakaba, Danda'a, Kingbird, Sofumer, Tay and KBG-01 have Sr2 stem rust adult plant resistance gene. Likewise, seedling susceptibility to nine yellow rust races (Ayele et al 2008a) and relatively low adult plant diseases severity under field conditions at multi-location hot spot sites in Ethiopia indicated that bread wheat varieties K6295-4A, ET13A2 and K6290-bulk have good adult plant resistance to stripe rust. All these genotypes could be priority resources for rust resistance breeding in Ethiopia.

Table 9. Stem rust resistance genes postulated for selected old and commercial bread wheat varieties, 2013-2015,

Variety/Line	**Year of release**	**Resistance genes**	**Variety/Line**	**Year of release**	**Resistance genes**
K6295-4A		?	Enkoy		Sr36

ET-13		?	Ogolcho		Sr24/Lr24
Galema		Yr27	Qulqulu		Sr24/Lr24+ Lr37/Yr17/Sr38
Alidoro		Sr24/Lr24+ Lr37/Yr17/Sr38	Shorima		Sr24/Lr24
Biqa		Sr24/Lr24	Sofumar		Sr2/ Lr34+Sr31
Bollo		SrTmp+Lr37/Yr17/Sr38	Tay		Sr2+ Sr31?
Wane			Sanate		
Dambal			Mandoyu		
Buluk					
Digalu		SrTmp+Lr37/Yr17/Sr38	ETBW 6109		Sr24/Lr24
Ga'ambo		Sr24	ETBW 6114		Sr24/Lr24+Sr25/Lr19
Hidasse		SrTmp+/ Lr34	ETBW 6496		SrTmp + ?
Hoggana		Sr24/Lr24/ +Lr37/Yr17/Sr38	ETBW 6696		Sr2
Honqolo		Sr24/Lr24	ETBW 6832		SrTmp
Hulluka		Sr24/Lr24 +Lr37/Yr17/Sr38	ETBW 6875		Sr24/Lr24
K6290-Bulk		Sr2	ETBW 6939		Sr24/Lr24
Kakaba		Sr2	ETBW 7058		Sr24/Lr24
KBG-01		Sr2+Lr37/Yr17/+Sr38	ETBW 7101		Sr24/Lr24
Kingbird		Sr2	ETBW 7213		Sr24
ETBW 7364		Sr2	ETBW 7258		Sr24/Lr24
ETBW 7872		SrTmp + ?	ETHBW105		Sr25/Lr19

ETBW 8470	Sr24/Lr24	Menze	Lr37/Yr17/Sr38

commercially used in the current rust management practices in Ethiopia. Avoiding the sowing of mega varieties on large areas is one of means of avoiding the build-up of emerging new virulent rust races and reducing the chances of mutation and continued breakdown of effective resistance genes, the cause for re-emerging rust epidemics.

Fungicide application

Reasons for fungicide use in Ethiopia: Resistant variety and fungicides sprays are the two major wheat rusts management options for sustaining wheat production in Ethiopia and also globally (Kebede et al., 2011; Ayele et al. 2008b Mengistu et al., 1991; McIntosh et al., 1995). Application of fungicide is required in wheat production in Ethiopia due to various reasons such as all cultivars are not resistant to all diseases, resistance specificity and virulent new races evolving in)uccinia spp population and rust resistance genes knocking down; keeping susceptible varieties in cultivation for long and growers preference of keeping high yielding-susceptible varieties in production, presence of varieties characterized by adult plant resistance in production that commonly influenced by environmental factors fail to give unsatisfactory rust control. Moreover, fungicide application is required in integrated disease management strategy.

Fungicide research in wheat: Fungicides screening against diseases (rusts) has started in the early 1970s (Tsedeke, 1996). Since then several foliar systemic fungicides were screened against rust and registered and recommended for use in wheat production in Ethiopia. Fungicides of triazole, strobilurins and combination of the two classes are more in number in market (Table 11). Strobilurins fungicides inhibit rusts by interfering with energy production of pathogens and act as local systemic and thereby inhibiting fungal spore germination and early infection. These are more effective when used preventively. The triazoles are curative and have systemic movement through the plant xylem and slowing the fungal growth through inhibition of sterol biosynthesis the essential building blocks of fungal cell membranes. Over years accumulated worldwide experiences revealed that fungicidal application had a better impact when used within an IDM strategy (De Waard et al., 1993) and thus reduce fungicide resistance development.

Early warning for better rust management in Ethiopia: Most farmers commonly do not recognize the rust infection at early crop growth stages and most development workers hardily recognize wheat diseases. The problem of not recognizing rust infection precisely on-time at early crop stage created time shortage to get enough chemical on time and spray all the fields affected by rust (Table5) and resulted in damage of wheat enterprise by yellow rust and stem rust epidemics for instance in 2010 and 2013, respectively. To date, plant pathologists based national agricultural research system conduct early meher season surveys when the crop is at an early crop stage, usually in August. The different survey teams identify the type of rusts present, disease intensity and susceptibility levels of commercial varieties , crop growth stages, crop stand and potential crop loss levels if untreated. This packed survey information is quickly communicated to EIAR, CIMMYT-Ethiopia and MoANR at federal level at the soonest time after the end of the survey and is connected to farmers, development workers and experts at grass root levels through regional BoA so that stakeholders are alarmed on rusts occurrence and their distribution by locations and cultivars.

This early warning system as components of integrated disease management helped and helping a lot in mobilizing farmers toward field scouting on-time, getting enough time for fungicide purchase and applying on susceptible and moderately susceptible varieties on-time and getting better economic returns from the investment. Also, this system allowed extension system and private chemical companies to get enough time for importing chemicals and mobilizing them to farmers at grass root levels. Efforts are underway to establish a rust early warninig unit within EIAR, supported by THE , MoANR and including the use of modern IT technology to improve the speed of information flows amongst stakeholders and the interventions.

Table11. Fungicides (product formulation) recommended as foliar sprays for the control of rust diseases of wheat in Ethiopia

Common name-Formulation	Trade name	Rate	Target disease	Class
Epoxiconazole+Thiophanate-methyl	Rex Duo*	0.5 l/ha	Yr	Triazole
Pyraclostrobin+Epoxiconazole	Opera™ Max*	1l/ha	Yr	Strobilurin& triazole
Trifloxystrobin100gm+Tebuconazole 200gm/lt	Nativo SC300*	0.5l/ha	Yr	Strobilurin& triazole
Propiconazole	Tilt 250 EC*	0.5-1 l/ha	Rusts	Triazole
Triadimefol	Noble 25 WP*	0.5kg/ha	Yr	?
Azozystrobin	Ecostar 250 SC*	05 l/ha	Yr	Strobilurin
Azozystrobin 200gm/lt + Cyproconazole 80gm/lt	Amstar Xtra 280 SC*	0.5l/ha	Yr	Strobilurin& triazole
Propiconazole	Bumper *	0.5 l/ha	Yr	Triazole
Propiconazole	Panazole 25 EC*	0.5l/ha	Sr	Triazole
Triadimefon	BayletonWP*	0.5-1 kg/ha	Yr&Lr	?
Triadimefon	Prevent 20 EC	0.65 l/ha	Yr	?
Propiconazole	Topzole 250 EC*	0.6 l/ha	Yr	Triazole
Tebuconazole	Orius 250 EW	0.5 l/ha	Yr & Sr	Triazole
Tebuconazole	Natura 250 EW*	0.6 l/ha	Yr	Triazole
Epoxiconazole	Soprano	0.75 l\ha	Yr&Sr	Triazole
Propiconazole	Progress 250 EC	**0.5 l/ha**	**Yr**	Triazole
Picoxystrobin+Cyproconazole	Acanto® plus	**0.5 l/ha**	**Yr**	Strobilurin & triazole
Triadimenol	Sayfidan	**0.5-1 l/ha**	Yr	?

Yr=yellow rust, Sr=Stem rust, Lr=Leaf rust *= registered fungicide

6. Conclusion and Future directions:

Knowing the production constraints is a critical step towards developing better control options and reducing yield losses. It was understood that a disease occurs when virulent isolate; susceptible host and favourable environment occur simultaneously.Studies undertaken in Ethiopia so far enable us to group wheat production seasons and altitude ranges with minimum rust risk or without risk. Rust race analysis works predominantly conducted in foreign laboratories before the establishment of scientific phytopathology lab and after 1983 E.C. These rust race monitoring works have detected several races in)uccinia graminis ,).striiformis and)ucinia tritici populations although hardily used in anticipatory breeding for rust resistance. Although stem rust race analysis is now fully operating at Ambo, PPRC and efforts underway to strengthen stripe rust at KARC and leaf rust at Debrezeit ARC. Yield loss data due to rusts were generated and used in prioritizing diseases for research and find management options. Alternate (stem rust) and accessory hosts (stem and yellow rusts) and various planting times within seasons, green bridges in wheat production pathosystem are known, factors for harbouring the rust inoculum, perpetuation, build-up and releasing to atmosphere. These factors are major potential reasons for making the rusts a standing threat to wheat production in Ethiopia. Rust management options such as cultural practices, resistant varieties and chemical (triazole and trobilurin classes)have been developed and used and being used in sustaining wheat production. Of all aforementioned rust management options, management by resistance breeding has been kept a major economically and ecologically friendly disease management approach used to limit rust epidemic outbreaks in Ethiopia. Resistance genes of commercial varieties and advanced lines were identified through genotyping using molecular tools or rational gene postulation. These activities have revealed that resistance based on race specific and nonspecific genes are operating in Ethiopian wheat varieties targeting stem and stripe rusts management. However, varieties of effective race nonspecific resistance and high yielding are few in number, and breeding strategies targeting durable resistance minor additive genes based to be dealt aggressively. Varieties with race specific resistance are more in number and yellow and stem rusts of these types are operating in several commercial varieties. Studies confirmed that 'boom and bust' cycles are common phenomenon in wheat-Puccinia-pathosystems in Ethiopia, especially under a single mega variety production on large hectares exemplified by varieties such as Kubsa and Galema production in 2010, a condition helping mutation of pathogens to new virulent races. Several commercial varieties currently in production have been developed through integrated efforts of national and international research institutes research programs.

An effective disease surveillance system is in place and is successfully guiding the deployment and more efficient reactive rust management using fungicides and cultivars. Monitoring of rusts importance and variability especially variability in rusts caused by)uccinia graminis and).striiformis has been given due attention.

Migration of virulent new rust race/s from abroad to Ethiopia has been perceived and understood that this phenomenon could continue to happen or increase, due to international travels and wind excursion. Epidemiological factors such as rust pathogens, production inputs such as nitrogen and climate conditions experienced changing unpredictably, thus, rust resistance source identification based on conventional and molecular techniques for resistance genes detection and anticipatory breeding for race specific, nonspecific and moreover resistance combing the two types of resistance is to be intensified. Stripe rust race analysis work need to strengthen in line with maintaining the isolates in local laboratories and exploiting them in anticipatory resistance breeding and resistance source screening. Farmers fields/farms with good agronomic practices and high fertilizer inputs at least semi-mechanized ones are increasing in wheat production system and yield loss figures and fungicide spray timing may not representing this system and thus to be re-searched and updated for both current subsistence and mechanized farms under crop rotation halting residue and soil-borne crown and root rot and foliar diseases.

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Entomology Papers

The consequences of cochineal (*Dactylopius sp.* (Hemiptera: Diaspidiae) introduction in Tigrai region

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Abstract

*his review "riefly narrates how the cochineal, :actylopius sp. was introduced and analy%es what happened after the release of the insect in the *igrai region. =oth the cactus, Ipuntia ficus indica and the cochineal were introduce without scientific studies and knowledge, as a result of which the cactus had invaded large areas including cultiva"le lands, while the cochineal destroyed much of the cactus plantation in homesteads and fences and forest in the southeastern %one, the southern %one, and few ke"eles in -ilte +wulalo wereda of the eastern %one. *he remaining %onesD weredas of the *igrai region and the ad!oining weredas in the +mhara and +far regional states are free of cochineal. =efore the introduction of the insect, the communities were not informed a"out the "enefit and risk of cochineal; nor were involved in decision making whether or not to introduce the insect. <onse6uently, in the infested %ones, there was conflict of interest "etween those who consider harvesting and selling cochineal as a "usiness and those who consider selling cochineal as a curse and value cactus for livestock feed and human food. *o resolve this conflict the measures taken "y the regional government to eradicate cochineal were insecticide spraying program, revoking license from investor, closing cochineal market, implementing mechanical control method (cutting, chopping and "urying infested plants) using free community la"or and others, although none of the methods were effective in reducing the damage and spread of the insect. @owever, the esta"lishment of "uffer %one in the southern tip of -ilite +wulalo wereda effectively "locked the spread of the insect further north in the Eastern %one.

Introduction

Cactus, *Ipuntia ficus indica* is believed to be originated in the current Oaxaca, Mexico (van Dam *et al*. 2015). It means the cactus is an introduced plant to Ethiopia, although the origin, means and purposes of introduction is not clearly known. But, in the Tigrai region, it is believed that it was introduce by missionaries sometime between the mid and end of nineteenth century (Mulugeta *et al*. 2010). Cactus is also found in the eastern and southeastern part of the country. According to Tesfaye (2015) the species *I. ficus$ indica* is the only species found in Tigrai region, while in other parts of Ethiopia, other than *I. ficus$indica*, *I. stricta* is found in eastern part of the country. Once introduced the cactus established and spread quickly because of favorable edaphic and climatic conditions and the absence of natural enemies of any sort. It is also believed that unsuitable harvesting methods and indiscriminate use as fences have aggravated the rapid spread of the plant (Cuevas *et al*. 2013).

In the Tigrai region, the system of cactus production is broadly classified into three, which are homestead, fenced and communal. However, the majority of the cactus grows as communal in the wilderness on more than 300,000 hectares of land on mountains, valleys and cultivable lands, while it grows as homestead crop on 30,000 hectares of land (Cuevas *et al*. 2013). It is used as a living fence, for erosion control and for feeding ruminant livestock, while the fresh fruits are used as food and as limited source of household income (Brutsch 1997).The fruit, which are harvested by children and sold by women, becomes the main source of income and food for many people in Tigrai during the period from June to September (Cuevas *et al*. 2013; Tesfaye 2015). However, it is questionable if farmers are getting the benefits that they should get from their cactus as it is virtually impossible to access dense canopies (thickets) and harvest fruits and cladodes. Besides, there are significant losses resulting from poor harvesting practices and little or no understanding of good post-harvest handling practices (Cuevas *et al*. 2013).

The introduction of the cactus to Ethiopia was not backed by scientific studies and knowledge, as a result of which the cactus had invaded large cultivable areas like in Raya-Azebo valley (fig.1), or it might have displaced many indigenous floras of the eastern and southern Tigrai region. It is, perhaps due to these reasons that Brutsch (1997) considered cactus in Tigrai as a curse and recommended the introduction of specific and less drastic biocontrol agent such as *<acto"lastis cactorium*, or labor-intensive physical clearing. The cactus has also exhibited similar invasive behavior in Australia and South Africa, where it was also introduced without sufficient knowledge and where it is considered as serious weed problems. However, unlike in Ethiopia, this invasive weed was successfully controlled through the introduction of natural enemies including some species of the genus *:actylopius* (Rodriguez *et al*. 2001).The main objective of this paper is to highlight the process and outcome of the introduction of cochineal in Tigrai region.

Fig.1. Communal cactus in Raya Azebo valley (a) and Ganta Afshum wereda (b)

Insects of cactus

In Ethiopia, the number of phytophagous insect species that feed on cactus, in general, is not known. However, in the Tigrai region, other than the introduced cochineal, the cactus (prickly) pear scale insect, :iaspis echinocacti, synonym :. calyptroides, (Hemiptera: Diaspididae) infests cactus in few areas (Fig. 2)

Fig.2. The cactus (prickly) pear scale insect, :iaspis echinocacti infested (a) and dead cladode due to heavy infestation (b)

The carmine cochineal

The carmine cochineal, :actylopius coccus Costa is believed to be endemic to Mexico and Peru (Teklenberg 2001), while Rodriguez et al. (2001) argued that the insect originates from South America and was introduced to North America through sea routes. However, recently van Dam et al. (2015) using ecological evidences and mitochondrial DNA (mtDNA) affirmed that the carmine cochineal originated from the current Oaxaca region in Mexico. Rodrigues et al. (2001) indicated that the carmine cochineal has been used as source of natural dyes in Mesomerica and the Andean area since pre-Columbian times. The insect is sessile that lives on cladodes of cactus (prickly) pear (Ipuntia ficus$indica Miller).

History of cochineal introduction to Ethiopia

The history of introduction of cochineal, :actylopius sp. to Ethiopia was not properly documented. For instance, the ad-hoc committee, which was established in August 2013 and was composed of members from Ethiopian Institute of Agricultural Research (EIAR), Tigrai Agricultural Research Institute (TARI), Mekelle University and the Tigray Science and Technology Agency, did not find any supportive official documents that show the introduction was legal.

According to Chipeta (2010) the insect was introduced through the project "Cactus Pear (Ipuntia spp) Production and Utilization in Ethiopia", which was hosted by Mekelle University and financed by the Food and Agriculture Organization (FAO) of the United Nations. The aim of the project was to help to control cactus where it is an invader and to present an economic activity in wild cactus populations taking into consideration the total absence of pests and diseases on cactus. However, the ad-hoc committee did not find the project documents, the import and the release permits issued by the then Federal Ministry of Agriculture and Rural Development (MOARD) in the University's archive nor from individuals who were principal investigators. Moreover, the Tigrai Agricultural Marketing and Promotion Agency (TAMPA), facilitated the establishment of cochineal producer and exporting company, but the agency failed to deliver any document that confirm the agency was involved in helping the establishment of cochineal producer and exporter company.

Tesfaye (2015) gives an account of what happened after the introduction of the insect in the Tigrai region. According to Tesfaye et al. (2008) cochineal was introduced from South Africa to the Tigray region in April 2003. The insect was introduced after undertaking pest risk assessment (PRA) by FAO recruited expert and found that the introduction of cochineal was safe (Tesfaye et al. 2008; Tesfaye and Bustamente 2010). However, analysis of the PRA document revealed the existence of two contradictory statements. Under the subtitle environmental conditions for the pest in Ethiopia, it is stated that "environmental conditions for the establishment and spread of the insect are present in Ethiopia. The potential is there for the insect to be widely distributed and although low, the potential does exist to become economically important on one hand,

and based on experience with :actylopius coccus in other countries, this is considered unlikely as the cochineal bug can be considered as a species that has difficulty in surviving without the intervention of man on the other hand." These contradictory statements suggests that

1. It should not have been permitted to introduce an insect with "low potential to become economically important" unless the phrase "economically important" is understood as beneficial by inept officials
2. The introduced insect to the Tigrai region spread to wide area in relatively short time and survived without the intervention of man, but according to the PRA D. coccus does not survive without the intervention of man. Besides Tesfaye (2015) stated that Australia and South Africa introduced :. opuntiae for the control of invasive cactus species like Ipuntia stricta and I. ficus$indica. Therefore, it is possible to speculate that the introduced insect might be a wrong species.
3. If the introduced insect is not a wrong species as speculated above, then the introduced insect might be aggressive biotype of :. coccus selected for efficient destruction of cactus weeds in South Africa.
4. If the probability of becoming "economically important" is known, then cochineal management contingency plan should have been developed to circumvent the problem if the insect turns to major pest status

Tesfaye et al. (2008) and Tesfaye and Bustamente (2010) indicated that following the PRA result cochineal introduction permit no 1020 was granted by MOARD, although the document was not found. After introducing the insect, it was raised on detached cladodes for five generations under partially conditioned greenhouse at Mekelle University and during this period freedom from unwanted organisms that might have been accompanying the cochineal was confirmed (Tesfaye et al. 2008).Then approval for field release was granted by the MOARD (ref. no. 21/126/1.1 dated 4/01/97) and the insect was released on the 12th of September 2004 to cactus fields in Tsehafti area in Wejerat, Embachra area in Mehoni and Endayesus campus of Mekelle University (Fig.3) (Tesfaye and Bustamente 2010). Once released the insect established and spread to different cactus growing areas and affected cactus fruit and cladode production.

Fig. Current distribution of cochineal in Tigrai region: green triangles = first release sites; red dots = infested areas and blue dots= cochineal free areas

Geographical distribution of cochineal

Currently, the geographical distribution of cochineal is limited only to the southern part of the Tigray region (fig. 3 and table 1). It is prevalent in the southern, the southeastern and the eastern zones. Out of the three zones, the southeastern and the southern zones are the worst cochineal affected areas. In the eastern zone, it has invaded only Kihen and Mahbere Woyini kebeles in Kilte Awulalo wereda, while the Ganta Afeshum wereda is free of carmine cochineal. Kilte Awulalo wereda adjoins Enderta wereda of southeastern zone, which is cochineal infested woreda. In Kobo and Sekota weredas of the Amhara regional state there is no cochineal infestation. However, of the two weredas Kobo is at stake because of the movement of live cactus material from infested weredas of the Tigray region to this wereda. In weredas of the Afar region that are contiguous to the Tigray region there was neither cactus nor carmine cochineal.

Table 1. Cochineal distribution by zone and wereda

Zone	Wereda	Growing areas	Area infested (ha)
Eastern Zone	Ganta Afeshum Kilte-Awulalo	homestead and communal homestead	0.0 two kebeles
Southeastern	Enderta Hintalo Wajirat	homestead homestead and communal	408.0 10662.0
Southern	Raya Azebo Raya Alamata Ofla Woreda Endamehoni Emba-Alaje	homestead and communal fence fence communal fence	3415.0 0.0 infested 1600.0 161.1
North Wello	Kobo	mostly fence	0.0
Wag-Himra	Sekota	fence and communal	0.0
Zone 2	Ab-Ala	No cactus	00

According to Moran (1980) the spread and establishment of cochineals is hampered by the limited dispersal of the wind-blown female crawlers, whereas the establishment of the crawlers after landing on new host plant is influenced by the position and condition of the cladode on the plant and by several biotic and abiotic factors. If this is the case, how the carmine cochineal rapidly expanded in the southern Tigrai region within relatively short period of time? There is no definite answer to this question, but the likely reasons are:-

1. In the Tigrai region cactus is not attacked by phytophagous insects. Therefore, the absence of competitors coupled with complete absence of natural enemy of cochineal might have contributed for the unchecked spread of the insect
2. The nature of the cactus vegetation present in the region, which is unmanaged homestead, fence and cacti forest
3. The introduced cochineal might be the most aggressive biotype.
4. Uncontrolled spread of the insect by people from outside the community
5. The possible existence of an illegal market for cochineal sale
6. Unnoticed or unconsciously spreading of the insect by walking in infested fields, by animals that pass by, by selling infested fruits, by transporting infested cladodes for animal feed or as plant material for new fences or plantations.
7. Winds can be very strong in the region, especially dust-bowls that can sweep crawlers high into the air and move them over long distances and unexpected places (fig. 4).

Fig.4. Cochineal infested cactus plants naturally grown on rooftop in the middle of Mekelle town (right: closer view)

Cochineal Marketing

Since the purpose of introducing cochineal to Tigrai region was to establish viable cochineal industry, markets were sought to sell harvested cochineals. Accordingly Roeper from Germany and Foodsafe from Chile were identified with the help of Dr. Helmuth Zimmermann from South Africa (Tesfaye 2011). Although both companies did assess the cochineal production potential in the region, only Foodsafe submitted letter of intent (copy of the letter of intent is found in TAMPA's archive), which consisted of expression of interest to produce and export cochineals and train farmers who will be an out-grower for the company, to the regional government and got investment license in 2007 (Tesfaye 2015).The company was granted 300 ha of communal cactus in southern zone, a tax exemption of 5 years and investment protection for about 10 years (Tesfay, 2011.

The Foodsafe opened the cactus thickets and used cochineals from experimental sites i.e. from the previous introduction to establish cochineal nurseries at the site granted for cochineal production. Moreover, in about three years the company established new cactus plantation on 45% of its land and the new plantation was also infested with cochineal. At the same time, TAMPA in collaboration with FAO initiated Tele Food project, trained and provided farm equipment to 80 farmers, who were involved in cochineal production in Raya-Valley (Tesfay and Bustamante, 2010).These authors also indicated that with support of engineering capacity building project of the German

Government additional 380 farmers and landless youths were trained and provided with seed to start cochineal culture in the Maichew-Mehoni mountain chains.

Foodsafe exported its first dried cochineal insects to Mexico in April 2009 (Tesfaye 2015). The quality of cochineal is gauged by the content of carminic acid and the higher the carminic acid the better the quality. The cochineals produced in the Tigray region was high grade since the carminic acid content ranged from 21-23% (Tesfay and Bustamante, 2010), which might be associated with higher phosphorus content of soils in the cactus pear growing areas. Between 2007 and 2009, about 32 fulltime workers and more than 136 casual laborers were involved in cochineal production and selling and they earned about USD $71 to 130/person/month (Tesfaye 2011).

Consequence of carmine cochineal introduction

The cochineal continued to invade new areas and at same time the harvesting and selling of cochineal in the newly invaded areas has been terminated. The insect killed large number of cactus trees throughout the infested areas by re-infesting re-growth that arise from the dead mother plants (fig. 5). Consequently, conflict of interest arose between the young, the landless and women, who consider harvesting and selling cochineal as a business and the landowner and elderly, who consider selling cochineal as a curse and value cactus for livestock feed and human food (Tesfaye 2015). This conflict might have arisen because the communities were not involved in decision making before introducing the insect. In some villages, the insect was first introduced to cactus owned by elderly and disabled individuals. Moreover, the communities perceived the multiplication rate of cochineal to be high or very high as a result of which they consider it as devastating pest, although they sit and wait until help comes from elsewhere to control the insect.

Response of the Regional government

The regional government first responded in 2009 by recommending planting trees as windbreaks around the Foodsafe holding. However, because of the rapid expansion of the insect to non-infested areas and high pressure from the community, the regional government embarked on insecticide spraying program in 2010 using free labor from the Wejerat communities. Dimethoate, Fenitrothion and Malathion were some of the insecticides used in this campaign. This campaign neither prevented the spread of the insect nor reduced the damage done to cactus plant by the insect, which is due to:

- hidden nature of the insect
- the nature of the cactus plant (upright and interlaced branches with waxy cladodes)
- very dense, impenetrable and inaccessible cactus stand (fig. 5 (left))
- rugged and mountainous terrain

- presence of deep incised river valleys

Fig. 5. Newly cochineal infested cactus (left) and dead cactus due to cochineal attack (right)

As time goes the conflict grew stronger and the regional government revoked the license from the Foodsafe and closed the farm on 17 December 2010 (Tesfaye, 2015). In 2011, the regional government set regional committee mandated to develop action plan for cochineal control in infested and uninfested areas. The committee developed an action plan and the plan was implemented but it does mitigate neither the expansion of cochineal nor the conflict between the two rivalry groups. As a result, the regional government set another committee and improved the previous action plan. In 2012, attempts were made to mobilize communities to mechanically control the insect by cutting and burying cactus plants (fig. 6).

Fig. 6. Partially stumped homestead (left) and completely stumped (right) cactus

As was the case in the insecticide spraying program, the mechanical control method was not effective in limiting the spread of the insect. Following the unsuccessful attempts the regional government established two task forces: -

1. The coordination team, which makes high level decisions and approves strategic action plans
2. The technical team, which coordinates research efforts, technology delivery pathways, resource allocation, communication strategies, evaluate gaps and management options.

But, both task forces were not full engaged in the cochineal eradication and management activity due to other important agricultural issues, unavailability of resources and absence of clearly defined mandates. Stakeholders involved in the development and implementation of cochineal management technologies included FAO, Helvetas, Embassy of Mexico, Tigray Agricultural Research Institute, Mekelle University and Adigrat University.

Tested cochineal control methods were: spraying detergents, salt, botanical extracts, chemicals and adhesive agents; mechanical control – chopping and burying of infested plants; comparison of farming systems – fruit production alone and fruit and cochineal production together and assessment of biological control agents. Other than the research effort, stakeholders were also involved in capacity building, which included training farmers on cochineal control, awareness creation on the means of dispersal of the insect and, monitoring and reporting system in cochineal free areas.

Establishement of Cochineal free buffer zone

The regional agricultural bureau through the Ministry of Agriculture and Natural Resources (MOANR) requested FAO to provide technical backstop to manage cochineal in infested areas and prevent entry of the insect in Eastern zone. Accordingly, FAO approved and implemented the project "Comprehensive assessment and identification of a management strategy for the carmine cochineal in cactus pear in Tigray (TCP/ETH/ 3502)."The project objectives were determining the incidence and severity of carmine cochineal infestation in cactus in the region and adjoining weredas of Amhara and Afar regional states and to assess the socio-economic impact of carmine cochineal introduction and multiplication on cactus pear in Tigrai. The outputs of these activities were used to formulate policy and sustainable cochineal management strategies. One of the management strategies was the establishment of cochineal free buffer zone. In February 2016, cochineal free buffer zone was establishedin between the southern part of Kilte Awulalo wereda and northern part of Enderta wereda (Fig. 7). The procedure followed to establish the buffer zone was

- detail data and information on the incidence and distribution of the insect were generated prior to the delineation of the buffer zone
- guideline describing the requirements to establish, maintain and verify pest free areas for carmine cochineal, :actylopius coccus Costa (Hemiptera: Dactylopidae)

in the Eastern zone of the Tigrai and all contiguous weredas of the Amhara and Afar Regional states was developed

- training was given to scouts to manage the buffer zone and maintain the pest free area
- the cochineal free buffer zone effectivel curtailed further spread of the insect in the Eastern zone.

Fig 7. Distribution of carmine cochineal in southern Tigrai region (a), the green triangles indicates the initial release sites (Mekelle, Tsehafti and Embachara); the buffer zone (b) and the cochineal free zone (c)

The outcome of the conflict

The conflict of interest in producing and selling cochineal and the use of cactus for other purposes than cochineal production resulted in double losses. First, tens of thousands of hectare of cactus was destructed by cochineal. Therefore the cactus was not used for food for human and as feed for livestock. Second, the cochineal was not sold. Harvesting cochineal is one of the methods for cochineal control. If the insect was collected and sold, much of the damage done to cactus could have been reduced. Besides, Tesfaye (2015), using the cochineal infested area (table 1), 265kg/ha per one harvest as average yield of dried cochineal under Tigrai region, and assuming three harvest per year and USD 4 per kilogram as an average price, the region has lost close to 52 million USD per year. The other lost opportunity is the modernization of cactus production in the region.

Conclusions

The introduction of the cochineal to the Tigrai region without undertaking prior in-depth ecological studies has led to unanticipated negative impact that severely destroyed the cactus ecology in the southern and southeastern zones. This negative impact could have been minimized if preparedness and contingency plan was in place had the pest risk assessment report been critically analyzing. Moreover, the measures taken to resolve the conflict of interest between the two groups has worsen the negative impact of cochineal as it was evident from the increase in infested area after the market outlet was completely closed. This disturbance needs immediate intervention to prevent further deterioration of the entire ecology of the affected zones. Besides, the surveillance data and reports from the buffer zone have not been communicated to stakeholders involved in cochineal management programs.In conclusion, the region has lost both the cactus and the cochineal due to the lack of scientific evidences, which could have been used as base for wise decision making.Therefore, in the future, all potential risks must be properly assessed before the introductions and the releases of biological entities into the country.

Recommendations

- Develop and/or implement codes of conduct and guidelines for import and release of biological agents
- Encourage participatory approach to involve communities in decision make whether or not to introduce biological entities into an area
- Developing standards of data management and archiving of reports, projects and other documents related to introduction and release of biological entities
- Ensure stringent implementation of phytosanitary measures to effectively limit the introduction of cochineal to new areas within and outside the region
- Increase public awareness about the risk of cochineal invasion in free areas
- Allocate adequate resource for sustaining the buffer zone
- Rehabilitate the ecology through modernizing the existing cactus production system in the affected zones

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Fall Armyworm, *Spodoptera frugiperda* (J.E Smith): A new threat to maize production in Ethiopian (status, impact, interventions, lessons learned and prospects)

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Abstract

*he fall armyworm (;+9), ,podoptera frugiperda (1. E. ,mith) is an endemic and important agricultural pest in +merica. *he pest has a wide host range and has "een reported in over 1.. plant species "elonging to 2C families and causing su"stantial losses in many economically important crops like mai%e, sorghum, rice, and wheat. *he presence of ;+9 in Ethiopia was reported on 1st /arch 2.1C from ,outhern 0ation, 0ationalities and)eoplesL 4egional ,tate (,00)4). <urrently it has spread and con6uered all regions of the country and reported in 21C districts from across the country. *he speed with which it con6uers the country highlights its adapta"ility, invasiveness and pro"a"ly superior competitive a"ility over indigenous species. 9e do not yet understand enough a"out ;+9 "ehavior in Ethiopia, in terms of its migration, interaction with other crops, pests and natural enemies to predict migration, larvae populations and their damage. ,uch factors need to "e tested with further research studies even if this does not change the reality that ;+9 is here to stay in Ethiopia. I ut of 2.1 / ha of land currently under mai%e cultivation in Ethiopia 22.2 O (7G.,... ha) of the total mai%e planted has "een infested with ;+9. #n general, without use of control options, the potential impact of ;+9 on the country wide mai%e yield lies "etween 1.2 and .1 million tons per year of total expected production of C million tons per year and with losses lying "etween 3,Q 2A2.7 and 3,QC2B. million per year of total expected value of 3,Q 1,GB..2 million per year. #n response to the arrival of ;+9 to Ethiopia, various attempts have "een made for the past one year to com"at the threat of ;+9 on mai%e. 3rgent action include (i) awareness raising campaigns and capacity "uilding on ;+9 symptoms, identification, early detection and control, including pheromone lure, "eneficial agronomic and other cultural practices; (ii) national preparation and communication of a list of recommended, regulated pesticides and "iopesticides and their appropriate application methods (whenDwhen not, and how to apply chemical control) and proper

handling. =esides urgent action some information that contri"utes to the ; + 9 management program has "een generated "y research institutions and ministry of +griculture. ,tudies were focused in the area of insecticide screening, "io$pesticide screening, pheromonal control, cultural control, natural enemies, and varietal screening. ,ome of these studies generated "ase$line information for future research than for immediate use. *his paper provides> (#) + comprehensive review of ; + 9 history, pathway of introduction, management experience in +merica; and (##) #ts status, impact, efforts made so far, lessons learned and future prospect in Ethiopia.

-ey words> ,podoptera frugiperda, #nvasiveness, / ai%e, +frica, Ethiopia

Introduction

History and origin

The Fall armyworm (FAW), *,podoptera frugiperda* (J.E. Smith)(Lepidoptera: Noctuidae) is an alien, invasive insect pest native to tropical and subtropical regions of the Americas (Knipling 1980, Pashley et al. 1985, Pashley 1986, 1988). The fall armyworm is so called because it does not appear in more northern parts of America until late summer or in the fall. The scientific name is derived from the feeding habits of the larval life stage, *frugiperda* meaning "lost fruit" in Latin, as the pest can cause damage to crops resulting in severe yield loss. Although FAW is highly polyphagous with a host range of about 100 plant species, it prefers to feed on gramineous plants in particular on economically important crops such as maize, millet, sorghum, rice, wheat, and sugar cane. Other crops of major agricultural importance attacked by the pest include cowpea, peanuts, potato, soybean and cotton (Knipling 1980, Pashley 1986).The recognition of FAW as a serious economic pest in America dates back more than 250 years. The fall armyworm has a remarkable dispersal capacity and is observed to migrate every year from its endemic area in the warmer parts of the new world over more than 3000 km crossing the entire US up to Canada in the North and reaching the northern parts of Argentina and Chile in the South (Barfield et al. 1980; Difabachew, 2011). It can have a number of generations per year and the adult moth can fly up to 100 km per night and up to 500 km/generation before oviposition, which is sufficient to move from seasonally dry habitats to wet habitats in Central America (Sparks 1986; Johnson 1987). This seasonal migration of FAW could occur in response to seasonal changes in rainfall, temperature, and planting of host plants. Moreover, prevailing winds and frontal systems with their converging air masses during the spring are thought to largely determine the extent and direction of FAW adult migration (Rainey 1979, Pair et al.

1986). When the wind pattern is right, moths can move much larger distances: for example, 1,600 km from Mississippi to southern Canada in 30 hours has been recorded (Rose et al. 1975). But, unlike African armyworm (,podoptera exempta) FAW generations are resident and continuous where host plants are available and climatic conditions are favorable (Andrews 1980). High infestations can lead to significant yield loss. Farmers in the Americas have been managing the pest for many years, but at significant cost. It was estimated to cause annually a loss worth of $300 to $500 million on maize in the USA and ca. $600 million in Brazil.

The first detection of FAW in Africa was notified in January 2016 when it was reported from Nigeria, Sao Tomé, Benin and Togo (IITA, 2016; IPPC, 2016). From there it spread to several other West African countries and to Central Africa by April 2016. In late 2016 and early 2017 it was detected in Angola, Botswana, Burundi, Democratic Republic of Congo, Zambia, Zimbabwe, Malawi, Southern Africa (except Lesotho), Seychelles (Island State), Burkina Faso, Cape Verde, Cameroon, Gambia, Ghana, Guinea Bissau, Niger, Senegal, Ethiopia, Burundi, Kenya, Rwanda, Somalia, South Sudan, Uganda, and it is expected to move further north and beyond. (FAO, 2017; BBC, 2017). FAW was first observed in Ethiopia on off-season irrigated maize in the rainforest zone of Southwestern Ethiopia on 1st March 2017 (Mizan-Tepi plant health clinic report, 2017). Pathways of the recent accidental introduction of the FAW into Africa are yet unknown but increase in international trade volume and easy air travel of people from one continent to another has amplified the phytosanitary risks of even multiple introductions.Introduction may have been as eggs, caterpillars, pupae or adults, or any combination of these. For the time being, its modality of introduction and its spread to Africa and adjustments of its bio-ecology are still speculative (FAO, 2017). The pest is labeled as a new invasive species in Africa where every country reported outbreaks. The presence of at least two distinct haplotypes within samples collected on maize in Nigeria and São Tomé suggested multiple introductions into the African continent (Goergen et al., 2016).

Of the six possible types of pathway of entry that Hulme et al.(2008) recognize (intentional introduction of a commodity, escape of an intentionally introduced commodity, contaminant of a intentionally introduced commodity, stowaway on a vector, dispersal along a human-created corridor, unaided dispersal), only three might have been applicable in this case: contaminant of a commodity, stowaway on a vector and unaided dispersal. Adults fly actively and, as noted, regularly move over long distances with air currents before oviposition; however, the prevailing trade winds are from Africa to the Americas, not the other way around, making unaided dispersal by adult flight a very unlikely pathway of entry in this case. Furthermore, if this were a possibility, it seems unlikely that it would not have happened before, perhaps long ago. Clearly, FAW has the potential to spread rapidly across Africa: at least 500 km per generation, with a suitable wind. Due to their suitable climate, it's life cycle can be as short as 30 days and the adult moth is able to fly 100km a night. It is no surprise then that it has invaded over 30 African countries since it was first reported in Nigeria in early 2016. The patterns of population persistence, dispersal and migration in Africa have yet to be determined. FAW's presence in Africa will likely be irreversible. Large-scale eradication efforts are neither appropriate nor feasible.

Extent of the threat

FAW in Africa has the potential to cause maize yield losses in a range from 8.3 to 20.6m tonnes per annum, in the absence of any control methods, in just 12 of Africa's maize-producing countries including Ethiopia. This represents a range of 21%-53% of the annual production of maize averaged over a three year period in these countries. The value of these losses is estimated at between 2.5 and 6.2 million dollars. In addition, there is also FAW attack concern on many other important food crops including sorghum and millets, where damages have already been reported in countries like Ethiopia, Kenya, Malawi, Uganda, Mali, Niger and Rwanda.

The effects of FAW infestation go far beyond reducing crop yields in a season. The vast majority of farmers in Sub-Saharan Africa are smallholder family farmers, who often depend on production to maintain household food and nutrition security, as well as household livelihoods. There are tens of millions of smallholder farmers produces maize across Sub-Saharan Africa, farming the majority of the 35 million hectares of maize produced annually in the region. For the most part, the farmers face very significant risks with little risk transfer mechanisms and marginal economic viability of their production systems, putting them at great risk to the added shock of FAW infestation. Economically, the expected crop losses caused by a particular pest and inappropriate and significant use of insecticides against the pest can double the cost of crop production and thereby reduce profit and also poses a significant threat of putting smallholder family farmers on an unsustainable "pesticide treadmill". All these impacts are detrimental to country's sustainable food security and livelihood.

A number of countries in the region have already begun significant programmes of providing pesticides to farmers, often as the main response to FAW infestation. The Government of Zambia, for instance, allocated $3m to smallholder maize farmers in 2017 for pesticides, including provision for replanting 90,000 hectares affected. Government of Ghana provided $4m as an emergency measure to procure plant protection products. The Government of Rwanda mobilized the armed forces to engage in mechanical control, crushing egg masses, and treating attacked fields. The

Government of Ethiopia allocated nearly $4m as an emergency response to procure chemicals, sprayers and personal protective equipments for smallholder maize farmers. Most smallholders in Africa do not use pesticides in their maize production. The introduction of sustained use of pesticides in these systems may make the systems not only economically unviable, through increasing the costs of production, but also introduce significant risks to human health animal health and environment. Women are responsible for performing most farming tasks in these systems, including application of pesticides, and their direct exposure can be transferred to children and the entire households. The pesticides (often older chemicals no longer approved in Europe or North America) also represent risks to the environment and can have a significant impact on both local human health and trade due to pesticide residues in food.

The pest is known to cause extensive crop losses of up to 73 percent depending on existing conditions and is difficult to control larvae with a single type of pesticide, especially when it has reached an advanced larval development stage (IPPC, 2017). Farmers will need great support to sustainably manage FAW in their cropping systems through Integrated Pest Management.

FAW management experience in Americas

FAW attacks many crops, but in Africa, the vast majority of the reports and requests from farmers have come from infestations in maize. Both maize and FAW are native to the Americas, where farmers have been managing the insect in their fields for many years. HenK7HK:eI071WWK7WB:vIB3U3HD:.I0H7: I0HD7:HI0 percff HaHU7:fI0K1WWV7V:oI,eymI

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[illegible] I0K1WWUHW:eI071WWK7WB:sI031K likely to stay in the same area, mate and lay eggs, surviving on weeds and other plants during periods of no maize crop.

Farmers' ingenuity of the pest and its environment

- FAW has a cohort of natural enemies (predators, parasitoids and pathogens) that provide a high level of natural control of FAW populations. Even in landscapes with high pesticide use, when fields are left unsprayed, natural parasitism levels of 44% have been measured. This high level of natural control has several important implications for devising management options in the Ethiopian context at least in the long-term.
- Smallholder farmers in Mesoamerica often enter their fields when maize plants are in the early whorl stage, checking for FAW egg masses or young larvae, and killing them via mechanical crushing.
- Mixed planting systems (either poly-cultures of two or more crops, or the use of certain non-crop plants) is believed by some farmers to lower FAW oviposition on maize and/or create environments that attract and maintain higher levels of natural enemy populations.
- Maize response to FAW damage is growth-stage specific and dependent on the nutritional and water-balance status of plants. This has important implications for training farmers about FAW damage and crop management practices, as well as the development of action thresholds.
- Smallholder maize farmers in Mesoamerica apply ash, sand, or soil into the whorls and reported significant control of FAW larvae. Reported are also use of soap solutions or local botanical mixtures (including, but not exclusively using extracts from neem trees) that provided good control.
- Smallholder family farmers in Mesoamerica manage FAW in maize as part of their cropping systems. They acknowledge the important role of natural enemies in controlling FAW populations, understand that not all level of damage lead to significant yield loss and not to over-react to low-level of damage, regularly visit their fields, observe their crops and directly control FAW, take advantage of cropping patterns to reduce FAW populations, and try local solutions when they feel they have to take a direct action to control larval populations.

Current Status and Distribution of FAW in Ethiopia

In Ethiopia the presence of FAWwas reported in early March 2017, by a team of experts from Mizan Plant Health Clinic who first intercepted the insect on 1st March 2017 in Yeki woreda, Sheka zone of Southern Nation, Nationalities and Peoples' Regional State of Ethiopia (SNNPR). Since that time, the insect has been spreading to new areas in SNNPR, Gambella, Oromiya, Amahara, Benishangul Gumz and Tigray regional states (Figure 1). It's distribution has been covered these six major maize producing regions within six months of period. The most recent report showed that the insect has reached Afar and Somali regions, thus showing that the pest is rapidly spreading. Severer infestations were reported from all regions mentioned above. Currently it has spread than 650,000 ha of maize planted (which is 22.23%of total area planted) has been infested with FAW and re-invasion has occurred in most places. Currently about 2 millions farm families have been affected by FAW. Neither there is a hard data on yield and economic loss nor overall impact of FAW known in Ethiopia.But, CABI (2017 estimate that, without use of control options, the potential impact of FAW on country wide maize yield lies between 1.23 and 3.1 million tonnes per year of total expected production of 7 million tonnes per year and with losses lying between US$ 292.6 and US$728.3 million per year of total expected value of US$ 1,580.2 million per year (Table 1). Estimated damage ranged from 15-30% in SNNPR and 5-20% in Oromia region, varying from plot to plot. In extreme cases, the damage in some farms in Bench-Maji reached 100% though the crops have been recovered using insecticidal control intervention.

The range of potential impacts of the FAW is broad and not confined to damage and yield loss reductions in maize. For all affected crops, impact assessment will need to look at issues including the financial, time and environmental costs of control methods, including pesticide use. The potential increased use of pesticides is especially problematic, in that the impacts will be both direct (increased economic costs to farmers and capital cost) as well as indirect (potential for impacts on human and animal health and environmental contamination). An impact assessment protocol will have to be implemented that examines and quantifies both the direct and indirect impacts of FAW.

Table 1. Expected maize production and estimated lower and upper yield and economic losses in the top maize-producing countries of Africa

Source: CABI, September 2017

Interventions made in Ethiopia

Immediate/Emergency Response

Smallholder family maize farmers, especially in America have been managing FAW in their maize fields for centuries. So immediate recommendations for smallholders in Ethiopia had to start from the lessons learnt from them. Accordingly, all the immediate interventions made by MoANR, EIAR and other partners based on the experiences adapted from Americas' smallholder farmers proved to be of crucial assistance in early detection and monitoring the FAW, recommendation of effective agrochemicals and bridging the knowledge gap on management practices. Added to the success was also that of the Ministry of Agriculture and Natural Resources timely communication with other victimized African countries prior to FAW entry to Ethiopia andawoke regional Bureaus of Agriculture. Following its arrival, the MoANR, EIAR, regional BoANRs and other partner institutions have been making multifaceted efforts to curtail the damage and losses. These include, among others, review of global information sources on the FAW, establishing technical committee, developing standard survey protocol, establishing common platforms for continual exchange of information, producing awareness creation materials, organizing training of trainers program for federal and regional stakeholders that was extended to within regions, woredas and kebeles; producing emergency action plan; which included training provision, wider awareness creation using different communication media, distribution of technical leaflets and posters in different local languages, sensitization of the farmers and the general public, and mobilization of resources (finance, vehicles and insecticides). Holistic national FAW management strategy and action plan have been developed. Human and material resources were drawn from different federal government and non-governmental institutions including regional BoANRs, EIAR, Hawassa University, DLCOEA, FAO, CIMMYT, SG2000, ICIPE, USAID, and CABI.

Series of short-term technical trainings were given for 105 Researchers/University lecturers, 293 experts from all regions, Plant Health Clinics and seed companiesduring early interception of the insect. The training further extended up to district level and 630 district experts, extension agents and heads were trained. At village level, 280 development agents, 120 Kebele leaders and model farmers have been trained. Besides, on site hand on training was given to more than 165,000 people and more than 6000 copies of extension materials have been distributed to create awareness.

The Ministry of Agriculture and Natural Resources secured around USD $4 million (123,000,000.00 ETH Birr) from government to purchase pesticides, sprayers and personal protective equipments. Excepting what the farmers might have been used from their own sources, a total of 277,703 liters of pesticides were supplied by the GoE free of cost for the control of FAW. From the total insecticides used 250,000lts were purchased by the federal ministry and distributed to infested regions while 27,703lts were purchased by regional bureaus.

In general using all the available means and resources, it was possible to save maize crop. Very interestingly, the larger part of FAW control (53.50% of the total infested area to date) was achieved through cultural control that includes handpicking and killing and other indigenous knowledge of farmers Chemical control accounted for only 38.75% of infested area, while about 8.75% (46522.94) of the total infested area, which is about eightfold of the total area planted in Rwanda every year, received no control of any kind. Such a country wide intervention within a short period of time was made possible because of the significant engagement and participation of farmers in using cultural control measures, mainly handpicking and killing for the efforts made to increase their awareness and possible impact of FAW on maize and other cereals production. Unfortunately, however, the action taken to date in the lately infested areas like Afar, Ethiopian Somali and also Gambella regions has been limited to the use of synthetic insecticides. What is important to note here is that insecticide applications were done mainly as emergency responses, not based on a cost-benefit analysis. Although farmers are receiving insecticides for free now there is no guarantee this will continue in the future. So, it's important to look for longer-term solutions. They could also try local remedies, including application of ash, sand, or soil directly into infested whorls. Or the use of locally-produced botanical insecticides (e.g. neem, pepper) or the use of soap solutions.

Overall, the lessons and experiences from American farmers had to form the basis of immediate information and experimentation by farmers. Accordingly, the recommended practices and actions are synthesized into leaflets and brochures as key concepts and messages. The messages are useful in creating and maintaining a harmonized, consistent set of updated information to be used in all media and mass communication campaigns.

Short-term Research Efforts

In addition to immediate recommendations and actions, short-term adaptive and action research is important. Currently, several sort-term research activities are taking place on the biology, ecology and management of the FAW, inventory of natural enemies (predators, parasitoids, pathogens), fast track testing of management options including insecticides, sex pheromone traps, biopesticides, botanicals, screening of popular cultivars and cultural methods. Studies on bio-ecology and inventory of natural enemies are also supported by thesis research, typically at the Masters' degree level.

Evaluation of Low-riskInsecticides against FAW

Looking at what happens in their native lands in Americas, when caterpillars damage over a quarter of the crop field, systemic pesticides are recommended. Numerous synthetic pesticides that are able to kill FAW are registered and recommended in Latin America. Nonetheless, most of the chemicals that control FAW are not tested and registered in Ethiopia. Therefore, there was a need to evaluate and fast track registration of effective chemicals for the control FAW. Accordingly several insecticides from different chemical classes were pre-verified and verified for registration and use in Ethiiopia. These include Coragen 200 SC (Chlorantraniliprole), BELT 480 SC (Flubendiamide)and Thunder® OD. Many of these compounds exhibit novel modes of action to which the insect has not yet been exposed. One such group of insecticides is the diamides and includes chlorantraniliprole, cyantraniliprole, and flubendiamide. These molecules are described as ryanodine receptor modulators and affect nerve and muscle action (IRAC Mode of Action Working Group 2009). The modes of action for diamides and spinosyns differ greatly from that of products currently recommended for control of FAW in Ethiopia.

Verifications of Coragen 200 SC (Chlorantraniliprole) and BELT 480 SC (Flubendiamide) were conducted at Bako in 2017. An attempt was made to spray directly into the whorls of the maize plants early in the morning between 6-8 o'clock. The results showed that Coragen 200 SC (Chlorantraniliprole) and BELT 480 SC (flubendiamide) were as effective as and/or even more effective than the standard insecticide Dursuban (Chlorpyrifos) in protecting maize from FAW damage (Tables 2 & 3). Therefore Coragen 200 SC and BELT 480 SCcan be recommended for use as an alternative chemical in the management of FAW on maize in Ethiopia.

Table 2. Mean percent ,podoptera frugiperda larvae infested whorls, silks, tassels and cobs in maize plots subjected to the application of different insecticides in 2017 at Bako

Treatment	% FAW infested whorls	% FAW infested silks	% FAW infested tassels	% FAW infested cobs	Yield (qt/ha)
Coragen 200 SC (Chlorantraniliprole)	13.92b	3.71b	5.05c	7.98b	58. 4a

Dursuban (Chlorpyrifos)	19.58b	5.39b	10.0b	11.50b	47.80a
Untreated control	55.93a	8.36a	22.50a	32.35a	23.06b
LSD (5%)	10.23	2.14	4.63	5.67	13.67
CV (%)	21.93	19.20	25.20	22.48	24.62

/ eans within a column followed "y the same letter are not significantly different (pN...G)

Source: Girma et al., Unpublished data 2018

Table 3. Mean percent ,podoptera frugiperda larvae infested whorls, silks, tassels and cobs in maize plots subjected to the application of different insecticides in 2017 at Bako

Treatment	% FAW infested whorls	% FAW infested silks	% FAW infested tassels	% FAW infested cobs	Yield (qt/ha)
BELT 480 SC	13.12b	0.46b	2.69b	4.18b	57.37a
Dursuban (Chlorpyrifos)	17.50b	2.57b	5.50b	8.3b	48.44a
Untreated control	64.50a	12.49a	18.74a	20.60a	21.47b
LSD (0.05)	3.71	4.08	3. 50	5.82	10.06
CV (%)	21.20	27.5	37.83	28.13	22.31

/ eans within a column followed "y the same letter are not significantly different (pN...G)

Source: Girma et al., Unpublished data 2018

Similarly pre-verification of Thunder® OD 145 insecticidefor the control of FAW on maize was evaluated at Bako in 2017. Three rates of Thunder® OD 145 (recommended rate of 0.5, one rate up 0.75 and one rate down 0.25 L/ha) were evaluated against FAW on maize. The results showed that the newly tested insecticide i.e. Thunder® OD 145 at its higher rate of 0.75L/ha was as effective as the standard insecticide, Dursuban 0.5 l/ha and significantly protected the maize plant fromfall armyworm infestation (Table 4).

Table 4. Mean percent ,podoptera frugiperda larvae infested whorls, silks, tassels and cobs in maize plots subjected to the application of different insecticides in 2017 at Bako

Treatment	% FAW infested whorls	% FAW infested silks	% FAW infested tassels	% FAW infested cobs	Yield (qt/ha)
Thunder® OD 145 0.75 l/ha	12.63	0.58	3.84	7.34	57.68
Thunder® OD 145 0.5 l/ha	17.32	1.83	6.56	13.71	43.07
Thunder® OD 145 0.25 l/ha	25.75	3.70	12.21	16.87	34.7
Dursuban 0.5 l/ha	14.25	2.38	10.65	10.42	45.78
Un treated control	49.75	8.36	27.5	35.0	19.89
LSD (0.05)	3.96	0.98	3.98	3.50	10.12
CV (%)	26.96	22.37	21.44	17.55	15.29

Source: Girma et al., Unpublished data 2018

A widespread problem with pesticides in Ethiopia is adulteration or selling of fake products. This may increase the risk of pesticide resistance development, and wastes farmers' money, making them more cautious about buying pesticides in the future. There are already frequent reports of pesticides 'not working' in Ethiopia, though it is not clear whether that is due to inappropriate use, substandard pesticides, or resistance development. Survey conducted in Ghana and Zambia indicated that, of the farmers who had used pesticides for FAW control, only 27% reported total success, with 57% and 16% reporting the control as somewhat or not successful, respectively (CABI, Sep. 2017). It is not known whether the FAW populations in Ethiopia were already resistant on arrival, but strategies should be devised and implemented to reduce the likelihood of pesticide resistance development. It is known that pests develop resistance to pesticides through repeated exposure of successive generations to chemicals with the same mode of action.

Most of the above tested chemicals are a bit expensive and recommended without cost-benefit analysis. So a conducive policy environment should promote use of insecticides through short term subsidies and rapid assessment and registration of lower risk insecticides and biopesticides.

Evaluation of Bio-pesticides Against FAW

As FAW is a recent introduction to Ethiopia, the use of synthetic insecticides and handpicking and killing have been promoted to address the problem. Nonetheless, despite the strenuous efforts to contain the spread and damage of FAW by use of insecticides, reinvasion has already occurred in most of the places it was initially observed. As a result, there is a fear that total reliance on the use of synthetic pesticides may lead to the emergence of resistant pest populations. Besides, insecticides are frequently applied without sufficient safety precautions taken, and there is a growing evidence of pesticide poisoning. Given the dangers of chemical insecticides and development of resistant population, the development of lower-risk approaches such as use of biological pesticides is high on the list of short-term priority activities. Biological pesticides such as the spray application of =acillus thuringiensis and +"amectine have

Standard check (Chlorpyrifos)	Larvacidal action	
Untreated control		

Table 6. Treatment combinations

Treatment	Mode of action
Fytomax PM + Antario	Ovicidal + Larvacidal action
REcharge + Fytomax PM + Antario	Preventive + Ovicidal + Larvacidal action
Fhytomax PM + Biotrin	Ovicidal + Larvacidal action
REcharge + Fytomax PM + Biotrin	Preventive + Ovicidal + Larvacidal action
Standard check (Chlorpyrifos)	Larvacidal action
Untreated control	

Applications of biopesticides were madeusing a CP 15 knapsack sprayer. Except Recharge were done directly into the whorls of the maize plants early in the morning between six and eight o'clock. Recharge was applied to soil following planting. The results obtained from both single applications and combinations indicated that, biorational products offers significant FAW management when treated appropriately and timely. On individual basis, Antario and Biotrin were found effective, whereas all combination of treatments were found very effective with all damage variables (percent whorl, silk and cob damage) below 10% (Girma et al., Unpublished data 2018). Thus, the biorational nature of pesticides depends upon the time, method of application, stage of pest and crop upon which they are used. In order to maximize the effectiveness of these biorational products in managing FAW, it is essential to emphasis on timely and appropriate spraying techniques, proper inspection, scouting and field identification of eggs, early larva instars and plant damage symptoms. While scouting for damage is important for all insects, careful and frequent inspection is especially important for this pest because it feeds rapidly and is very destructive.

Evaluation of Pheromone Traps for Monitoring and Management of FAW

The same pheromones that can be used for monitoring FAW can also be used as a control method. If sufficient male moths can be captured, not all females will be able to find mates, thus reducing the number of fertilized eggs that are laid. As one male can mate with several females, a high proportion of males needs to be trapped for this approach to be effective. It is also usually more effective over a large area, to reduce the impact of immigrating moths. A report by Andrade et al. (2000) suggested that use of mass trapping reduced the need for expensive applications of =. thuringiensis by 30%–70%. Effectiveness depends in part on how attractive the artificial pheromone is.

As a short-term research intervention evaluation of the efficacy of FAW lure I, II, III, IV and Xlure-FAW was done for monitoring and management of fall armyworm moth in Ethiopia. The results revealed that FAW lure III, IV and Xlure-FAW pheromone lures captured maximum moths and were specific to ,podoptera frugiperda with a very few non-target capture rates (Table 7). The results suggest that these pheromone lures may be a good candidate to consider as a mating disrupting tool in future strategies to monitor & control FAWin Ethiopia.

Data from pheromone traps can complement but not substitute field scouting. Pheromone traps can be appropriate for (a) local FAW monitoring, (b) local FAW control, (c) early alerts and (d) research on the pattern of FAW migration. Attract and kill traps that consist of both a pheromone bait and a control agent could be considered as part of the control strategy for FAW.

Table 7. Number of FAW male moths captured at traps baited with different pheromone lures in Ethiopia (2017)

Treatment/Lure	**Mean moths/trap/night**	**Maximum moths/trap/night**
FAW Lure-I	6.03	28
FAW Lure-II	8.97	33
FAW Lure-III	13.52	41
FAW Lure-IV	10.80	39
Xlure-FAW	20.72	62

Source: Girma et al., Unpublished data 2018

Evaluation of released maize cultivars for resistance to FAW

Host plant resistance is among the best and sustainable practices and compatible with other tactics of pest control and is thus the most important component of an integrated pest management. If FAW larvae fed on foliage of resistant varieties of maize during the growing season, they will show reduced growth, prolonged developmental time, and they would be exposed to parasites and predators for a longer period of time (Molina-Ochoa et al. 1999). Traditional host plant breeding seeks to produce lines that combine this trait with other desirable traits, such as high yield. Even if, there is good evidence of variation between maize varieties (and other crops) in susceptibility to FAW, though given the predominance of Bt maize the opportunities this provides have probably not been explored in full. ICRISAT has already developed sorghum lines resistant to stem borer (Lepidoptera) that will be evaluated for responses to FAW, working closely with EMBRAPA-Brazil who has in the past screened sorghum germplasm for FAW resistance. Two potential sorghum lines have been identified in the ICRISAT Genebank, which could be useful for breeding for FAW resistance.

In Ethiopia, various commercially released cultivars, including hybrids and composites, were evaluated for their resistance and tolerance to fall armyworm at Bako in 2017. Trials composed of twenty commercially released cultivars were organized and evaluated under natural insect infestation. Data were collected on FAW incidence and injury level. The levels of insect injury was visually rated using a scale of 1-9 (Davis et al. 1992 and Smith et al. 1994). 1 = no damage or few pinholes; 2 = few short holes (also known as shot holes) on several leaves; 3 = short holes on several leaves; 4 = several leaves with short holes and a few long lesions; 5 = several holes with long lesions; 6 = several leaves with lesions < 2.5 cm; 7 = long lesions common on one half of the leaves; 8 = long lesions common on one half to two thirds of leaves; and 9 = most leaves with long lesions.

The results showed some variations in infestation levels among the cultivars.Some of the maize genotypes, including BH546, SBRH1, SPRH1, BH547, BH661, BH660 and AMH800 were found to be relatively tolerant to the FAW (Girma et al., unpublished data). The experiment will be repeated for one more season to get reliable data. Over all, developing and distributing resistant varieties could be central to an Integrated Pest Management strategy against FAW in Ethiopia.

Evaluation of different botanicals against FAW

The utilization of plant materials to protect field crops against insect attack has a long history. Botanicals have the advantage that they are generally lower risk than many other pesticides, in terms of human health – an advantage in a context where safety precautions are often not taken. A wide range of home-made pesticides are used and recommended in Africa. In Kenya, for example, mixing chilli powder with ash and dropping it into maize funnels is recommends. In Ghana, two botanicals are being recommended: maltodextrin and ethyl palmitate. Maltodextrin is registered as an insecticide and is used for controlling various pests, especially in horticulture (Root et al. 2008), while ethyl palmitate is reported to have acaricidal properties but is not registered as a pesticide. In Ethiopia, several studies were carried out to screen effective botanicals for the control of the maize stem borer, =usseola fusca (Fuller). Among the botanicals, outstanding ones were chinaberry (/elia a%edarach L.), endod ()hytolacca dodecandra L.), pepper tree (,chinus molle L.), neem berries (+%adarachta. indica), pyrethrum flowers (<hrysanthemum spp.), kosso (@aggenia a""ysinica) and birbira (/ellitia furregemia), which performed very well and resulted in high percent larval mortality and significantly reduced the levels of leaf infestation and dead heart injury (Firdu et al., 2001; Girma et al., 2012). But no information is available whether it works for management of FAW.

The most widely available botanicals should be tested for efficacy against FAW so that clear and authoritative recommendations can be made. Thus, evaluation of plants with insecticidal and/or antifeedant effect on FAW has been made. Laboratory evaluation of leaves and seeds extracts of 11 botanicals against FAWwere conducted during 2017 at Melkassa Research Center. The botanicals under evaluations were +%adirachta indica, /illitia ferruginea,)hytolacca dodecandra, ,chinnus molle, /elia a"yssinica, /ilitia ferruginea, <roton macrostachyus, 0icotina ta"acum, 'antana camara, Eucalyptus glo"ulus,<henopodium am"rosoids and 1atrophacurcas. Laboratory evaluation showed that +%adirachta indica, ,chinnus molle and)hytolacca dodecandra resulted in the highest percentage larval mortality (96-100%) 72 hrs after treatment application (Table 8). The other five botanicals namely /elia a"yssinica, /illitia ferruginea, 1atropha curcas, <roton macrostachyus and 0icotina ta"acum caused >50% larval mortality 72 hrs after treatment application. Field evaluation of dust and spray application of the botanicals against FAWwill be conducted in 2018 to get reliable data on their field efficacy.

Table 8. Mean percent cumulative mortality of FAW larvae 24, 48 and 72 h after of application of botanicals in laboratory test in 2017 at Melkassa

Treatments	Percent mortality of the larva after		
	24 hrs	48 hrs	72 hrs
+%adirachta indica	66.7 ± 2.10 a	86.7 ± 2.01a	100 ± 0 a
,chinnus molle	66.7 ± 5.39 a	80 ± 5.39 a	96.7 ± 6.04 ab
/elia a"yssinica	23.3 ± 6.05 bc	56.7 ± 6.05 abc	93.3 ± 6.04 ab
/ilitia ferruginea	10 ± 0 cd	33.3 ± 0 c	76.7 ± 2.22 bc
)hytolacca dodecandra	70 ± 3.66 a	86.7 ± 3.66 a	100± 0 a
1atropha curcas	53.3 ± 5.17 ab	76.7 ± 5.17 ab	90 ± 7.75 ab
<roton macrostachyus	13.3 ± 2.71cd	43.3 ± 2.71 bc	86.7± 2.71 ab
0icotina ta"acum	6.7± 6.04 cd	26.67 ± 6.04 cd	50 ± 3.33cd
'antana camara	6.7± 6.04 cd	26.67 ± 6.04 cd	46.7± 1.92cd
Eucalyptus glo"ulus	0 ± 0 d	0 ± 0 e	10 ± 7.75ef

<henopodium am"rosoids	3.3$\pm$ 6.04 cd	6.67 $\pm$ 6.04 de	20 $\pm$ 4.27de
Untreated	0 $\pm$ 0 d	0 $\pm$ 0 e	0 $\pm$ 0 f

/eans within a column followed "y the same letter are not significantly different (pN..G)

Source: Birhanu et al., Unpublished data 2018

Survey for local natural enemies of FAW

Biological control is an important and integral component of an IPM program. Understanding the natural enemies associated with the insect pest is the basis for implementing successful biological control program. Biological control, i.e. the use of natural enemies of a pest, is a successful approach for many devastating insects pests. FAW has several enemies (predators, parasitoids and pathogens) in its native continent. As a recently introduced insect pest to Ethiopia, it may be less likely to find natural enemies associated with FAW in Ethiopia. However, natural enemies of African army worm and other related insect pests may adapt/might have adapted necessitating inventorying the natural enemies associated with FAW in Ethiopia. Therefore, studies on what type of natural enemies are attacking FAW in Ethiopia, what level of mortality they cause, and how they can be enhanced, are required urgently.

Accordingly survey for local natural enemies of FAW has been conducted in the year 2017 with the objective to assess indigenous natural enemies of FAW available in Ethiopia. Results revealed that numerous parasitic wasps and natural predators associated with FAW are available. Among parasitoids, larval parasitism by Braconid wasps, Tachinids and Cotesia sp have been observed from larvae collected from Hawassa, Jimma and Awash melkassa areas. Besides Ichneumon wasp has also been noted. Level of parasitism ranged between 4.6 and 45.3% (Birhanu et al., unpublished data 2018). Insect predators, such as :oru luteipes (earwig), Irius insidiosus (pirate bug),and ants have been noted in all surveyed areas of Ethiopia. Among vertebrate, common birds have also been observed when feed on FAW larvae. In further studies, it is important to see whether these enemies are transient polyphagous feeders or are specific to FAW. Here, it is important to note that FAW being a new pest to the country it is too early to get adequate association with natural enemies. Once, effective biological agents are found and effective biological control methods defined, local production of parasitoids and predators would need to be set up.

Evaluation of push-pull strategy for management of FAW

Plants also have the extraordinary capacity to repel or attract insects by emitting specific volatiles. The push-pull strategy involves the combined use of intercrops and trap crops, using plants that are appropriate to the farmers. The Push-pull strategies for cereal stem borers involves trapping stem borers on highly attractant trap plants (pull) while driving them away from the main crop using repellent intercrops(push). Plants that have been identified as effective in the push-pull tactics for management of stem borer include Napier grass ()ennisetum purpureum), Sudan grass (,orghum vulgare sudanense), Molasses grass (/elinis minutiflora), brachiaria/mulato and Desmodium (:esmodium uncinatum and :.intortum). Napier grasse, Sudan grass and =rachiaria are used as trap plants, where as molasses grass and Desmodium repel ovipositing stem borers(Khan et al., 1997; Khan et al., 2008). Planting Sudan grass around maize field reduced stem borer infestation on maize and also increased efficiency of natural enemies. Molasses grass and desmodium, when intercropped with maize, not only reduced infestation of crops by stem borers, but also increased parasitism particularly by the native larval parasitoid, <otesia sesamae (Girma et al., 2012).

No information is available whether the push-pull strategy works for FAW management. Hence, the same methodology was followed as described in Khan et al., 1997 and Khan et al 2008 to assess the applicability of the method to reduce FAW infestation on maize in Ethiopia. One year data showed that there were slight variation between plots receiving push-pull strategy and maize crop alone. This might be due to the reasons that both plots are nearby each other or due to poor establishment of border crop and also the insect might have different behavior than stem borer moths. In order to generate reliable data the trial should be repeated for the coming two seasons. In Kenya, a push-pull strategy using Desmodium as intercrop and =rachiaria another forage crop as border reported to have reduced FAW damage by more than 80% (Midega et al., 2018).

Besides the above mentioned works several parallel efforts are also going on by other regional agricultural research institutions and Universities.

Lessons learned

- FAW is probably the first pest which required maize farmers/growers in Ethiopia to regularly scout their fields as well as "udget for chemical pesticide applications.
- Early detection and early management, target young larvae (L1 –L3) and young crops (V2-V5 critical for yield potential) is very effective as FAW attacks from seedling to seed stages
- Unlike FAW in the Americas, or the African Armyworm, FAW in Ethiopia may not develop a migratory pattern. Most likely the populations will be resident, surviving on weeds and other plants during periods without maize even if, new infestations could come from other places including abroad. So, the pest has become endemic and stay for a long time in Ethiopia

- Even as we respond to FAW, it should be noted that the other pest challenges exist, and a holistic management system is needed
- Phytotoxicity has been observed as a result of overdosing as pesticide is literally drenched into whorls to kill larvae feeding underneath layers of frass.
- The occurrence of natural enemies that assist in the biocontrol of the pest
- Preliminary information on the potential of plant extracts in the control of FAW

Future Prospects

Given the suitability indices and the amount of maize grown, the situation of the FAW damage could be extremely serious in Ethiopia c. Maize is the staple crop for food in the entire regions of Ethiopia, and it is also the fall armyworm's favorite diet. Besides, there are multiple host crops in the country and multiple maize growing seasons per year (meher, residual moisture, belg and irrigation) represent a continuous source of food for the pest. So, FAW populations may continue to build and stay in the same area, as they find more host plants to multiply on, favourable climatic conditions, and in the absence of the complex of natural biological enemies (general predators like ants and earwigs, specialized parasitoids) and a host of entomopathogens (virus, bacteria and fungi). Seasonal migration might be exist depending on population number but study is needed to verify this. It could spread to new areas in the country not yet infested in the next few seasons and years, becoming a major threat to Ethiopian agriculture and agricultural trade as well.

For many crop pests sustainable solution is development of resistant varieties. However, in the Americas, a large proportion of maize (and some other FAW-susceptible crops) is genetically modified to produce one or more Bt proteins. Thus, there is less demand for pest-resistant crops produced by conventional approaches and also there was no success history on development of resistant variety through conventional breeding. Bt maize, grown throughout the Americas for many years, is resistant to the insects even the insect developed resistance to some gene. Bt maize has largely saved Brazil's maize crop from fall armyworms. However, most African countries including Ethiopia forbid the growing of genetically modified crops. Recently, Africa is changing its policy on biotech crops, though only South Africa has approved Bt maize. Nigeria, Uganda, Kenya and Ethiopia are slowly changing their legislation. This is a good start, since if all other conventional methods fail Bt maize could be considered as a potential management option in the long-term, which otherwise FAW threaten people's food security. There will also be a prospect of far more pesticides and bio-pesticides usage, which small-scale farmers cannot afford, and which come with environmental and safety risks, or lead to expensive import of food.

Conclusions and Future Directions

- The recent detection of FAWin Ethiopia presents a very serious threat which requires country wide collaboration in the search for a sustainable management strategy. The pest is likely to stay for a long timein Ethiopia due to highly conducive climatic conditions and availability of continuous source of food and has the potential to cause significant maize yield losses in the absence of any control methods.FAW attacks maize plant from seedling to seed.
- The country's largely tropical climate and year-round cultivation of maize plants offers ample opportunities for its further spread into new areas of the country. The high levels of infestation so far noticed on maize poses a major control challenge particularly in those parts of the country where maize is the staple crop. So, much needs to be studied about the pest now that it has become endemic in Ethiopia where the need to migrate long distances may not be necessary given the readily availability of host plants of varying phenologies.
- The invasiveness and damaging potential of the fall armyworm as well as transboundary migrations therefore highlight the need for a coordinated national and regional approach in building capacities to deal with the pest menace.
- In general, various attempts have been made for the past one year to combat the threat of FAW on maize. Some information that contributes to the FAW management program has been generated by research institutions and ministry of Agriculture. Studies were focused in the area of insecticide screening, bio-pesticide screening, pheromonal control, cultural control, natural enemies, and varietal screening. Some of these studies generated base-line information for future research than for immediate use.
- Immediate recommendations include (i) awareness raising campaigns and capacity building on FAW symptoms, identification, early detection and control, including pheromone lure, beneficial agronomic and other cultural practices; (ii) national preparation and communication of a list of recommended, regulated pesticides and biopesticides and their appropriate application methods (when/when not, and how to apply chemical control) and proper handling.
- Work should also start immediately to (i) breed crop varieties for resistance or tolerance to FAW; (ii) introduce classical biological control agents from the Americas; (iii) develop sound integrated pest management options from the existing control options.
- A conducive policy environment should promote lower risk control options through short term subsidies and rapid assessment and registration of biopesticides and biological control products.
- Further studies should also needed to understand the full biology, ecology, migration pattern and population dynamics, besides looking into other crops other than maize

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Bio-ecology and Integrated Pest Management Studies against Tomato Leaf Miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) in West Shoa, Ethiopia

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+"stract

=iology, ecology and management of *. a"soluta were studied for two years in 9est ,hoa %one under la"oratory, glass house and open field conditions. *. a"soluta was reported from Ethiopia in 2.12. ,ince then the pest was posing serious crop losses to tomato in the country. ;emale *. a"soluta laid an average of 1CC.G eggs at hot and dry condition, while 2 .CG eggs under warm and moist conditions in +m"o area. *he longevity of the female is greater than the male. *he sex ratio of male to female is ›2. *. a"soluta for its optimum "iological parameters performance, it re6uires hot and dry conditions. *he female lay the highest proportion of its egg on the upper side of the tomato leaf, while the highest proportion of eggs laid on under leaf in case of tomato. ;rom the experiment done only tomato and potato fund to "e hosts of *. a"soluta. ;or integrated management of *. a"soluta the use of "otanicals such as +. sativum and +%adirchata indica, fungi isolates of =eauveria "assiana and the insecticides chlorantraniliprole 2.. ,< and coragen 2.. ,< were found to "e effective. *he integration of these management component under large plot need to "e done for the utili%ation of the results o"tained with this studies.

#ntroduction

Tomato ('ycopersicon esculentum Mill.) belonging to Solanaceae family is an important and remunerative vegetable crop grown around the world for fresh consumption and processing. It is widely cultivated in tropical, sub-tropical and temperate climates. Tomato ranks third in terms of world vegetable production and it is a crop of large importance throughout the world (Abdussamee et al, 2014; Mehraj et al., 2014; Kaur et al., 2014). Global tomato production is currently around 130 million tons of which 88 million tons are intended for the fresh market and the rest 42 million tons for processing. In Ethiopia, it is one of the economically important vegetable crop and the annual production of the crop is 30,700 tons from about 5,026 ha of land (FAO, 2015; Fact fish, 2016). Tomato is produced by small and medium scale farmers under open field and greenhouse conditions for fresh consumption and as a source of income (Bawin et al., 2014; Retta and Berhe, 2015). It is an important source of vitamins such as vitamin A, B, C and E (Baloch, 1994; Bhowmik et al, 2012; Kaur et al., 2014). It is also a source of basic raw materials for processing industry for the production of tomato paste and tomato juice among others (EIA, 2012; AVRDC, 2014). The production potential of tomato is 15.9 to 46.3 tons/ha (CSA, 2013), but the average production of tomato per hectare in Ethiopia is estimated to 7.67 tons which is far below the potential yield. Various constraints contributed for the low yield of tomato including insect pests. Insects which constrained tomato production include tomato leaf miner, tomato fruit worm, whitefly, leafhopper, aphid, mites and thrips (Daniel and Bajarang, 2017; Tonnang et al., 2015; Bawin et al., 2015; El-Arnaouty et al., 2014; Assefa et al., 2013).Tomato leaf miner, *uta a"soluta (Meyrick) is an invassive pest of tomato and other Solanaceous crops in many areas of the world and causes severe damage and yield losses.

In Ethiopia, the occurrence of *. a"soluta was reported in 2012 and cause tremendous losses since then (Retta and Berhe, 2015; Muluken et al., 2014; Goftishu et al., 2014; Gashawbeza and Abiy, 2013). Even though studies on the distribution and extent of losses of *. a"soluta are at initial phase, the fact that the pest was first recorded and evedence for its existence still now in high potential tomato producing areas of rift valley and central parts of Ethiopia the pest can be considered a highly economically important pest in the country (Bawin et al., 2014; Retta and Berhe, 2015; Materu et al., 2016.

*. a"soluta cause damage to different genera and species of the solanaceae family in addition to tomato. Larvae attack the plants at any developmental stage from seedlings to maturity in greenhouses and open field. The damage may result in 80-100% defoliation, flower shade, stalk burrowing, apical bud damage, green and ripe fruits damage (Harizanova et al., 2009; Desneux et al., 2010; Garzia et al., 2012; Öztemiz, 2012; Yankova, 2012). It has high reproductive capacity with a short developmental time which enable the pest to produce up to 12 generations per year under favorable conditions (Mollá et al., 2011).

Addis Ababa University through its Insect Science Stream always assign post graduate students to work on critical problems of the country. To mention some; Bionomics and management of white mango scale by Dr. Ofgaa Djirata, Studies on some Ecological aspects of termites and their management in Ghimbi District of western Ethiopia by Dr. Mulatu Wakjari, Studies on Ecology of termites and their management in the central Rift Valley of Ethiopia by Dr. Daniel Getahun, Development of mycopesticide for the management of sorghum chafer by Dr. Belay Habte Gebreal and Ecology, Biology and Management of T. a"sulota by Tadele Shibru. The purpose of this paper is to highlight on the studies concerning *. a"soluta. From this work 9 papers were published on peer reviewed journal and others are under preparation. These include:

1) Tadele Shiberu and Emana Getu (2017). Biology of *uta a"soluta (Meyrick) (Lepidoptera: Gelechiidae) under different temperatures and relative humidities. Journal of Horticulture and Forestry9(8): 66-73.

2) Shiberu T, Getu E (2017) Evaluation of Bio-Pesticides on Integrated Management of Tomato Leafminer, *uta a"soluta (Meyrick) (Gelechiidae: Lepidoptera) on Tomato Crops in Western Shewa of Central Ethiopia. Entomol Ornithol Herpetol 6: 206. doi:10.4172/2161-0983.1000206

3)Tadele Shiberu and Emana Getu (2017) Effects of crude extracts of medicinal plants in the management of *uta a"soluta (Meyrick) (Lepidoptera: Gelechiidae) under laboratory and glasshouse conditions in Ethiopia. Journal of Entomology and Nematology 9(2):9-13

4)Tadele S, Emana G (2017) Entomopathogenic Effect of =eauveria "assiana (Bals.) and /etarrhi%ium anisopliae (Metschn.) on *uta a"soluta (Meyrick) (Lepidoptera: Gelechiidae) Larvae Under Laboratory and Glasshouse Conditions in Ethiopia. J Plant Pathol Microbiol 8: 411. doi:10.4172/2157-7471.1000411

5) Shiberu T, Getu E (2018) Experimental Analysis of Ecomomic Action Level of Tomato Leafminer, *uta a"soluta Meyrick (Lepidoptera: Gelechiidae) on Tomato Plant under Open Field. Adv Crop Sci Tech 6: 327. doi:10.4172/2329-8863.1000327

6) Tadele Shiberu and Emana Getu (2018) Determination of oviposition preference and infestation level of *uta a"soluta on major solanaceae crops under glasshouse conditions in Ethiopia International Journal of Fauna and Biological Studies; 5(1): 130-136

7) Tadele Shiberu and Emana Getu (2017) Evaluation of Some Insecticides against Tomato Leaf Miner, *uta a"soluta (Meyrick) (Gelechiidae: Lepidoptera) Under Laboratory and Glasshouse Conditions **Agricultural Research & Technology** 7:DOI: 10.19080/ARTOAJ.2017.07.555711

8) Tadele Shiberu and Emana Getu (2017)Evaluation of Colored Sticky Traps for the Monitoring of *uta a"soluta Meyrick (Lepidoptera: Gelechiidae) in Tomato under Glasshouse in Ethiop Agri Res & Tech: Open Access J 9(3): ARTOAJ.MS.ID.555762

9) Tadele Shiberu and Emana Getu (2017) Estimate of yield losses due to *. a"soluta Meyrick (Lepidoptera: Gelechiidae) on tomato crops under glasshouse and field conditions in Western Shewa of Central Ethiopia. International Journal of Fauna and Biological Studies 2017; 4(5): 104-108

1.2. Rationale of the studies

The use of chemical pesticides is the major control options practiced by tomato growers across the globe wherever the problem of *. a"soluta exists. However, the pest developed resistance to many of the pesticides under use which call for the need of having alternative control options. Moreover, basic aspects such as the biology and ecology of *. a"soluta need to be studied under Ethiopian/local condition as the knowledge generated are highly useful for developing Integrated Management of the pest (Bawin et al., 2014). The following three factors make control of *. a"soluta difficult:

1. Larvae mines within plant tissue (leaves surface and fruits) and are thus protected from contacting insecticides (Abbes and Chermiti, 2011; Guedes and Picanço, 2012; Guedes and Siqueira, 2013; Sevcan, 2013; Daniel and Bajarang, 2017).
2. They have high reproduction potential, capable of producing 10 to 12 generations per year under the favorable environmental conditions. With such high reproduction potential, they are likely to undergo genetic changes (mutation) which in turn causes resistance to pesticides (Arnó and Gabarra, 2010; Muruvanda et al., 2012; Daniel and Bajarang, 2017). The pests were reported to be resistant to dozens of insecticides including chlorantraniliprole, abamectin, methamidophos, permethri cartap (Haddi et al., 2012).

3. Some female *uta a"soluta are able to reproduce parthenogenically which makes the use of pheromone trap not applicable for either monitoring and/or mass trapping as part of the pest control (Megido et al., 2012).

1.3. General objective:

- To develop knowledge based Integrated Pest Management against *. a"soluta

1.3.1 Specific objectives:

- To study the biology and Ecology of *. a"soluta
- To evaluate different bio-pesticides at different doses against *. a"soluta

Description of the study area

Different studies on *. a"soluta were conducted during 2015-2017 in the greenhouse and open-field. The glasshouse studies were carried out at Ambo University Plant Sciences Laboratory. Ambo is found at 8°59′N latitude and 37.85°E longitude with an altitude of 2100 m.a.s.l. The greenhouse study was conducted at the outside air temperature of 22±2°C and inside temperature of 32±2°C. The field experiments were carried out on farmers' field at three different districts including Ambo, Dandi and Toke Kutaye. **The average annual rainfall was 1028.7 mm and maximum and minimum temperatures of the area were 29.6°C and 11.8°C, respectively.**

Biology and Ecology of *T. absoluta*

Developmental stage of *T. absoluta*

Female, *. a"soluta laid an average of 177.5 eggs at 32±2°C and 40±5% r.h, while the number of eggs increased to 233.75 at 20.5±2°C and 55±5% r.h. Eggs hatch after 13 to

13.5 days at 20.5±2^{o}C and 55±5% r.h., while egg hatching shortened to 10 to 10.5 at 32±2^{o}C and 40±5% r.h.. Larval development takes an average of 12.5 days at 20.5±2^{o}C and 55±5% r.h., but larval development shortened to 11 to 11.5 days at 32±2^{o}C and 40±5% r.h. Pupal development takes 8.2–9.8 days at 20.5±2^{o}C and 55±5% r.h., but shortened to 6.5–8.6 days at 32±2^{o}C and 40±5% r.h. *. a"soluta needs 30.6±0.59 days to complete its life cycle at 20.5±2^{o}C and 55±5% r.h., but shortened to 27.8±0.57days at 32±2^{o}C and 40±5% r.h. Female *. a"soluta longevity is greater than the male longevity at all the temperatures and relative humidities tested. The longevity of the male was 9.0±0.30 days at 20.5±2^{o}C and 55±5% r.h., but shortened to 6.8±0.27 days at 32±2^{o}C 40±5% r.h. Female *. a"soluta lived for 18.40 ±1.45days at 20.5±2^{o}C and 55±5% r.h., but shortened to 15.2±1.40days at 32±2^{o}C and 40±5% r.h. The sex ratio was a little bit male biased with an average male to female ratio of 3:2.

Generally, the biology of *. a"soluta is highly temperature and relative humidity dependent where hot and dry conditions are conducive environmental factors for the pest.

Egg laying positions of *T. absoluta* on tomato plants

Oviposition sites of *. a"soluta varies with the highest proportion (60.56%) being on upper leaf, intermediate on lower leaves (35.21%) and the lowest proportions of 1.97%, 1.4% and 0.85% eggs were laid on fruits, flowers and on stems, respectively.

Host preferences of *T. absoluta*

Host preference of *. a"soluta is shown in Table 1. From the result it can be summarized that both tomato and potato are the most preferred hosts, while pepper is a remote host for the pest. The oviposition site looks different for tomato and potato such that the preferred egg laying site was on upper leaf in case of tomato, while the lower leaf was the preferred egg laying site in case of potato. Variations among varieties of different crops are not significant.

Table 1: Mean number of eggs laid by *. a"soluta on different varieties of tomato, potato and pepper in 2015-2017

	Eggs laid by females/plant							
	2015/16				2016/17			
Treatments	Upper leaf	Lower leaf	Stem	Flower	Upper leaf	Lower leaf	Stem	Flower
Koshoro (Tomato)	62.23^{bc}	36.80^{c}	0.48	0.50	67.35^{a}	31.93^{c}	0.33	0.33
VF-Roman	66.39^{ab}	35.97^{c}	0.49	0.23	63.96^{a}	34.35^{c}	0.53	2.17
Galila (Tomato)	60.88^{c}	35.41^{c}	0.27	0.68	68.09^{a}	30.82^{c}	1.09	0.0
Local var. (Tomato)	67.24^{a}	32.01^{c}	0.36	0.36	64.51^{a}	34.50^{c}	1.0	0.0
Jalane (Potato)	23.33^{e}	73.89^{a}	2.78	0.0	31.75^{d}	56.49^{b}	1.75	0.0
Tolcha (Potato)	26.84^{e}	71.31^{a}	1.85	0.0	37.11^{c}	57.48^{b}	5.41	0.0
Menagesha (Potato)	35.15^{d}	63.69^{b}	1.15	0.0	40.08^{c}	59.92^{b}	0.0	0.0
Local var. (Potatao)	23.96^{e}	75.75^{a}	0.0	0.0	23.21^{e}	76.80^{a}	0.0	0.0
M. Awaze	0.0^{f}	0.0^{d}	0.0	0.0	0.0^{f}	0.0^{d}	0.0	0.0

(Pepper)								
M. Fana (pepper)	0.0^{f}	0.0^{d}	0.0	0.0	0.0^{f}	0.0^{d}	0.0	0.0
M. Zala (pepper)	0.0^{f}	0.0^{d}	0.0	0.0	0.0^{f}	0.0^{d}	0.0	0.0
Local var. (pepper)	0.0^{f}	0.0^{d}	0.0	0.0	0.0^{f}	0.0^{d}	0.0	0.0
LSD	4.90	5.73			6.44	11.91		
CV (%)	9.48	9.56			11.38	21.80		
SE±	2.89	3.39			3.80	7.03		

Means followed by the same letter (s) within a column are not significantly different from each other at 5%, DMRT.

Evaluation of bio-pesticides for the Management of *Tuta absoluta*

Table 2 demonstated botanical plants tested for their efficacey against *. +"soluta. These plants are considered as medicinal plants because of their chemical contents.

Table 2: Lists of botanical plants tested against, *. a"soluta under laboratory and glasshouse conditions

Common name	Amharic name	Scientific Name	Family	Used part (s)
Soap berry	Endod	)hytolacca dodecandra	Phytolacaceae	Leaf and seed
Tobacco	Timbaho	0icotiana sp.	Solanaceae	Leaf and stalk
Lemon grass	Keysar	<ym"opogon citrates	Gramineae	Leaf
Garlic	Nich shinkurti	+llium sativum	Lilliaceae	Cloves
Neem	Yekinin zaf	+%adirachta indica	Meliaceae	Seed

The efficacy of different botanicals in killing *. a"soluta larvae is shown in Table 3. Endod seed and leaf at all concentrations gave the lowest mean percent larval mortality of *. a"soluta, while neem seed gave the highest larval mortality at the intermediate and highest concentration. The botanicals remained effective up to 120 days after application.

Table 3: Efficacy of botanical plants in killing *. a"soluta larvae at different.

rates and time of exposure under laboratory condition

Botanicals	Conc.	Mean percent larval mortality of *T. absoluta*			
		After 24 hrs	**After 48 hrs**	**After 72 hrs**	**After 120 hrs**
	5%	21.67^{gh}	33.33^{ef}	35.00^{hi}	40.0^{h}
Endod seed	7.5%	26.67^{fg}	36.67^{def}	38.33^{h}	43.33^{h}
(). dodecandra)	10%	31.67^{ef}	36.67^{def}	53.33^{ef}	56.67^{fg}
	5%	23.33^{h}	26.67^{g}	28.33^{j}	36.67^{h}
Endod leaf	7.5%	23.33^{gh}	26.67^{g}	33.33^{ij}	36.67^{h}
(). dodecandra)	10%	38.33^{fg}	31.67^{fg}	51.67^{fg}	55.0^{g}
	5%	38.33^{d}	38.33^{de}	46.67^{g}	66.67^{ef}
Garlic cloves	7.5%	38.33^{d}	53.33^{b}	63.33^{bc}	86.67^{bc}
(+. sativum)	10%	56.67^{b}	66.67^{a}	73.33^{a}	95.0^{ab}
	5%	38.33^{d}	56.67^{a}	56.67^{def}	61.67^{efg}
Tobacco	7.5%	46.67^{c}	58.33^{a}	61.67^{cde}	70.0^{de}
(0icotiana sp.)	10%	66.67^{a}	71.67^{a}	71.67^{a}	80.0^{cd}
	5%	33.33^{de}	41.67^{cd}	53.33^{ef}	88.33^{abc}
Lemongrass	7.5%	36.67^{de}	46.67^{c}	56.67^{def}	91.67^{ab}
(<. citratus)	10%	38.33^{d}	56.67^{b}	63.33^{bc}	96.67^{ab}
	5%	46.67^{c}	46.67^{c}	58.33^{cde}	90.0^{abc}
Neem seed	7.5%	66.67^{a}	68.33^{a}	68.33^{ab}	90.0^{abc}
(+. indica)	10%	66.67^{a}	68.33^{a}	71.67^{a}	98.33^{a}

Control	0.00^{i}	0.00^{h}	0.00^{k}	6.67^{i}
LSD	3.73	3.81	3.74	10.81
CV (%)	4.54	4.14	3.73	7.17
MSE ±	1.68	1.72	1.69	4.87

Means followed by the same letter (s) within a column are not significantly different from each other at 5%, DMRT

Table 4 demonstrated the efficacy of botanical plants in killing *. a"soluta under glass house condition.). dodecandra seed and leaf gave the lowest mean percent larval kill, while the highest mean larval kill was recorded with +. sativum. The mean percent larval kill increased with exposure time.

Table 4: Mean percent mortality of *. a"soluta larvae with the application of different botanicals at different rates and time of exposure under glass house condition

Treatments	**Mean percent mortality of *T. absoluta* larvae**			
	After 1 day	**After 3 day**	**After 5 day**	**After 7 day**
). dodecandra seed	18.65^{d}	24.03^{c}	36.51^{bc}	36.51^{b}
). dodecandra leaf	23.33^{cd}	26.11^{c}	32.72^{c}	36.94^{b}
+. sativum clove	43.45^{a}	58.59^{a}	58.93^{a}	59.92^{a}
0icotiana sp.	33.61^{ab}	45.71^{ab}	45.83^{abc}	62.10^{a}
<. citratus	30.63^{bc}	33.97^{abc}	47.62^{ab}	57.9^{a}
+. indica seed	24.52^{bcd}	46.79^{a}	50.95^{a}	66.54^{a}
Control	0.00^{e}	0.00^{d}	0.00^{d}	0.00^{c}
LSD	6.17	12.0	7.98	11.64
CV (%)	8.91	14.98	8.83	11.59
SE±	2.47	4.81	3.20	4.67

Means followed by the same letter (s) within a column are not significantly different from each other at 5%, DMRT

Table 5 demonstrated the effect of fungal isolates on larval mortality of *. a"soluta under laboratory condition. =eauveria "assiana isolates gave comparable control of *. a"soluta with the standard insecticide which gave over 95% larval mortality. Isolate PPRC-56 at the highest concentration significantly (P<0.05) gave the highest larval mortality which increased as the exposure time extended from 3 days to 7 days. Similar results were obtained from glass house experiment with over larval mortality reduction (Table 6).

Table 5: Mean percent larval mortality of *. a"soluta treated with fungal isolates at different
concentrations and exposure times under laboratory condition

Treatments	Conc.	Mean percent larval mortality after treatment application		
		3 days	5 days	7 days
	2.5×10^7	37.50^{c}	58.33^{c}	79.17^{b}
Beauveria bassiana	2.5×10^8	70.83^{bc}	70.83^{bc}	83.33^{ab}
(PPRC-56)	2.5×10^9	79.17^{ab}	91.67^{ab}	95.83^{a}
	2.5×10^7	58.33^{bc}	58.33^{bc}	66.67^{b}
Metarhizium	2.5×10^8	58.33^{bc}	79.17^{bc}	79.17^{ab}
anisopliae	2.5×10^9	66.67^{bc}	83.33^{abc}	87.50^{ab}
(PPRC-2)				
Chlorantraniliprole (Coragen 200 SC)		95.83^{a}	95.83^{a}	95.83^{a}
Control (water)		0.0^{d}	0.0^{d}	0.0^{c}
LSD at 0.01		20.15	19.95	21.82
CV (%)		16.47	14.19	14.61
SE±		8.29	8.21	8.96

Means followed by the same letter (s) within a column are not significantly different from each other at 5%, DMRT

Table 6: Mean percent mortality of Entomopathogenic fungi at different concentration on larvae *. a"soluta under glasshouse condition

Treatments	Conc.	Mean percent mortality after treatment application			
		3 days	**5 days**	**7 days**	**10 days**
	2.5 x 10^{7}	43.85^{c}	57.57^{bc}	75.17^{ab}	81.64^{ab}
Beauveria bassiana	2.5 x 10^{8}	56.27^{bc}	56.27^{bc}	73.0^{ab}	76.62^{abc}
(PPRC-56)	2.5 x 10^{9}	63.84^{b}	67.05^{b}	67.05^{bc}	84.04^{ab}
	2.5 x 10^{7}	38.76^{c}	42.93^{c}	53.37^{c}	53.37^{d}
Metarhizium	2.5 x 10^{8}	44.07^{c}	51.98^{bc}	61.49^{bc}	64.65^{cd}
anisopliae	2.5 x 10^{9}	64.05^{b}	68.21^{bc}	71.98^{abc}	76.31^{abc}
(PPRC-2)					
Chlorantraniliprole (Coragen 200 SC)		91.84^{a}	91.84^{a}	91.84^{a}	91.84^{a}
Control		2.78^{d}	4.76^{d}	4.76^{d}	7.14^{e}
LSD at 0.01		18.61	21.12	21.73	14.85
CV (%)		15.10	15.65	14.21	9.09
SE±		7.66	8.69	8.94	6.11

Means followed by the same letter (s) within a column are not significantly different from each other at 5%, DMRT

Tables 7 and 8 demonstrated the efficacy of some insecticides in the management of *. a"solutaunder laboratory and glass house conditions. Under both cases the insecticide Chlorantraniliprole (Coragen 200 SC) followed by Prove 1.9 E.C + Levo 2.4 SL gave the highest larval mortality of *. a"soluta though the overall larval mortality was higher under laboratory than under glass house condition.

Table 7: Mean percent larval mortality of *. a"soluta caused by different concentrations of
insecticides after treatment exposure of 24, 48 and 72 hours under laboratory conditions

Treatments	Conc.	Mean percent larval mortality after		
		24 hrs	48 hrs	72 hrs
Emamectin benzoate (Prove 1.9 E.C)	1%	31.11[cd]	42.22[de]	51.11[cd]
	2%	37.78[c]	44.45[cd]	57.78[c]
	3%	37.78[c]	46.67[c]	60.0[c]
Prosuler oxymatrin (Levo 2.4 SL)	1%	22.22[d]	33.33[e]	37.78[e]
	2%	35.55[c]	35.55[de]	42.22[de]
	3%	35.55[c]	37.78[cde]	42.22[de]
Prove 1.9 E.C + Levo 2.4 SL	2:2%	62.22[b]	77.78[b]	80.0[b]
Chlorantraniliprole (Coragen 200 SC)	1%	93.33[a]	95.55[a]	95.55[a]
Control		0.0[e]	0.0[f]	0.0[f]
LSD at 0.01		12.79	12.68	12.27
CV (%)		13.96	12.26	11.07
SE ±		5.36	5.31	5.15

Means followed by the same letter (s) within a column are not significantly different from each other at 5%, DMRT

Table 8: Mean efficacy of two commercial bio-pesticides in different concentrations against
tomato leafminer, *. a"soluta under glasshouse conditions

Treatments	Conc (%)	Mean efficacy percent		
		1 day	3 day	5 day
Emamectin benzoate (Prove 1.9 E.C)	2%	30.55[c]	34.26[c]	39.81[b]

Prosuler oxymatrin (Levo 2.4 SL)	2%	17.49[d]	22.25[c]	25.28[c]
Prove 1.9 E.C + Levo 2.4 SL	2:2%	51.52[b]	74.77[ab]	78.94[a]
Chlorantraniliprole (Coragen 200 SC)	1%	76.59[a]	89.68[a]	89.68[a]
Control		3.33[d]	7.50[d]	7.50[d]
LSD at 0.01		12.42	24.70	17.83
CV (%)		12.63	19.73	13.49
SE±		4.53	9.02	6.51

Means followed by the same letter (s) within a column are not significantly different from each other at 5%, DMRT

Treatment combination of botanicals, fungi isolates and insecticides were tested under field condition at different locations of West Shoa results of which are shown in Tables 9-14. Three days after treatment application (Table 9) the botanicals showed similar level of efficacy which ranged from 39.35% to 54.55% where the lowest value was obtained from 0icotiana sp., while the highest was from <ym"opogon citratus. None of the fungi isolates was effective against *.a"soluta three days after application. Both Tetraniliprole (Vayego 200 SC) and Coragen 200 SC gave the highest efficacey percentage as mean percent efficacy were 96.19% and 94.74%, respectively.

Five days after treatment application (Table 10) the efficacy percentage of the botanicals raised where the lowest efficacy by 0icotiana sp. Became 47.63% and the highest efficacy of 60.39% was obtained from +llium sativum. However, the variations among the botanicals in terms efficacy percentage were not significant. The fungi isolates became effective five days after treatment application as efficacy percentage of 30% was recorded. The insecticides gave the highest efficacy percentage of 95-96%.

Seven days after treatment application (Table 11) 0icotiana sp. Significantly gave the lowest efficacy percentage of 49.65%, while +. sativum, <. citrates and +. indica gave comparable mean efficacy percentage of 69.28%, 69.22% and 67.03%, respectively. The efficacy percentage of the fungi isolates increased to over 50% where the efficacy percentage of =. "assina was 56.31% and that of /. isoplliae was 51.26% which was not statistically significant. The efficacy percentage of the insecticides were 96.19% for Tetraniliprole (Vayego 200 SC) and 94.55% for Coragen 200 SC which are not statistically different from each other.

Ten days after treatment application (Table 12), there was no much change in efficacy percentage of the botanicals and the insecticides from the earlier exposure time of 7 days, while efficacy percentage of the fungi isolates increased with efficacy percentage of 74.14% for =. "assiana and 59.31% for /. anisopliae. Table 13 demonstrated the effect of different treatments for the management of *. a"soluta on yield of tomato. +. sativum, +. indica, =. "assiana, Ttraniliprole (Voyego 200 SC) and Coragen 200 SC gave the highest yield per hectare, while the lowest yield was obtained from the untreated check followed by 0icotiana sp.

Yield losses due to T. absoluta on plots received different treatments are shown in Table 14. The lowest yield losses were recorded on the plots that received +. indica, +. sativum and =. "assiana.

Table 9: Mean efficacy percentage of bio-pesticides against *. a"soluta after 3 days of

treatment application under field condition at different locations.

Treatments	Locations			
	Ambo	Dandi	Toke kutaye	Mean
+llium sativum	50.86^{bc}	57.57^{bcd}	43.10^{c}	50.51^{b}
0icotiana sp.,	33.33^{bc}	43.60^{d}	41.11^{c}	39.35^{b}
<ym"opogon citratus	59.26^{b}	66.67^{b}	38.91	54.55^{b}
+%adirachta indica	27.61^{c}	61.24^{bc}	42.26^{c}	43.70^{b}
Tetraniliprole (Vayego 200 SC)	96.78^{a}	93.38^{a}	98.42^{a}	96.19^{a}
=eauveria "assiana	0.00^{d}	0.00^{e}	0.00^{d}	0.00^{c}
/etarhi%ium anisopliae	0.00^{d}	0.00^{e}	0.00^{d}	0.00^{c}
Coragen 200 SC	91.41^{a}	96.97^{a}	95.83^{a}	94.74^{a}
Control	6.27^{d}	0.00^{e}	0.00^{d}	2.09^{c}
LSD at 0.01	16.11	8.95	12.77	13.53
CV (%)	20.47	20.29	16.57	19.11
SE ±	6.76	3.75	5.35	5.67

Means followed by the same letter (s) within a column are not significantly different from each other at 5%, DMRT

Table 10: Mean efficacy percentage of bio-pesticides against *. a"soluta after 5 days of treatment application on field conditions.

Treatments	Locations			
	Ambo	Dandi	Toke kutaye	Mean
+llium sativum	62.48^{d}	69.80^{b}	48.90^{bc}	60.39^{b}
0icotiana sp.,	41.67^{b}	60.12^{b}	41.10^{bc}	47.63^{bc}
<ym"opogon citratus	65.74^{b}	60.32^{b}	49.14^{bc}	58.40^{b}
+%adirachta indica	52.31^{b}	59.02^{bc}	52.80^{b}	54.71^{b}
Tetraniliprole (Vayego 200 SC)	96.78^{a}	93.38^{a}	98.42^{a}	96.19^{a}
=eauveria "assiana	37.29^{b}	13.35^{de}	29.17^{cd}	26.60^{d}

/etarhi%ium anisopliae	45.19^b	30.16^cd	16.31^d	29.45^cd
Coragen 200 SC	91.41^a	96.97^a	95.83^a	94.74^a
Control	6.27^c	6.27^e	0.00^d	4.18^e
LSD at 0.01	18.66	16.36	12.77	13.59
CV (%)	18.66	20.65	13.32	13.19
SE ±	8.37	6.86	5.35	5.70

Means followed by the same letter (s) within a column are not significantly different from each other at 5%, DMRT

Table 11: Mean efficacy percentage of bio-pesticides against *. a"soluta after 7 days of treatment application on field conditions.

	Locations			
Treatments	**Ambo**	**Dandi**	**Toke Kutaye**	**Mean**
+llium sativum	68.29^b	69.10^bc	70.45^b	69.28^b
0icotiana sp.,	46.22^bc	50.80^cd	51.85^b	49.65^c
<ym"opogon citrates	65.66^bc	77.3^b	64.71^b	69.22^b
+%adirachta indica	69.69^b	60.10^bcd	71.29^b	67.03^b
Tetraniliprole (Vayego 200 SC)	96.78^a	93.38^a	98.42^a	96.19^a
=eauveria "assiana	47.75^bc	54.13^cd	67.04^b	56.31^bc
/etarhi%ium anisopliae	55.71^bc	39.68^d	58.40^b	51.26^c
Coragen 200 SC	94.19^a	93.64^a	95.83^a	94.55^a
Control	9.97^d	6.23^e	0.00^c	5.40^d
LSD at 0.01	21.44	13.35	11.67	12.22
CV (%)	18.69	20.65	19.78	10.44
SE ±	8.99	5.60	4.89	5.13

Means followed by the same letter (s) within a column are not significantly different from each other at 5%, DMRT

Table 12: Mean efficacy percentage of bio-pesticides against *. a"soluta after 10 days of treatment application on field conditions.

	Locations			
Treatments	**Ambo**	**Dandi**	**Toke kutaye**	**Mean**
+llium sativum	68.28^{b}	76.40^{b}	72.78^{bcd}	72.49^{b}
0icotiana sp.,	46.29^{bc}	49.90^{de}	51.85^{e}	49.35^{c}
<ym"opogon citrates	65.57^{bc}	77.30^{b}	64.71^{bcde}	69.19^{b}
+%adirachta indica	72.39^{b}	74.03^{bc}	76.07^{bc}	74.26^{b}
Tetraniliprole (Vayego 200 SC)	96.78^{a}	93.38^{a}	98.42^{a}	96.19^{a}
=eauveria "assiana	78.37^{b}	65.66^{bcd}	78.40^{b}	74.14^{b}
/ etarhi%ium anisopliae	64.76^{bc}	54.76^{cde}	58.40^{cde}	59.31^{bc}
Coragen 200 SC	94.19^{a}	96.97^{a}	95.83^{a}	95.66^{a}
Control	9.97^{d}	6.23^{f}	0.00^{d}	5.40^{d}
LSD at 0.01	20.04	12.32	12.02	10.87
CV (%)	18.83	19.94	19.81	18.81
SE ±	8.31	5.16	5.04	4.56

Means followed by the same letter (s) within a column are not significantly different from each other at 5%, DMRT

Table 13: Mean marketable yield per hectare in tons on different locations of West Shewa, Central Ethiopia

	Locations			
Treatments	**Ambo**	**Dandi**	**Toke kutaye**	Mean
	Marketable yield/ha	Marketable yield/ha	Marketable yield/ha	Marketable yield/ha in tons

+llium sativum	23.63[b]	26.8

<ym"opogon citratus	23.92^{cd}	31.11	28.36^{bc}	16.37	23.36^{bc}	17.69
+%adirachta indica	30.16^{abc}	13.13	30.46^{ab}	10.17	26.23^{ab}	7.33
Tetraniliprole (Vayego 200 SC)	35.31^{cd}	---	36.22^{c}	---	28.62^{de}	---
=eauveria "assiana	31.22^{ab}	10.08	31.01^{ab}	8.55	26.43^{ab}	6.87
/etarhi%ium anisopliae	26.64^{bc}	23.28	27.22^{bc}	19.73	21.47^{cd}	24.35
Coragen 200 SC	34.72^{a}	---	33.91^{a}	---	28.38^{a}	---
Control	14.18^{e}	59.16	11.64^{e}	65.67	8.48^{f}	70.12
LSD at 0.01	6.12		4.22		2.92	
CV (%)	10.77		6.64		5.58	
SE ±	2.78		1.77		1.23	

Means followed by the same letter (s) within a column are not significantly different from each other at 5%, DMRT

Conclusion

Biology of *. a"soluta showed that the pest can produce as high as 12 generations per year. The fecundity of the pest was also found to very high. *. a"soluta a little bit seems male biased. Data obtained on the biology of the pest deviate from the biology data obtained elsewhere. The pest prefers hot and dry condition. Tomato and potato found to be preferred to hosts of the pest. More eggs are laid on the upper leaf in case of tomato and lower leaf in case of potato.

For integrated management of *. a"soluta the use of botanicals such as +. sativum and +. indica, fungi isolates of =. "assiana and insecticides chlorantraniliprole 200 SC and coragen 200 SC can be used.

Recommendation

The integration of the management options found to be effective should be done on large plot to facilitate immediate recommendation of the outcome of these studies to the end users, so that tomato crop will be protected from the damage by *. a"soluta.

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The larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae): Status, interventions and the way forward

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Abstract

*he larger grain "orer ('?=),)rostephanus truncatus (@orn), is native to <entral +merica, tropical ,outh +merica, and the extreme south of the 3,+. #t was first introduced into *an%ania pro"a"ly in the late 1AC.s and early 1AB1, and then in *ogo into 1AB2 where it has "ecome a serious pest of stored mai%e and dried cassava. *he "eetle has spread following these introductions to many countries across East, 9est and southern +frica. #n mid 1AA.s, it was reported to spread in 11 +frican countries. *he affected +frican countries reported to date include *an%ania, -enya, =urundi, /alawi, 4wanda and 3ganda in the East; =enin, ?hana, ?uinea <onakry, ?uinea =issau, =urkina ;aso, 0igeria, 0iger and ,enegal in the 9est, and 8am"ia, 0ami"ia, ,. +frica, /o%am"i6ue and 8im"a"we in the southern part of +frica; and is almost certainly present "ut unreported from several other countries in the continent. :espite its occurrence in neigh"oring -enya since 1AB , in Ethiopia, it was not recorded until 2..B; however, later reports showed that it was first occurred at /oyale)lant Ruarantine ,tation on a wood ladder a"ating the wall of the 6uarantine la"oratory in +pril 2..B. ;ollowing this it was found in the la"oratory refrigerator with poorly fitting door which contained pheromone capsules put in it for over 1. years. #ts occurrence in Ethiopia has not "een officially reported yet. =ut unconfirmed report also indicated its incidence of infestation in ?am"ella region in "oth 2.12 and 2.1G. + survey conducted in the vicinity of /oyale in 2.11 did not reveal the pest anywhere outside the 6uarantine station. @ence, the source of the "eetles caught in the 6uarantine station is not clear. #t could either "e from the forest surrounding the 6uarantine station or through mai%e grain that came to the area from -enya "ut the infestation was too low (due to scarcity of the host crops in the area) to detect in farmers stores, grain market places and grain traderLs stores investigated during the 2.11 survey. #n either case it seems that the pest was introduced in the area sometime "efore 2..B and after 2..2DG when pheromone traps deployed did not catch any '?=. 'ater in 2.12 the pest was reported to "e caught in pheromone traps deployed in /oyale woreda of the ,omali region and =ur!i woreda in ,00)4; in =ur!i pro"a"ly through a separate introduction, since people from =ur!i fre6uently shuttle "etween =ur!i and -enya. *he current status of distri"ution of the pest is not known as there was no serious follow$up was made to the pro"lem except two sensiti%ation workshops organi%ed for

concerned people from Iromia, ,omali and ,00)4 regions in mid 2.1G at @ageremariam and in early 2.1B at -onso. #t is regretta"le that no significant attention is "eing given to this important pest since its first introduction reported a"out 1. years ago. #n this paper, different options recommended for the management of the pest are reviewed and future directions are suggested.

Introduction

Species of the Bostrichidae (horned powder-post beetles) family are xylophagous, harmful to dry wood, bamboo, wooden or bamboo artifacts; a few species attack living trees and another few species attack stored grain and tubers (cassava, yam). The latter ones are larger grain borer, *)rostephanus truncatus*, lesser grain borer, *4hi%opertha dominica* and bamboo borers, *:inoderus* spp. Several species of Dinoderus are known of which *:. minutus* is reported to be more dominant. The lesser grain borer is an established pest of stored grains in Ethiopia; *:inoderus* species are not recorded in Ethiopia to date but they are important pests of dried cassava in South and West Africa. These beetles are morphologically very similar and difficult to distinguish.

The larger grain borer (LGB), sometimes also called greater grain borer, *)rostephanus truncatus* (Horn) (Bostrichidae), is native to Central America, tropical South America, and the extreme south of the USA (CABI, 2018). LGB was first accidentally introduced into Tanzania, probably in the late 1970s and early 1981 (Dunstan and Magazini, 1981; Nwankwo *et. al.*, 2015) where it has become a serious pest of stored maize and dried cassava. Hodges and Tyler (2002) indicated that the establishment of *). truncatus* in Africa has highlighted the inherent weakness of phytosanitary measures against exotic pests. The initial introduction into Tanzania was believed to have been connected with the supply of seed maize that came from Mexico to refugees. The seed was allegedly not treated as dressed wheat seed supplied in a similar situation in Pakistan had been consumed by hungry refugees who had died as a result (Hodges and Tyler, 2002). The case for West Africa was different. In the early 1980s, there were good harvests in East Africa and maize was being procured in Kenya by the government body responsible for export. At the time, Kenya apparently did not have any recorded LGB infestations but as maize prices were lower in Tanzania, it is highly likely that there would have been cross border movement of stock to Kenya. Maize was shipped from Kenya to Togo and in 1984 the first infestation of LGB was observed in Togo in a village just outside Lome (Krall, 1984). The beetle has spread following these introductions to at least sixteen countries across East, West and southern Africa (Farrell, 2000; Ogemah, 2003). In mid 1990s it was reported to spread in 11 African countries (Hodges (1994) cited in CABI, 2018). The affected African countries reported to date include Tanzania, Kenya, Burundi, Malawi, Rwanda and Uganda in the East; Benin, Ghana, Guinea, Guinea Bissau, Burkina Faso, Nigeria, Niger and Senegal in the West, and Zambia, Namibia, S. Africa, Mozambique and Zimbabwe in the southern part of Africa; and is almost certainly present but unreported from several other countries in the continent (CABI, 2018). In Ethiopia, it was not recorded until 2008 (Abraham *et. al.*, 2008). However, later reports showed that it was first occurred at Moyale Plant Quarantine Station (EIAR, 2009; Abraham, 2011; Abraham *et. al.*, 2012). However, its occurrence in Ethiopia is not yet officially reported. But APHLIS (2017) reported unconfirmed incidence of LGB infestation in Gambella in 2014 and 2015. Results of subsequent confirmation surveys, review on the economic importance and different control options available as well as the way forward for Ethiopia are discussed in this paper.

The status of LGB in Ethiopia

Despite its occurrence in neighboring Kenya since 1983, it was not known in Ethiopia prior to 2008 (Abraham *et al*, 2008). Later it was learnt that the Plant Quarantine Station at Moyale reported that adults suspected to be LGB were caught in pheromone traps at the station on the 16 April 2008 and thereafter. Trap deployment was initiated following observation of a severe damage symptom on a dry wood ladder placed outside the office building. Then a team of staff from the Ambo Plant Protection Research Center of the EIAR and the Department of Animal and Plant Health and Quarantine of the then MoANR went to the area in order to confirm the reported pest which was later identified to be the larger grain borer at the International Institute of Tropical Agriculture (IITA), Biological Control Center for Africa in Benin in October 2008 (Abebe and Hiwot, 2009). This was necessary because there are other similar bostrichids namely lesser grain borer (*4hy%opertha dominica*) and bamboo post powder (*:inoderus* spp.) associated with stored produce which can confuse identification for inexperienced person. Lesser grain borer is an established pest of stored produce in Ethiopia; while the presence of *:inoderus* spp. has been reported. According to the team, limited observations and samples of maize in the field and in private stores in Moyale town, stores of farmers in the vicinity of Moyale (and all the way from Moyale till Arsi Negele), as well as seeds of a few tree species at the quarantine station did not show any insect similar to the one caught in the traps at the quarantine station. The uncontrolled entrance of grain from Kenya during the time the insects were trapped was suspected to be a possible cause of introduction of the pest into the country (Abebe and Hiwot, 2009).

Following this information a survey was conducted in the vicinity of Moyale (Moyale Plant Quarantine Station, Tuqa, Mudhi-Ambo, Argenie, Medo, Bekolla and Dembi kebeles) between 16 and 22 March 2011 to determine the status and distribution of the pest in Moyale area (Abraham, 2011). These kebeles are maize growing kebeles in the woreda in good years of rainfall. Concerned officials, key informants and farmers in the area were interviewed; farmers' stores and stores of grain traders in the area, and grain being sold in the open market during the time of visit were examined. Newly trapped beetles were examined under a binocular microscope of the quarantine station to compare with the reference spacemen of). truncatus available in the laboratory of the quarantine station at Moyale.

According to the person in charge of the Moyale Plant Quarantine Station, who worked in the station for over 10 years, the first damage symptom was observed on a dry wood ladder whose rungs or steps were made from Eucalyptus citriodora (lemon-scented gum; shitto %af) placed at the back of the office building abating on the office wall. The rungs or steps were damaged by the beetles but the stringers or stiles (vertical members of the ladder) were a different species of Eucalyptus and were not attacked. Then a pheromone trap was placed near the ladder caught the first batch of beetles on 16 April 2008 (8 Miazia 2000 E.C). Ten beetles on the first day and 21 beetles a week later were recorded (Bullo Taba pers. comm.). Later some beetles were also observed on the pheromone capsules kept in the office refrigerator with a poorly closing door. The envelope containing pheromone capsules were open from one side allowing release of the pheromone through the ill-fitting door of the refrigerator.

In Tuqa kebele, the store of a grain traders named Didha Gonute was found with an old pheromone trap (without the pheromone capsule) that was hung from the ceiling of the store in early 1997 E.C (2004/5) (the Plant Quarantine person at Moyale had mentioned about the traps that came from Melkassa Research Center in 1997 and 1998 E. C. and failed to catch any insect at the time). A few moths and other beetles were found stuck in the trap but there was no). truncatus among these insects during the survey. Moreover, none of the farmers, grain traders and maize grain samples observed in all of the kebeles surveyed indicated the presence of any new insect pest in general.

The source of the beetles caught in the pheromone traps at the quarantine station is not clear. There was no maize stored around the station. However, the station is surrounded by trees of different species and it appears that these trees could be the source of the beetle. Reports indicate that the larger grain borer lives on felled and or dried wood. Ramirez-Martinez et al. (1994) found branches of certain tree species cut down were colonized by). truncatus in the tropical deciduous forest of the Pacific Coast of México. He indicated that no). truncatus were observed in either maize fields or rural storage houses of the region, while the pheromone traps in the forest were capturing). truncatus. Hence, populations of). truncatus are considered to be utilizing the natural vegetation as possible dissemination points for colonizing neighboring agricultural fields as food sources to which they were suited by chance (Ramirez-Martinez et al., 1994). It seems that these insects might have arrived from the neighboring Kenya by flight. This is in line with Hodges et al. (1996) cited in Hodges and Tyler, 2002) who reported that the pest is capable of spreading itself by flight, although movement through the grain trade seems to be a considerably faster method.

It was learned from the key informants that maize was not formally imported from Kenya. But because of the porous border informal imports could not be ruled out. It was observed that movements of people and things were free, although there are check points at the border for commodities. The informants also mentioned that some three or four years ago there was a serious shortage of maize in the area and maize was coming from Kenya. Hence, it appears to be possible that those years when maize was said to be imported could be the time when). truncatus might have been introduced in the area. In any case, it seems that the pest was introduced sometime after 1998 E.C (2005/6) (when pheromone traps were set and failed to catch the beetles for the last time) and obviously sometime before 2008 and remained undetected until a considerable population density had been reached. The absence of the pest in other areas may also suggest that the population is not high enough for detection, and also due to lack of adequate host crop (especially maize) in the area during the time of the survey (Abraham, 2011). Reports indicate that except when populations are very high it is not possible to detect the pest by visual inspection (www. infonet-biovision.org).

In 2012, the Plant Health and Regulatory Directorate of the MoANR deployed a total of 84 pheromone traps between February and June 2012 in different kebeles of Moyale woreda of Somali region, in Moyale and Miyo woredas of Oromia region, and in Burji, Hammer and Konso woredas of SNNPR. The pest was reported to be recorded in Arbele, Dembi and Mudi Ambo kebeles of Moyale woreda of Oromia region; in Chamuke and Moyale Zuria kebeles in Moyale woreda of Somali region; and in Walia, Oto Molo and Kilicho kebeles of Burji woreda in SNNPR. High number LGB was reported from traps in Arbele kebele (19) and in all of the three kebeles of Burji woreda (a total of 198 beetles). Traps in Miyo, Konso and Hammer woredas did not catch any LGB. However, it was reported that some of the traps were lost and the general follow-up by the regional offices was reported to be poor. Burji is not very near to Moyale but it was reported that people from this place are said to visit Kenya frequently (Hiwot Lemma pers. comm.) who might have carried LGB infested maize with them.

According to Kemal Ali (pers. comm.), surveys were conducted between 2015 and 2017 in Moyale and Burji areas, and samples of dried cobs from the field and maize grain from different stores were collected and kept in sealed jars in the laboratory at the Holetta Agricultural Research Center until adult beetles emerged. It was reported that from about 150 grain samples collected from 14 kebeles of three woredas (Burji, Borena (Finchawa) and Moyale Zuria) in 2016 only one beetle was recorded in the sample obtained from Dinbicho kebele of Burji and one from Mokanisa kebele of Borena (Finchawa) woreda. All other samples collected did not reveal any LGB.

A sensitization workshop was organized by MoANR and EIAR at Bule Hora (Hageremariam) on 29-30 June 2015 where officials, agricultural experts, researchers, DAs and farmers participated in the workshop which discussed on the problem and options for its management. The numbers of participants were 14 from Oromia, 12 from Somali, 12 from SNNPR, 4 from plant health clinics, 4 from MoANR, 3 from Yabello, Jinka and EIAR Research Centers. About 2500 posters and 5000 brochures on the pest identification and management were provided to participants for distribution in their respective regions (HARC, 2015). While searching for information on the issue for this paper, a concerned staff of MoANR responsible for this tusk was reached through a cell phone on 25 January 2018 and it was learnt that nothing was done after the abovementioned workshop but there is a planned sensitization workshop to be organized by MoANR and EIAR for concerned people (officials, experts, researchers and farmers) from the three regions (Oromia, Somali and SNNPR) and metal silo fabricators and PICS bag suppliers between 2-6 February 2018 at Konso. The purpose of the training is awareness creation, implementation of demonstration of storage containers at FTCs and to create linkage between farmers and suppliers of storage containers (Awraris Asfaw pers. comm.). In a latter conversion it was learnt that the workshop was implemented as planned and a total of 49 people (two women) from the three regions have participated (Awraris Asfaw pers. comm.).

3. Host crops, damage caused and weight losses reported

LGB is of primary concern in dried maize and cassava, although it has also been observed to attack wheat, sorghum, rice, dried sweet potato, yam, groundnuts, beans, cowpea, cacao beans, coffee beans (Shires, 1977). It attacks maize before harvest and continues to infest during storage. CABI (2018) indicated that attempts to rear the species on cowpea, haricot beans, cocoa, coffee beans and rough rice in the laboratory have been unsuccessful, although development is possible on soft wheat varieties, and adult feeding may damage these other commodities (Shires, 1977). It attacks even wooden utensils and storage structures. Several authors indicated that extensive populations of). truncatus occur in the natural environment, and it has been recorded from a number of tree species in Central America and Africa (CABI, 2018).

The beetle bores into the central core of the cob or through the outer sheath in order to reach the grains. Shelled maize is less attractive to the beetle but grains which are densely compressed, for example, within a bag stack, will support infestation. Cassava is attacked in the form of dried whole roots or chips. Maize and cassava flours may contain). truncatus but it is unable to breed in these foods. The pest can survive for a long periods in wooden bins and cobs and stalks of maize. Regarding damage symptoms, adult). truncatus produce neat round holes where they eat into the maize grains. They tunnel from grain to grain producing large quantitiesof maize dust. Damaged grains can be identified as they are usually covered by a layer of this dust.). truncatus cause direct damage by feeding on stored grain and damage grain through physical deterioration by encouraging fungi development, thus reducing grain quality. Peter et al. (1991) indicated that in extreme cases 70-80% of farm-stored maize grains may be damaged and the maize rendered totally unfit for human consumption. Losses in cassava are comparable (Peter et. al., 1991). A detailed review of the damage and loss caused by). truncatus has been published by Boxall (2002). He considers loss of value, nutrition as well as impact at the national level and effect on international trade. The Larger Grain Borer poses an increasing threat to the official maize trade. In the early days after the arrival of). truncatus in East Africa, countries with the pest found their maize exports banned. For example, in 1987-1988, it is estimated that Tanzania lost US$ 634,000 in export earnings; although this situation improved following efforts to upgrade phytosanitary procedures in the region but such procedures, involving fumigation, have their own continuing costs (Boxall, 2002).

Infestations in maize may start on the mature crop in the field, i.e. when moisture content is at or below 18%. Weight losses of up to 40% have been recorded in Nicaragua from maize cobs stored on the farm for six months (Giles and Leon 1975, cited in Osipitan et al., 2015). In Tanzania, up to 34% losses have been observed after three months storage on the farm (Hodges et al., 1983, cited in Abraham et al., 2012).). truncatus is a much more damaging pest when compared to other storage insects including ,itophilus ory%ae, ,. %eamais and ,itotroga cerealella, under similar conditions.

Losses caused by). *truncatus* in dried cassava roots can be very high; the dried roots are readily reduced to dust by boring adults and a loss of 70% has been recorded after only four months of farm storage (Hodges *et al*., 1985, cited in Abraham *et al*. 2012). In general, LGB infests granaries of subsistence farmers and in sub-Saharan Africa the losses result much more than that caused by other storage pests. Subsistence farmers rely on their stored maize as food until next harvest. The depredation of LGB results in farmers having to purchase maize, or those farmers with more extensive stock will have no maize to sell. The pest is thus a threat to food security and to the livelihoods of poor people.

Control methods of LGB

A detail review of chemical, physical and cultural control of LGB is reported by Golob *et al*. (2002). The phytosanitary measures that should be taken against LGB in international trade have been reviewed by Tyler and Hodges (2002). Abraham *et al*. (2012) reviewed details of different control options recommended by different authors. In this review brief summary of those and details of those which were not included and recent reports on different management methods recommended are presented as follows.

Cultural control

The severity of an). *truncatus* infestation can be reduced by good store hygiene: cleaning the store between harvests, removing andburning infested residues, immersing grain sacks in boiling water and removing wood from stores or fumigating the store toeliminate residual infestations and the selection of only uninfested material for storage. Harvesting the maize as soon as possibleafter it has reached maturity will reduce the chances of attack by). *truncatus* and other storage pests. Shelling and drying maize until a moisture content of below 13% is achieved for long-term storage is recommended.

The removal of adult insects from the grain by sieving can reduce populations but this is very labor-intensive. The addition of inertdusts such as ash and clay to the grain can reduce insect numbers by causing the insects to die from desiccation. Insect control using diatomaceous earth is similar to the traditional methods used in parts of Africa where sand or ash is used to limit insects. However, field and laboratory studies have shown that unless inner dusts are applied at very high rates, they are not particularly effective on LGB. Diatomaceous earth is a viable alternative means of stored grain.

However, good control can be achieved when they are mixed with insecticides or soil bacteria metabolites such as Spindeba (Stathers (2003), cited in CABI, 2018)

Botanical control

Niber (1995) tested oils from neem, castor and slurries from *<issampelos owariensis* (root and leaf), neem kernel, neem leaf and *<hromolaena odorata* leaf against *). truncatus* on stored loose maize grain for three months. Neem oil at 1.5-2 ml/100 g maize kept weight loss < 16%, compared with 70% in untreated controls. Slurries from neem kernel seed were the best protectants, especially at concentration of up to 5% (w/w). Similarly, Ogemah (2003) evaluated different neem products and suggested that neem oil may be utilized in combination with other pest management practices, in an integrated control strategy against *). truncatus*. A study by Aidoo *et al*. (2009) assessed the biological activity of neem oil and NeemAzal on adult and immature stages of *). truncatus* as well as on its F_1 progeny in stored maize in the laboratory. Repellency and persistency effects of the treatments in grain to the insect, as well as the effect of the treatments on grain damage, were also determined. NeemAzal was more toxic to *). truncatus* than neem oil. The highest dosage of 0.8 ml/ 200 g grain killed 100% adult *). truncatus* after 72 h exposure but the same dosage of neem oil resulted in 70% mortality after 96 h. The products also caused significant (p<0.05) mortality in *). truncatus* eggs and larvae. NeemAzal provided greater protection of maize grains with no noticeable boreholes on grains treated with 0.6 and 0.8 ml/ 200 g grain. All treatments repelled less than 50% *). truncatus* adults. Activity of the two products significantly (p<0.05) declined in treated grain after 24 h of storage following treatment. NeemAzal offered greater protection against both the immature stages and adults of *). truncatus* in stored maize. A recent study by Ogemah (2012) indicated that neem oil is effective in controlling early stages of *). truncatus* while NeemAzal® is more effective in controlling the adults. It can therefore be concluded that the effect of the neem products used in this study on the pest depended more on the formulation than on the content or dosage of azadirachtin used. The results of this study will help refocus research on the control of *). truncatus* towards design of appropriate formulations of neem products, which will make them useful in the management of the pest by small scale, resource poor farmers in Africa. Moreover, Osipitan *et al*. (2008) studied the efficacy of extracts of seven tropical plants at reducing post-harvest losses caused by *). truncatus* to maize grains in the laboratory and in a crib; and found that extracts of *+%adirachta indica* and *0icotiana ta"acum* have great potential for post-harvest preservation of stored maize against infestation by *). truncatus*. Mukanga (2010) evaluated dried leaf powders of eucalyptus, guava, neem, Tephrosia (a flowering weed) and water hyacinth for their insecticidal activity against). truncatus in 8am"ia; and suggested that these materials tested have the potential in development of post-harvest protection technology against,). truncatus, the major pest of stored maize and dried cassava.

Use of resistant varieties

Varietal resistance plays a significant role in pest management. The use of resistant cultivars can reduce the severity of an infestation. Unfortunately traits that contribute to improved grain storage have been largely ignored by breeders until recently. An integrated approach to control). truncatus had been proposed to reduce the use of pesticides (Hodges, 1994, cited in CABI, 2018). However, host plant resistance was practically missing in this integrated approach because the traditional landraces and modern maize varieties/hybrids have not been evaluated systematically for resistance to). truncatus although biochemical studies have indicated phenolics in the grains to be correlated with the resistance against). truncatus (Arnason et. al., 1992). However, since recently, relatively better attention is being given to varietal resistance to post-harvest pests in general.

Harish Kumar (2002) reported that maize from the germplasm bank of CIMMYT showed resistance to). truncatus as evidenced by the low amount of powder formed 140 days after infestation. These ears showed a high level of resistance as indicated by a low powder production relative to the susceptible control. The). truncatus reproduction was adversely affected on resistant ears as indicated by the small size of adult populations. Thus, antibiosis could be the mechanism of resistance operating within the progenies of selected land races. Such sources of resistance can be very useful in developing maize populations/hybrids for use in IPM of). truncatus. Similarly, Tadele et al (2011a) from their studies on maize varieties concluded that host plant resistance can be used as a vital component of an integratedpest management strategy against). truncatus and ,. %eamais. According to Mwololo (2013), mechanisms of resistance to the maize weevil and larger grain borer aresimilar. As such breeding for resistance to both pests is possible within a breeding programme. The results obtained in this study are helpful in understanding the genetic basis of resistance to the maize weevil, management options for the). truncatus andfor fine mapping of QTL. There is potential for development of genotypes with dualresistance to the maize weevil and). truncatus. InNigeria, Nwankwo et al. (2015) evaluated eight varieties from IITA and two from localmarket and found that the maize varieties differed in their chemical and physical parameters andtheir responses to). truncatus attack were significantly different ($P < 0.05$). In Kenya, Ndiso et al. (2017) screened 25 land races and 5 improved checks for resistance to maize weevil and larger grain borer in a laboratory at Kenya Agricultural Research Institute (KARI), and found that there was variability for resistance to maize weevil and). truncatus in storage among Kenyan local coastal maize landraces. Landraces with superior responses to storage pests were identified, and it was recommended that these may be used directly or as sources of resistance in various insect resistance breeding program objectives in coastal Kenya. In Zimbabwe, Nilton (2013) evaluated selected maize varieties for susceptibility to larger grain borer and concluded that resistant varieties could be part of integrated management of). truncatus. Regarding cassava, Osipitan et al. (2015) evaluated 15 cassava varieties for resistance to). truncatus and concluded that the genetic variation in cassava varieties could be explored to breed resistant cassava varieties for use in larger grain borer-endemic areas.

Biological control

The use of synthetic insecticide has been faced with challenges of resistance among other drawbacks. This has necessitated the search for bio-pesticide that is environmentally friendly, non-toxic to humans and has no residual effect. Following investigations into the efficacy and specificity of predator *eretrius nigrescens (Lewis) (Coleoptera: Histeridae) in its region of origin, and in laboratory tests in the Federal Republic of Germany, this beneficial organism was exported to Africa. There, further tests were carried out under quarantine conditions, before it was released with the approval of national and international agencies. All the tests had demonstrated that, under controlled conditions, the predator is capable of significantly reducing the pest populations. The first release took place in 1991 in Togo, followed by Kenya, Benin, Ghana and Guinea to prevent the destructive outbreak of the pest in small-farm maize stores. The predator is highly host-specific, as it is lured by a pheromone of). truncatus when in search of its prey. Consequently, it poses no threat to beneficial species. Neither does it cause stored-food losses. In view of the positive properties of the predator as an antagonist of). truncatus, its release is recommended to those countries of Africa where). truncatus occurs (GTZ, n. d). Rechter et al. (1998) carried out follow up storage trials after the first release of the predator in 1991 in Togo in order to investigate effects on). truncatus in maize stores; and found that the number of). truncatus was reduced by 56.4% in stores with presence of *. nigrescens as compared to the control after eight months of storage in 1990/91. Damage and losses of stored maize cobs were 40.7% and 47.4% smaller than without the predator. Other workers also indicated that it has reduced the problem in some areas; although Holst and Meikle (2003) reported lack of control in Benin and Ghana. Some studies from W. Africa suggest that the predator can successful suppress). truncatus populations in maize stores, while in others the predator was unable to sufficiently control). truncatus densities. The predator is most likely incapable of controlling the pest once prey densities have surpassed a certain threshold. Some workers indicated that the predator is not likely to be successful mainly due to the predator's intra-specific density-dependence and its low population growth rate compared with its prey. Moreover, the predator seems to have less impact under drier conditions. Therefore, biological control of the). truncatus using the predator needs to be accompanied by compatible intervention techniques within the framework of integrated pest management (IPM). However, where pesticides are used on stored maize, the predator will have no effect because it is even more susceptible to these compounds than the pest itself (Golob et al., 1990, cited in Giles et al., 1996). According to Markham et al. (1994) cited in Giles et al., 1996), the predator is likely to be most beneficial in reducing pest populations breeding in natural environments outside of maize stores, in that case, the biological control will be completely integrated and compatible with chemical control being practiced within farmers' stores (Giles et al., 1996). To mass-rear the predator prior to release for the control of LGB, the production of large number of LGB as prey is required. This could raise the fear of the consequences of their accidental escape from the rearing facilities (if the area is uninfested with the pest). The use of alternative prey species such as lesser grain borer (4.dominica) may alleviate these fears as suggested by Rees (1991) cited in Giles et al., 1996).

Regarding other natural enemies, Helbig (1999) reported that the bug Jylocoris flavipes, a predator on a wide range of post-harvest pests, was the only one observed regularly and in higher numbers. Laboratory trials with). truncatus showed that the larvae were preyed on, and no preference for any one of the three instars was detected. In glass jar trials on loose maize J. flavipes reduced the numbers of). truncatus by 57.6% after 8 weeks. The losses and damage were reduced by 50 and 17.6%, respectively. Observations in traditional maize stores indicated a tendency to decreasing populations of J. flavipes when populations of). truncatus increased, presumably due to the unfavourable environmental conditions created by the pest. Therefore, it is concluded that J. flavipes does not play an important role in the control of this pest.

Regarding parasitoids, +nisopteromalus calandrae and *heocolax elegans were observed regularly and in higher numbers in traditional stores. In Tanzania, large numbers of +nisopteromalus calandrae were found to be associated with). truncatus when few other potential hosts were present (Hodges, 1983, cited in CABI, 2018). Helbig (1998) studied the relationship of +. calandrae and *. elegans with). truncatus in Togo, and reported that in stores the correlation coefficients for population densities of both parasitoids and). truncatus were mainly negative and very close to zero, but positive and greater in value for the parasitoids and ,itophilus %eamais. In glass jar trials on loose maize +. calandrae reduced numbers of). truncatus by 70.1% in the single species culture after 8 weeks, whereas *. elegans had no impact. In double species culture +. calandrae had an effect on both populations;). truncatus was reduced by 61.3% and ,. %eamais by 22.5%. *. elegans only had an influence on ,. %eamais.

In a survey of the pest in Kenya, (Odour et al., (2000), cited in CABI, 2018) found that the entomopathogenic fungus =eauveria "assiana occurred at a low infection rate on).

truncatus. The potential of =eauveria has been investigated in field trials designed to give a better understanding of how future research efforts can develop methods to make this fungus an effective means of control for). truncatus (Meikle et al., 2001 cited by CABI, 2018). Kassa et al. (2002) assessed the efficacy of 13 isolates of entomopathogenic fungi belonging to =eauveria, /etarhi%ium or)aecilomyces spp. from Ethiopia against ,. %eamais and). truncatus in the laboratory.). truncatus proved more susceptible to the entomopathogenic fungi tested than ,. %eamais. The results revealed the higher potency of /. anisopliae compared with the =. "assiana isolates tested; although a total immersion bioassay was used so this result might have been anticipated. The study suggests that the use of entomopathogenic fungi may hold promise as an alternative method to control pests of stored-products in Ethiopia. Recently, Popoolaet al. (2015) evaluated the entomopathogenic fungi, =. "assiana for biological control of). truncatus in maize grains, and reported that 86% of the dead insects from treated maize grains showed fungal growth of =. "assiana. Mortality of). truncatus generally increased with the concentration and the exposure time of the treatments. The weight of grain dust, percentage of grain damaged and percentage of grain weight loss were significantly ($p < 0.05$) higher in the untreated maize kernels. =. "assiana formulation was effective in controlling). truncatus and is recommended for maize storage. The researchers also suggested that further studies should be conducted to test the formulation under farmer situations in order to deal with practical challenges. In Ghana, Nboyine et al. (2015) assessed the compatibility of two bio-control agents (*. nigrescens and =. "assiana isolate) for management of). truncatus, and found that the upper dose of =. "assiana not only resulted in the highest grain weight compared with the control but also highest mortality of). truncatus. The lower does provided high grain weight compared with the control. Moreover, =. "assiana product killed *. nigrescens but its mortality was less than fourfold that of). truncatus in maize treated with the upper dose of =. "assiana product. In maize treated with the lower dose of =. "assiana product, *. nigrescens mortality was less than eightfold that of). truncatus. Thus, the lower dose of the =. "assiana product can be used in storage systems where *. nigrescens is already established. Mwathi (2006) demonstrated the potential of discovering isolates of =. thuringiensis that are toxic to adult). truncatus and could be, therefore, developed as biopesticides. Preservation of these isolates in a germplasm bank for pathogen biodiversity should be considered since these pathogens could be utilized as sources of new cry genes for genetic transformation.

Controlled atmosphere

Low oxygen and carbon dioxide-enriched atmospheres can be used to control stored product pests. Egas Nhamucho et al. (2017) indicated that metal silos demonstrated the best efficacy over other storage methods (super grain bag, inside polypropylene bags, etc), if adopted could reduce the negative impact of). truncatus and other storage pests that cause post-harvest losses among small-scale. A metal silo is a cylindrical structure, constructed from a galvanized iron sheet and hermetically sealed, killing any insect pests that may be present. According to Tefera et al. (2011) metal silo can be fabricated in different sizes, 100 kg–3000 kg holding capacity by trained local artisans, with the corresponding prices of $35 to $375. The use of metal silo, therefore, should be encouraged in order to prevent storage losses and enhance food security in developing countries. Gitonga et al. (2015) indicated that the use of metal silos prevented damage by larger grain borer and maize weevil for 98% and 94% of adopters, respectively. This study finds evidence that metal silo technology is effective against main maize storage pests and its adoption can significantly improve food security in rural households. It was concluded that metal silos are effective in reducing grain losses due to maize-storage insects, and that they have a large impact on the welfare and food security of farm households. The initial cost of metal silos is high and therefore policies to increase access to credit, to reduce the cost of sheet metal, and to promote collective action can improve their uptake by smallholder farmers (Gitonga et al., 2015).

Chemical control

It is also a widely accepted fact that insecticides will continue to play an important role in suppressing severe insect populations and minimizing storage losses, provided they are properly used and integrated in pest management system. Synthetic pyrethroid insecticides such as permethrin and deltamethrin which can beapplied as a dilute dust insecticide control). truncatus very effectively. However,these insecticides are not so effective against other storage pests such as grain weevils (,itophilus spp.) and flour beetles(*ri"olium spp.), which are often found together. These species are more susceptible toorganophosphorus insecticides. Hence, both types of insecticides can be applied in order to control the whole complex. Combinations suchas pirimiphos-methyl and permethrin (Actellic Super), deltamethrin and pirimiphos-methyl or fenitrothion and fenvalerate or fenitrothion and deltamethrin (Shumba Supper) have been usedsuccessfully to protect farm-stored grain. Farmers are advised to mix insecticide with shelled grain and use residual sprays in stores. Fumigation with phosphine is effective in large-scale stores. Nwankwo et al. (2015) reported that results obtained from the treatment of susceptible varieties of maize with the pyrethroid demonstrate the attractive potentials of bifenthrin and deltamethrin against the larger grain borer. When using a pesticide, always wear protective clothing and follow the instructions on the product label, such as dosage, timing of application, etc. After treating with dusts and before consumption, grain must be washed to remove pesticide dust particles and then dried before processing.

Integrated pest management (IPM)

The conflict between the goals of reduced pesticide usage and production of sufficient food and fiber for the ever increasing human populations provides a strong impetus for the development of cost-effective and ecologically friendly alternatives which are major components of integrated pest management (IPM). Integrated pest management (IPM) attempts to integrate available pest control methods to achieve economical and sustainable combination for a particular local situation. Often, emphasis is placed on the use of resistant host varieties, biological control, cultural methods and other non-polluting methods. In IPM, chemical pesticides are used only when necessary, especially when they can be integrated with other control methods.

Conclusions

). truncatus is an important introduced pest in about 20 African countries, including Ethiopia. Its occurrence in Ethiopia was known in early 2008 from an infested wooden ladder and a pheromone trap catches at the Moyale Plant Quarantine Station. The most probable source of the beetles appears to be different tree species surrounding the quarantine station because surveys conducted in the vicinity did not show any sign of its presence, although detection at low population density is said to be difficult. But the possibility of introduction through cross border movement of maize from Kenya cannot be ruled out. In whichever case it seems that the pest came much earlier than its first appearance on the ladder at the quarantine station in 2008. Reports indicate that except when populations are very high it is not possible to detect the pest by visual inspection; it also does not respond to traps until the population is dense enough. Reports show that small populations already present feeding on maize/cassava in a store cannot be detected by pheromone traps because the pest does not react to the pheromone until dispersing from its food source. Only when the population has increased to an extent whereby the infestation is obvious and the beetles are starting to disperse will the traps catch beetles (www.infonet-biovison.org). Hence, it must have already been established at least in the vicinity of the quarantine station well before the time it was detected. However, nothing has been done to address the problem until 2015 when a survey was conducted by EIAR and MoANR staff to assess its occurrence in some areas; which reported the presence of the pest in pheromone traps and grain samples obtained from Moyale, Somali and Burji woredas in three regions (Oromia, Somali and SNNPR). Consequently, the current status of the pest distribution in the country is not known. It is regrettable that no significant action has been taken to date on such a serious issue that has been reported about 10 years ago. There are numerous potential management options (cultural, varietal resistance, biological, chemical, etc) as reviewed in this and in Abraham *et al.* (2012) that can be tested and adopted to minimize its spread to other parts of the country to challenge the production and export of maize. The following recommendations are suggested as a way forward.

The way forward

- The number of devastating alien pests infesting different crops in this county are many; on maize alone MLND (maize lethal necrotic disease) from diseases, American armyworm (*,podoptera frugiperda*) from field insect pests and LGB in the store, not to mention invasive weeds, are challenging the agricultural sector in general and maize production and storage in particular. Why these pests are coming and getting out of hand? One may think of different answers such as globalization, climate change, etc. Of course these and other factors could contribute to the problem, but the primary reason appears to be the weakening of the plant protection discipline in general. This sector was undermined by all (policy makers, higher learning and research institutions as well as development organizations), especially since the time of the so called business process re-engineering which gave more emphasis to the production aspect disregarding the protection aspect. The discipline of crop protection was in a better position at one time. The dissolution of the department of crop protection and its merger with other disciplines severely weakened the plant protect research (Abraham *et al.*, 2008). Therefore, the first thing to be considered for sustainable solution to pest problems in general should be to revive and strengthen the plant protection sector as a whole.
- When it comes to the post-harvest sector, the problem is even more serious. This sector of agriculture has been ignored by research since long time ago. When the Institute of Agricultural Research (IAR) was established to coordinate agricultural research in the country in 1966, the special problems associated with post-harvest losses were left to be the concern of the then Plant Protection and Regulatory Division of the MoA, though limited studies on storage pests were made in staggering manner by some higher learning institutions since early 1960s (Abraham *et al.*, 2008). Since late 1980s some graduate students took the problem of post-harvest pest management as their thesis research topics and later some continued to work in the sector, but these were not organized and coordinated. Hence, it is mandatory that this sector should be organized and

strengthened at all levels in human and facilities to address the huge losses occurring in the post-harvest system in this country.

- This time there is some awareness that post-harvest problems exist, but more emphasis and policy support is needed to strengthening the education, research and development programs in the area of post-harvest.
- It was recommended long before the introduction of LGB in Ethiopia that post-harvest pests should be regularly monitored and the situation of quarantine pests such as LGB should be continually updated, enforcing serious control of materials moving within the country and from abroad (Abraham et al., 2008); however, this has not been done and now, a few years later, LGB is already in Ethiopia. Still continuous monitoring of LGB and creation of public awareness at all levels is crucial. Methods for detecting and monitoring of LGB are crucial components in phyto-sanitary control, research programmes and pest management against this beetle. This beetle is unusual in that its populations are distributed widely between natural habitats and stores holding maize grain and dried cassava roots, which necessitates a similarly wide range of sampling methodologies.
- All concerned stakeholders – education, research and the extension service, grain traders, and farmers should work together to fight this pest.
- Grain traders and farmers should be educated how to scout for the pest and take actions to limit their losses.
- It is mandatory that IPM should be the strategy Ethiopia should follow both in the field and in the post-harvest pest management approach, hence, research on suitable component measures and specifically on their integration is indispensible.
- At country level an overall contingency plan for LGB control and containment, and providing the necessary inputs is necessary.
- Adoption of stringent specifications for the purchase and movement of potentially-infested grain by the government, grain traders and food aid donors and tightening regulations on the requirement for phytosanitary certificates and for grain fumigation to prevent the spread of LGB to other countries is crucial.
- Since these bostrichids are also present in wood-packing materials, more careful and detail quarantine inspections on the imported woods and wooden products are needed.
- Challenges hindering the uptake of modern storage and control approaches such as the high cost of metal silos require policy intervention to increase access to credit, to reduce the cost of sheet metal, and to promote collective action can improve their uptake by smallholder farmers.

- Coordination of nationwide LGB activities involving participation of all stakeholders into appropriate technical measures is important.
- It is also important to establish a network among African countries to work together and share information and skills; this would also allow countries to prepare for the arrival of alien species, and to draw up plans to reduce their impact.

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White Mango Scale in Ethiopia: The Problem, Management Options andInterventions

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Abstract

/ango is one of the most important fruit crops grown "y smallholder farmers as well as "y private and state owned farms in Ethiopia. /ango plays an important role in poverty reduction "y contri"uting to food security and "y "eing a source of income to small holder farmers. #t is an important source of vitamins and minerals and thus contri"utes to "alanced nutrition for healthy citi%ens. #t also generates foreign currency to the country through export markets. #n addition to the economic "enefits, mango is an important shade tree and contri"utes to climate change mitigation. *he production of mango has recently "een threatened "y an economically important emerging insect pest. *his pest is the white mango scale insect. *he 6uantity and the 6uality of mangos produced under stress from this insect pest have dramatically fallen due to the damage incurred "y the pest. #n addition to this, the pest is spreading throughout the country in an alarming speed. *he yield loss incurred "y the pest is so high that if an efficient and effective integrated management package is not developed, mango production in Ethiopia can "e devastated within a short period of time. *o date, there are no integrated management packages availa"le for strict containment and control of the pest. *herefore, there is an urgent need for an integrated pest management technology package that should "e developed "y scientific research that com"ines local and international knowledge. *he history and introduction of the pest to Ethiopia, its distri"ution, and the conse6uences of poor 6uarantine, management options, and the lessons learned and interventions so far made to tackle the pro"lem are discussed.

-ey words> /ango white scale, #)/, 6uarantine, distri"ution, interventions

Introduction

Mango, *Mangifera indica* L, is one of the most important tropical and sub tropical fruit crops which belong to the Anacardiaceae family (Banerjee, 2011). It is an evergreen fruit crop native to Southern Asia and is grown in over 85 countries in the world (Takele, 2014). It is usually referred to as the king of fruits based on its nutritive values, contributions to human health, taste, odor and the extent of cultivation and trade linked to it (Banerjee, 2011; Takele, 2014). Mango contains high amount of sugar, fats, protein, salts and almost all vitamins (Nabil *et al*., 2012). It is consumed in various forms in addition to fresh fruits. Other uses of mango include animal feed, poultry diet and ethnopharmacology (Nwinuka *et al*., 2008; Kayode and Sani, 2008).

In Ethiopia as well, mango is one of the most important fruit crops grown by smallholder farmers as well as by private and state owned farms both for home consumption and income generation. It is widely grown in 8 regional states of the country *viz*. Oromia, SNNP, Benshangul-Gumz, Amhara, Tigray, Gambella, Harari and Somali with estimated total cultivated area of 15373.04 ha owned by some 1,754,294 holders and annual production of104,980.78 tons (CSA, 2018). Its area coverage and production has increased progressively in the last decade by 208% and 247 % respectively (CSA, 2014). Among the fruit crops, it ranks second in production, preceded only by banana (CSA, 2012). Mango plays an important role in agricultural diversification, food security, nutrition, rural and urban livelihood, agro-industry and contributes to the economic development in Ethiopia.

However, a recently introduced new pest is currently threatening mango production in Ethiopia. The pest which is called mango white scale insect, *Aulacaspis tubercularis* (Homoptera: Diaspididae), was first reported in east Wellega zone in August, 2010 at a private farm called Green Focus Ethiopia Ltd. (Mohamed *et al*., 2012). It has been spreading fast ever since then to almost all mango producing regions in the country and causing high losses on mango production and threatening the emerging fruit production and processing industry. Several surveys (Temesgen, 2014; Gashawbeza *et* al., 2015) have confirmed its spread to different parts of the country. The insect attacks the mango plant at all the growth stages from seedling to maturity

and leaves, twigs and fruits are attacked and die back is observed (Ofgaa et al., 2016). It covers about 33% of the mango canopy when severe (Mohamed et al., 2012) and thus deprives the plant of active photosynthetic leaf area by causing yellowing and blackening of the leaves. It also causes pink blemishes and yellowing of mature and ripe fruits rendering them unfit for both local and international markets. The scales of the insect are blown by wind and cause nuisance and allergic reactions to farmers (Belay, Personal observation).The white mango scale is known to lower productivity in mangos (Blackburn, 1984; Miller, 1990).It has caused serious damages to mango production in many countries (SRA, 2006; Germain et al., 2010; Abo-Shanab, 2012) and become an important mango pest in Africa, North America, South America and the Caribbean Islands (El-Metwally et al., 2011; Nabil et al., 2012). Once fertilization takes place, the white mango scale crawlers hatch out and attach to the plant part to suck the plant saps (Louw et al., 2008; Goble et al., 2012). Leaves, twigs and fruits of mango are affected by the insect. It causes defoliation, poor blossoming, decreased fruit bearing, reduce juice and can cause death of the whole plant if infestation occurs at seedling stage (Abo-Shanab, 2012).

Distribution of the white mango scale

The white mango scale is a tropical insect which probably originated in Asia and has been distributed to the rest of the world developing adaptations to a wide range of climatic conditions (Borchsenius, 1966; Ben-Dov et al., 2006). The crawlers of the newly hatched mango scale are very easily carried away by wind and can infest mango trees in un-infested areas. Its spread is mainly owing to uncontrolled transportation of infested plant materials including fruits, leaves and twigs. For instance, it was introduced to the USA (Florida) and Australia through importation of fruits from India. The same happened to the UK through importation of mangoes from Pakistan (DEFRA, 2008).

According to the pests distribution map of CABI which is published online, *+. tu"ercularis* occurs in several countries of west Africa and several Sub-Saharan African countries (http://www.plantwise.org/ Knowledge Bank/Datasheet.aspx). It has been reported in Egypt Abo-Shanab (2012), South Africa (Joubert *et al.*, 2000); Kenya (www.freshfromflorida.com), Pakistan and Australia (Khan *et al.*, 2016a, b; Pena *et al.*, 1997). It also occurs in North America, South America and the Caribbean Islands (El-Metwally *et al.*, 2011; Nabil *et al.*, 2012).

The first published record of the white mango scale in Ethiopia indicates that the pest was first observed in 2010 in East Wollega Zone of Oromia region in Green focus Ethiopia private farm at loko locality in Guto Gida district (Mohammed *et al.*, 2011). Currently the WMS is distributed throughout the country except Harar and Arbaminch areas (Teshale *et al.*, Unpublished data).

Taxonomy

The white mango scale, *+ulacaspis tu"ercularis* Newstead, belongs to the Order: Hemiptera the Suborder: Sternorrhyncha and the Diaspididae family (CABI website: https://www.cabi.org/isc/datasheet/7988).

Biology: Studies conducted in Australia have indicated that females can lay 80-200 eggs depending on temperature with their life cycle varying from 35-40 days during summer and 70-85 days during winter (managing mango scale: https://www.google.com/url

Morphology: The female body is elongated, its anterior part wider than the rest of the body. The dorsal macro-ducts are two-barred, arranged in transverse rows. The large median lobes are divergent, joined at their bases (“zygotic”) whereas the second and third pairs are smaller. The perivulvar pores occur in five clusters on either side of the anus. The white female shield is rounded, with the dark, dorsal juvenile exuvium at one end; the elongated male shield is also whitish, its exuvium at its apex.

Population dynamics: In Egypt the pest has 3-4 annual, partially overlapping population peaks, in spring, summer, autumn and winter. The pest is more abundant on lower, south-facing aspects of trees, and its crawlers are probably dispersed by wind currents.

In Ethiopia, population dynamics studies have been conducted on the WMS in the western parts of the country at Arjo and Bako (Ofgaa *et al.*, 2018). According to this study peak white mango scale crawler populations are observed at Arjo and Bako in April and May respectively, although population buildup starts in February in both locations. The study also indicated that WMS populations is highly affected by drought/rainfall as the population has been observed to remain extremely low during periods of less than 10mm of average monthly rainfall in the studied areas. The study has also indicated that WMS requires minimum rainfall of 50mm to initiate population buildup while excessive rainfall may negatively affect the population of the scales.

Another study conducted at Uke (Loko Raj Agro-industry former Green focus) private farm, Deddessa Valley and Bako Agricultural Research Center showed that WMS life stage populations reach a peak in April (Deddessa and Uke farms) and in May at Bako Agricultural Research Center (Teshale *et al.*, unpublished data).

Host range: According to CABI Plant-wise knowledge bank records, the species affected by the white mango scale include; *<arica papaya* (pawpaw), *<innamomum*

verum(cinnamon),Citrus, <ocos nucifera (coconut), Cucurbita (pumpkin), Dimocarpus, 'aurus no"ilis (sweet bay), Litsea, /angifera indica (mango),)ersea americana (avocado),)ittosporum undulatum (Australian cheesewood), 8ingi"er officinale (ginger).

Economic importance: The WMS is a significant pest of mangoes in South Africa, Egypt, Australia, East and West Africa, South America, the South Pacific region and the Caribbean Islands (Williams and Watson 1988;Colyn and Schaffer, 1993). The export potential and commercial value of the fruits injured by the scale is highly affected. The economic importance of the WMS in Ethiopia has not as yet been studied in a formal way. However a number of observations and reports from mango growers have confirmed that it can devastate mangoes when it occurs in severe conditions decreasing the yield drastically. As evidence, the contract agreement entered between mango producing small holder groups/cooperatives in West wellega zone and Etfruit enterprise was immediately cancelled due to high infestation of the fruits by the white mango scale causing production and marketing processes to be disrupted in west Wellega zone due to heavy infestation of the mango trees and fruits with the white mango scale insect (Tesfaye et al., 2014).

Literature from other countries indicate that the WMS can cause considerable loss. In a study conducted in Uganda, farmers have indicated that the WMS can be up to 60% severe and cause up to 50% yield loss (Acem et al., 2016). The feeding site of the scale exhibits conspicuous pink blemishes causing cosmetic damage and rendering the fruits unmarketable particularly to export markets.

Symptoms and impact: Symptoms of mango scale infestation can easily be identified on leaves, fruits, stems and twigs. Infested fruits exhibit discoloration ranging from black or brown to pink blemishes, the scales are observed feeding on fruits and lesions can be seen on severely infested fruits. Leaves show abnormal coloration initially becoming pale-greenyellow and gradually die turning black. The scales are seen feeding on the leaves usually covering the leaves with white scales. Scales can also be observed feeding on stems, roots and twigs of seedlings and heavily infested mature trees (Ofgaa and Emana, 2015). Fewer blossoms are observed as infested young twigs dry up. Late maturing cultivars suffer from most of the damage while seedling in the nursery may show retarded growth.

Growth can be retarded in nurseries if the infestation is severe and at early stage of the mangoes. Hot dry weather aggravates the vulnerability of young trees causing excessive leaf loss and death of twigs infested with the scale.

Management options: Control measures taken against the white mango scale include use of chemical insecticides, growth regulators, use of mineral oils, cultural practices, quarantine measures, host plant resistance and biological control using parasitoids and predators (Daneel and Joubert, 2009; Abo-Shanab, 2012; Gashawbeza et al., 2015).

Biological control: Theuse of living natural enemies such as predators, parasites, pathogens, competitors and parasitoids to suppress activities or abundances of pests has been used in biological control of pests with parasitoids being the most important in insect control (Mills and Wajnberg, 2008). Importation, augmentation and conservation are three broad categories of the use of parasitoids in biological control. Many species have been introduced to new areas by humans where they did not naturally occur. Introduced species may be well established and may even become invasive, causing economic and ecological damage. The absence of natural enemies in the new area (Enemy Release Hypothesis; ERH) is one of the most popular explanations which determine the success of non-native species although there may be many other factors. Importation ore classical biological control which involves importation of the natural enemies of the invasive pest from the country or regions of its origin is the most attractive of the three categories (Mills 2000; Hoddle, 2004). Classical biological control of insect pests was first used in 1886 in California, USA, against the cottony cushion scale insect (#cerya purchasi) using the vedalia beetle (4odalia cardinalis) imported from

Australia(Caltagirone & Doutt 1989). Ever since then, biologists and ecologists have been using biological control as an effective and safe strategy of managing invasive insect pests (Murdoch et al., 2003).Classical biological control programs are considered especially well-suited to certain types of systems. Because the goal is to establish natural enemies permanently in a new environment where they will persist, this strategy has been applied more successfully to more permanent ecosystems, such as forests, natural areas, orchards, and perennial crops.

In the case of the white mango scale, parasitoids and predators have been reported as its potential biocontrol agents. For instance, according to Labuschagne and Pasques (1994), the parasitoid +phytis mytilaspidis, was imported from Taiwan and released in mango orchards in South Africa after mass-rearing. Similarly, Schoeman (1987) reported on mass rearing and release of the coccinellid predator <hilocorus nigrita in mango orchards as a biological control agent against +. tu"ercularis and other scale insects, in South Africa.

Viljoen, (1986) reported the abundant presence of introduced coccinellid predators 4hy%o"ius lophanthae Blaisdell and <hilocorus nigrita (Fabricius) (Coleoptera› Coccinellidae)
in South Africa, although it was indicated that they were generally not sufficient in themselves to keep scale insect populations below economically damaging levels. Introduction of parasitoids such as the ectoparasitoid +phytis chionaspis Ren. (Hymenoptera: Aphelinidae) to mango producing areas in South Africa showed promising results to control the pest biologically (Daneel and Joubert, 2009).

In Egypt, natural enemies (Parasitoids (+phytis mytilaspidis (Le Baron) and Encarsia citrine (Craw) (Hymenoptera: Aphelinidae)), and predators (<hilocorus "ipustulatus (L.) and ,cymnus syriacus Marseul (Coleoptera: Coccinellidae)) were recorded on mango

orchards. However their impact on the white mango scale was not well studied(Abo-Shanab, 2012).

Perhaps the most recent success story in biological control of the white mango scale is the use of the parasitoid +phytis chionaspis Ren. in South Africa. The ecto-parasitoid was imported to South Africa in 1995 from Thailand, mass reared in insectaries on mango scale infested butternuts and released in different commercial and private mango orchards. The parasitoid established well in the release areas with up to 81% percentage parasitism observed in some areas (Daneel and Joubert, 2009). Most interestingly, the parasitoid was recorded in many of the release areas as well as where it was not released 10 years after the release with up to 77% parasitism indicating the establishment and dispersal of the parasitoid.

Another parasitoid, Encarsia citrina Craw, an endo-parasitoid was recorded in South Africa as the only parasitoid prior to the introduction of the ecto-parasitoid +. chionaspis but its numbers were low and effective control was not achieved until the introduction of the later (Labuschagne et al.1995; Daneel and Joubert, 2009). There are other natural enemies of the white mango scale documented in some parts of the world although their specificity and efficacy has not been well studied. Table 1 shows some of the natural enemies recorded.

Table 1: natural enemies of the white mango scale, +ulacaspis tu"ercularis Newstead

Natural enemy	Type	Life stages	Used for Biological control in (Country)	Biological control on
+leurodothrips fasciapennis	Predator	Adults/Eggs/Larvae		
+phytis	Parasite	Adults/Larvae		
+phytis hispanicus	Parasite			
+phytis lingnanensis	Parasite	Adults/Nymphs	India; Tamil Nadu; Karnataka	mangoes
+phytis mytilaspidis	Parasite	Adults/Larvae		
+rrhenophagus chionaspidis	Parasite		India	mangoes
<hilocorus nigrita	Predator	Adults/Eggs/Larvae		
<y"ocephalus "inotatus	Predator		South Africa	
Encarsia citrina	Parasite	Adults/Larvae		
Encarsia fasciata	Parasite			
)haroscymnus horni	Predator	Adults/Nymphs		
)teroptrix koe"elei	Parasite	Adults/Nymphs	India	mangoes
4hy%o"ius lophanthae	Predator	Adults/Eggs/Larvae/Nymphs/Pupae	South Africa	mangoes

Natural enemy	Type	Life stages	Used for Biological control in (Country)	Biological control on
4hy%o"ius pulchellus	Predator	Adults/Eggs/Larvae/Nymphs		
,ukunahikona prapawan	Predator	Adults/Eggs/Larvae/Nymphs		

Source: CABI; invasive species compendium, 2018

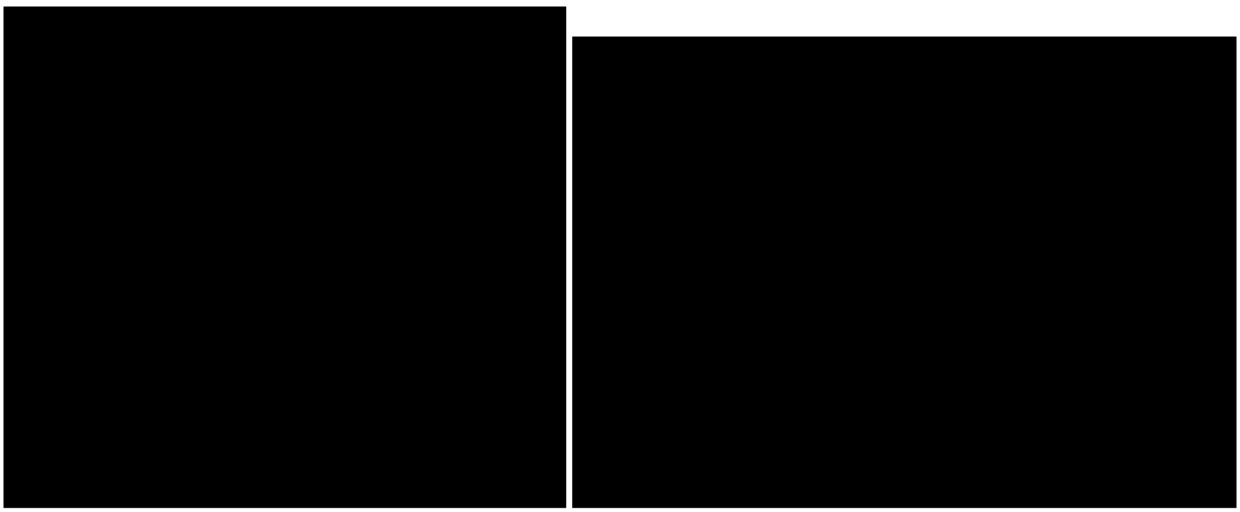

Figure1. Mango fruits severly infested by the white mango scale insect pest (Photo: belay Habtegebriel)

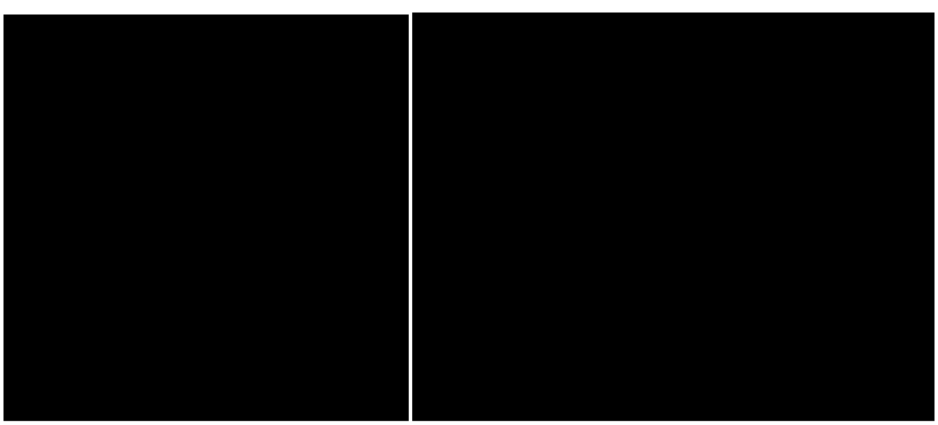

Figure 2. Mango leaves severly infested by the white mango scale insect pest (Photo: Belay Habtegebriel)

Cultural control: Canopy management is an important component of IPM of WMS. Regular pruning helps the introduction of light into the mango canopy and kills the WMS scales hiding in the shadiest part of the canopy. Post-harvest pruning is an effective control measure and also helps the penetration of sunlight and chemical sprays through the tree canopy (Cunningham, 1989).

Lopping, the cutting down of branches, twigs including the main trunk, is usually done to correct the size of big trees to a manageable size. Big old trees, besides being difficult to spraying, pruning and harvesting, harbor pests such as diseases and particularly scales. Lopping is a big procedure and has to well planned ahead of time and preparation should be made to compensate for the loss of harvest during the period it takes the mango trees to start producing fruits which may be three to four years.

Top working, adding grafts of other varieties to the top of a pruned back tree, is an important component of tree management helpful in replacing old big mango trees with improved varieties to manageable sized ones. However, it requires expertise and has to be done in a planned manner.

Chemical control: Chemical control of the white mango scale can be done by using either foliar sprays, soil drenching or tree injection methods. Both systemic and contact insecticides from various chemical classes are used. The type of insecticide used for control of white mango scale depends on the insecticide type registered for the purpose in the particular country. For example in California, USA, white mango scale management is done by integrating natural enemies (predators), petroleum oil, and some organophosphate insecticides such as malathion, and methidathion. (Mossler and Nesheim). In principle, the sole use of chemical insecticides is not advocated and it should be integrated with other control tactics preferably in an IPM scheme. In Ethiopia, Thiametoxam 250 WG is an officially registered neo-nicotinoid pesticide to be used as a soil drenching at 6g/tree. Several other insecticides are currently being tested for registration and the list of chemical insecticides is expected to grow. Experiments conducted in the Rift valley of Ethiopia showed that Spirotetramat resulted in lower number of WMS counts after five sprays indicating the efficacy of the insecticide against the pest (Gashawbeza et al., 2015). It is important to note that WMS prefers the shadiest parts of the mango tree canopy and pesticide application should target to treat young stages (crawlers) in these parts of the canopy.

Figure 3. Some Attempts of chemical control of the white mango scale

Use of Growth regulators: Insect growth regulators (IGR) are also used in some orchards for the control of mango white scale.Labuschagne et al., (1992) described the use of two insect-growth regulators and found them to be as effective as the currently used pesticides, but with greater potential for integrated control due to their specificity. The chitin biosynthesis inhibitor insect growth regulator, Buprofezin, which is absorbed by contact and ingestion, is well known for its efficacy on homopteran insect pest in Australia. It acts by suppressing the hormone in insects that regulates chitin biosynthesis process and is used for the control of the white mango scale in the country. (www.Hortsolutions.com.au). However, this product is not registered so far in Ethiopia.

Use of mineral oils: Mineral oils are used as a component of an IPM program usually as post harvest sprays. Abo-shanab (2012) tested three mineral oils with different purity percentages (Super Masrona oil® 95%, CAPL2 oil® 96.62% and Diver oil® 97%) and found that all resulted in reduction of the white mango scale infestation by up to 100% indicating the importance of using mineral oils against the pest. Petroleum oil is currently under trial in western Ethiopia by researchers from Ambo Plant Protection Research Center and preliminary data indicate promising results but the experiments need to be repeated overtime and location. If appropriately applied to all infested parts of the mango canopy, 1% petroleum oil can give adequate control. But the spray has to be timed so that it can coincide with recently hatched crawler stages of the pest appearing on the upper surfaces of mango leaves.

Use of white oil: For small scale mango orchards or for mangoes growing in homesteads of farmers, use of homemade white oil is an important control measure. It is especially recommended in the Ethiopian context where most of the mangoes grow around homes where animals, poultry and children sit under the tree canopy to avoid the heat. White oil is prepared from three ingredients: liquid dish washing soap, ordinary edible oil and water. Two hundred fifty milliliters of ordinary edible oil is mixed with 65ml of liquid dish washing soap and thoroughly shaken. A white milky suspension is observed and this is the stock solution. About 5-10 ml of this suspension is added in to each liter of water and sprayed on white mango scale infested trees. Trials conducted in Asosa area (Afasizim locality) by the Ambo Plant Protection Research Center Researchers under farmers' orchard conditions using white oil with other treatments has shown promising results (Ahmed Alamin personal communication).

Quarantine: According to Dawd et al., 2012, the white mango scale was introduced to Ethiopia because of poor quarantine facilities and lack of follow up of introduced planting materials (Mango seedlings) by a private company. Plant quarantine is an important system and an essential component of integrated pest management. A well established quarantine system helps prevent the entry of new pests to a country where they did not exist previously. The white mango scale has so far been reported in many parts of the country except in the eastern parts of the country such as Dire Dawa and Harer and in the Arbaminch area. To these areas, the WMS must be regarded as a quarantine pest. It is also important that the pest be regarded as a quarantine pest in any nursery where mango seedlings are raised. The quarantine system in the country needs special attention to protect Ethiopia's bio-diversity from invasive pests.

Host Plant Resistance: In Puerto Rico, Gallardo Covas (1993) found differences in susceptibility to mango scale in mango cultivars. The most heavily infested cultivar tested was Haden and the least heavily infested was Palmer.

Asked to rank the susceptibility of the mango varieties grown in a private farm at Uke, the owners of the farm put the Alfanso variety (the variety with which the white mango scale was introduced to Ethiopia) as the 1st and most susceptible one. Other varieties vi%. Kent, Tommy Atkins, Dodo, Apple and Keit were ranked from 2nd to 6th indicating that there may be varietal susceptibility differences. Although this is just a personal communication, the author has observed the seemingly resistance differences on the farm. However, this needs to be supported and proved by systematic research. In addition to this, the susceptibility or resistance of the locally grown unknown varieties widely grown in Ethiopia is not known.

Integrated Pest Management: Use of synthetic chemical pesticides as a sole tactic against the WMS is not a wise choice as the pesticides may devastate its natural enemies, cause environmental hazards and human health problems. For example, pesticide application in mango orchards resulted in high mortality of endemic parasitoids in South Africa (Labuschagne and Pasques, 1994). In addition to these, delivering foliar pesticides to big mango trees is problematic. Thus mango producers at all levels in Ethiopia are desperately looking for a control package to this devastating insect pest problem. So far, no specific integrated pest management (IPM) recommendations based on scientific research have been made available to the farming community to alleviate the mango white scale insect pest problem.

Interventions: There have been some attempts of controlling the WMS which mostly tried to use chemical methods (Gashawbeza, 2015). A project was formulated to develop an IPM package against the pest and obtained funds from the Ministry of Science and Technology of Ethiopia. This project aims at developing integrated pest management technology package for the pest. It envisages the use of up to date and standard research methods to deliver an ecologically friendly and economically feasible IPM technology package to manage the mango white scale and enhance mango production in Ethiopia. It is also processing the importation of natural enemies (parasitoids) from abroad. The project has attempted to train farmers and create awareness on the means of managing the pest in the western parts of Ethiopia. A leaflet of the white mango scale was also published by the project in collaboration with the Ambo Plant Protection Research Center. In addition to these efforts, some chemical insecticides are being verified for registration and use in the country by the Ethiopian Institute of Agricultural Research at different centers. Studies on the search for native natural enemies (Teshale *et al.*, unpublished ata), distribution (Temesgen, 2014, Tsegaye *et al.*, 2017) and population dynamics (Ofgaa *et al.*, 2018) of the WMS conducted by different institutions can also be regarded as contributions to tackle down the problem.

Conclusion and Recommendations

Mango is one of the most important fruit crops grown by smallholder farmers as well as by private and state owned farms both for home consumption and income generation in 8 regional states of the country *viz.* Oromia, SNNP, Benshangul-Gumz, Amhara, Tigray, Gambella, Harari and Somali. It plays an important role in agricultural diversification, food security, nutrition, rural and urban livelihood, agro-industry and contributes to the economic development in Ethiopia.However the introduction of the white mango scale since 2010 and its rapid spread to almost all regions of the country has created an impasse to its production, productivity and to its economic contributions.

Managing and controlling the pest requires concerted efforts. The major actors in this regard are the Ministry of Agriculture, Ministry of Science and Technology, Universities and Federal as well as Regional Agricultural Research Institutions. Recommendations on the integrated management of the pest need to be made based on the consolidated research results from all the concerned institutions. Importation of natural enemies from abroad, identification and augmentation or conservation of native natural enemies will be the ultimate solution to the sustainable management of this pest problem. Thus efforts must be geared into this direction. Strengthening the quarantine system in the country is generally issue of the time to protect Ethiopia's reach bio-diversity.

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Broomrapes (I ro"anche and)helipanche spp.) **in Ethiopia: Problems and Management-** ***A review***

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Abstract

=roomrapes (I ro"anche and)helipanche spp.) are root holoparasitic weed plants devoid of chlorophyll and entirely depending on the host plants for their growth re6uirements. *hey considera"ly infect plant species of)apilionaceae, ,olanaceae and +steraceae families, especially in the highly infested drier and warmer areas of this world. *he I. crenata attacks seriously fa"a "ean (5icia fa"a '.) while I. cernua and). ramosa considered most important parasites on tomato ('ycopersicon esculentum / ill.) in those crops fre6uently cultivating parts of Ethiopia. *hey are serious with their devastating effect on the crops threatening the livelihood of the large scale and su"sistence farmers. *he attacked cropsL yield losses reach up to 1..O depending on the level of parasitic weeds infection which also depend on the level of infestation, host species suscepti"ility and environmental conditions. *he long$term impact of the =roomrapes is even more serious that their seeds easily spread and can persist in the soil up to 2. years. *his review gives overview information on pro"lems and interventions of the =roomrape species in their respective host$crops, discusses and summari%es scientifically proved useful methods and forward prospects for effective =roomrapes management in this country. @owever, the main concern is that up to date no single control method proved to "e effective, economical and complete in controlling them. ;or this reason, in order to sustaina"ly manage =roomrapes and "ust the respective crops productivity of the country, "esides narrowing the knowledge gaps more strengthened efforts in searching for host plant resistance "ased integrated approach considering the socio$economic and ecological conditions is suggested.

Keywords: =roomrapes, Ethiopia, management, I ro"anche, parasitic weeds,)helipanche

1. Introduction

Weeds areunwanted plants which interfere adversely with the utilization of ecological resources and affect human welfare. Above all parasitic weeds parasitize economically important plants and seriously threaten the livelihood of human beings. The parasitic weed plants attack other plants by making an organic connection with the conducting tissues of the host and drive their supplies. Restuccia et al. (2009) indicated that the parasitic flowering plants exploit other flowering plants for water, nutrient ions, metabolites and hormones with the help of one or more haustoria.

Parasitic weeds from Orobanchaceae, Convolvulaceae (Cuscutaceae), Loranthaceae and Viscaceae families grow on their host plants in many countries of the world (Joel, 2009; Heide-Jorgensen, 2011). The parasitic weed species of the genus Iro"anche and)helipanche that belong to the plant family Orobanchaceae are considered to be among the serious agricultural pests of economic importance in Mediterranean and subtropical countries.

The genus Iro"anche and)helipanchecommonly named as Broomrapes, indicating the great impact and damage done by these parasites to flowering crops. They have more than 150 species but only few of them are considered as economically significant (Lambrada, 2008; Joel, 2009; Parker, 2009; Heide-Jorgensen, 2011). The most serious species are Iro"anche crenata Forskal, I. cumana Wallr, I. cernua Loefl, I.foetida Poiret, I. minor Sm.,)helipanche ramosa (L.) Pomel (previously named as I. ramosa L.) and). aegyptiaca (Pers.) Pomel (formerly I. aegyptiaca Pers.) (Joel, 2009).

The Broomrapes are root holoparasits and mostly annuals, devoid of leaves and totally dependent on their hosts for most of their life cycle depleting them from the growth factors (Parker and Riches, 1993). They are major biotic limiting factors to the production of crops of the family Papilionaceae, Solanaceae and Asteraceae.

In Ethiopia, Iro"anche crenata on faba bean, and I. cernua and)helipanche ramosa on tomato are increasingly become economically important. The I. crenata, commonly called Crenate broomrape also widely named as Bean broomrape,causes the most widespread damage on pulse crops of the family Papilionaceae (Dahan and El-Mourid, 2004; Lambrada, 2008).Whereas the I. cernua and). ramosa, commonly called respectively Nodding broomrape and Branched broomrape, cause the most intensive damage on horticultural crops of the family Solanaceae and Asteraceae (Parker and Riches, 1993).

Many cultural and agronomic control methods have been tried to manage them in the respective crops (Besufekad et al., 1999; Etagegnehu et al., 2009; Teklay et al., 20013; Mekonnen, 2016). However, so far there is no economical and feasible means in controlling them. The aim of this paper is to give overview information on problems and interventions of the Broomrape species in their relevant host-crops, and future prospects for effective management in Ethiopia, by way of reviewing, discussing and summarizing research driven possible management options that are available in this world.

2. Biological and ecological features of Broomrapes

Broomrapes are aggressive in nature, tolerant to control measures and cause the most widespread damage to their host crops (Dahan and El-Mourid, 2004). Broomrapes are thermophilic parasitic plants that frequently require dry condition and light soils to be an invasive. Most of them are native to the Middle East and they occur mostly associated with the crops which they attack.

According to Mohamed et al. (2006), the scenario analyses of climatic changes taking form of increased temperatures and drought in many areas of the world, I ro"anche spp. could pose greater threats to agriculture. In addition, Parker (2013) indicated that where there is moisture stress and poor soils, there can be greater damage to the point of total crop failure due toBroomrapes.

A characteristic of Broomrapes is that they have no green parts, with only the leafless flowering stem visible above ground. They are short-lived parasitic plants growing on the roots of broadleaf host plants to obtain their growth requirements.Normal development of the parasite starts with seed germination that comes in response to the reception of a chemical stimulus from host roots following a period of conditioning that is required for the dormancy-germination transition (Zhou et al., 2004).

They spend most of their life cycle underground, where they undergo processes of conditioning, germination, haustorium differentiation from the radicle, haustorial penetration of the host, formation of vascular connection with the host, acquisition of host nutrients, and initiation and development of tubercles before emergence of the shoot and diagnosis of infection as the parasite (Fernandez-Aparicio et al., 2011).

The seedling must have contact with a host root immediately after germination to ensure its survival. The Broomrape seedling depends totally on its host for all nutrition and become an active sink comparable to an actively growing part of the host plant itself. Most damage from root parasites occurs before the parasite emerges, and only 10 to 30% of attached parasites emerge (Sauerborn, 1991). In the crop plants, this day Broomrapes have found well-nourished allowing the parasites to develop extremely well and set lots of seeds.

Broomrapes can set large number of tiny seeds which can also easily disseminated over long distances by various means and in most cases remain in the soil viable for prolonged years. It has been estimated that per a season a given Broomrape plant can bear up to half a million seeds which can persist in the soil up to 20 years (Gevezova et al., 2012). A single broomrape plant is therefore capable of heavily increase the seed bank in the soil and/or rapidly infest the new fields.

The very small seeds may very easily be moved from one field to other fields of parasite-free by flood or irrigation water, wind, animal and human. The important spreading agent is the irrigation water in irrigated fields. While in rain fed agricultural lands, the important spreading vector is the uncontrolled movement of grazing animals. The seeds remain viable after passing through the alimentary system of animals, as a result manure may be contaminated with viable Broomrape seeds. The hair and feet of animals also can adhere and transfer the seeds. Human being engaged farm equipment like plough, bag, cloth, machinery and agricultural products of various crops including seed and hay may carry the seeds if contaminated in an infested field.

Broomrapes cause the most widespread damage, and considered as the major constraint and also remained constant threat to the cultivation of important crops. Up on the attack on the host plants they cause severe and visible damage: wilting, plant height and development reduction, flower dropping on the host plant, severe yield losses, and poor seed quality (Habimana et al., 2014; Fernandez-Aparicio et al., 2016a). The earlier symptoms can be observed even before the emergence of Orobanche shoots. Moreover, the earlier and dense infection can kill host seedlings before maturity.

The host crops cultivation is strongly hampered by the occurrence of these weeds threatening the livelihood of so many peoples in this world. They cause very high levels of damage on the crops in terms of both yield and quality. Yield losses reach up to 100% depending on the level of infection which also depend on the extent of infestation, host species susceptibility and environmental conditions (Lambrada, 2008). Heavy infestation of the parasitic weeds does not only lead to a complete crop failure, but make the fields Broomrapes sick for many years.

Broomrape species type that infested a given field could vary based on the cultivated major host crops, the infection levels on the host crops in the infested fields vary from year to year, and even the on field response of Broomrapes to the implemented control measures found inconsistent over seasons. Though the possible reason for such inconsistence is yet unknown. However, Broomrapes species of concern in Ethiopian that have been raised as the threat in cultivating economically important crops are I. crenata, I. cernua and). ramosa.

To discriminate visually from other species, I.crenatahas unique morphological characteristics such as unbranched stem and dense inflorescence which is usually white with purple veins (Lambrada, 2008). Typical picture of the parasitic plant and infection on faba bean are shown in Figure 1 (FAO, 1993).

Moreover, I. cernua has unbranched but nodded stem and on shoot scattered more deeply blueinflorescence while). ramosahas branched stem and white to pale blue flowers at the base and blue distally. Pictures in Figure 2 show from left to right I.

cernua (Joel, 2009) and). ramosainfection ontomato (Etagenhehu and Suwanketnikom, 2004a).

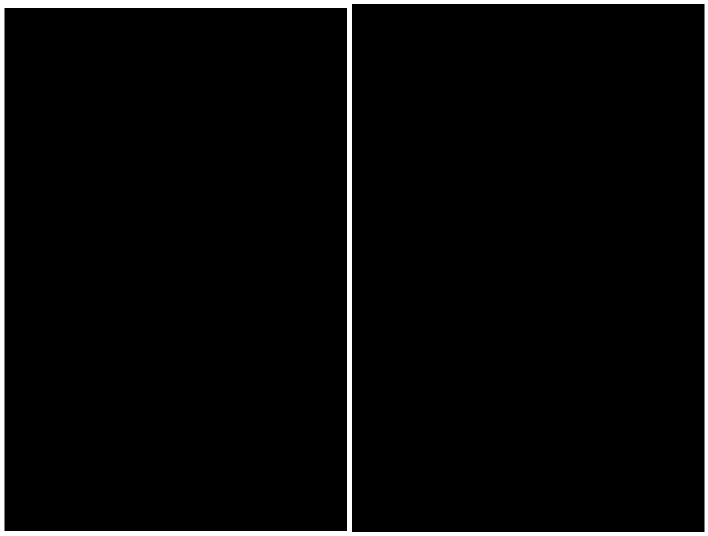

Figure 1 I. crenata plant (left) and infection on faba bean (right)

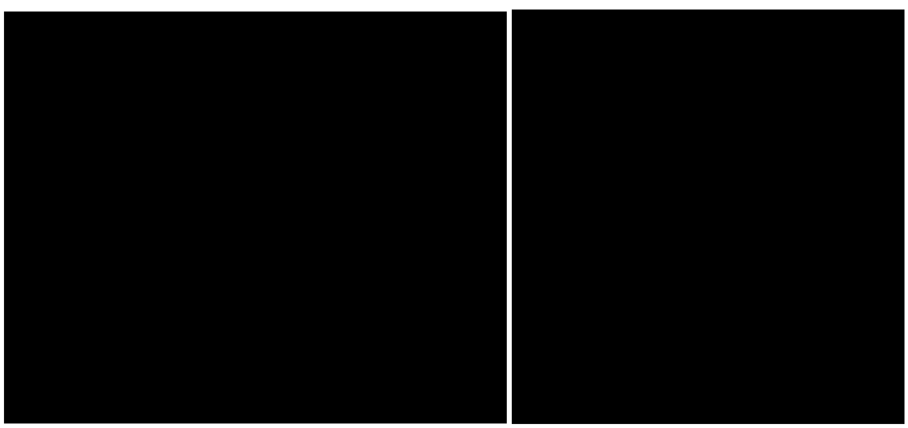

Figure 2 I. cernua (right) and). ramosa (left) infection on tomato

3. Problematic Broomrapes in Ethiopia

In Ethiopia, the Broomrape species that increasingly become actual and potential threat in cultivating economically important pulse and horticultural cropsare I. crenata, I. cernua and). ramosa. In addition, I. minor commonly named Clover broomrape also appears here and there sporadically on crop, ornamental and wild plants, although not reported as important crop pest in the country.

The I. crenata has been reported as pulse crops field invader parasitic weed since early 1990's (Asefa and Endale, 1994; Adugna et al., 1998). The problem of I. crenata on pulse crops mainly on faba bean (5icia fa"a L.), and also on field pea ()isum sativum L.), lentil ('ens culinaris Medik), chickpea (<icer arietinum) and vetch (5. sativa L.) is getting worse in northern part of the country (Besufekad et al., 1999; Rezene and Kedir, 2006; Teklay et al., 2013).

It is speculated that this detrimental weed introduced to the northern part of the country unknowingly with aid grains in 1970's (Besufekad et al., 1999). Initially Crenate broomrape was a lowland warm area problem but today it has become a problem of wide altitudes pulse growing areas. It is seriously threatening small-scale faba bean growers in South Tigray, South Gonder, and South and North Wello zones (HARC, 2001; Mekonnen, 2016).

The spread of this species in Amhara and Tigray National Regional States within few years of its discovery demonstrates that a joint program to contain, control and if possible eradicate this parasite found essential as suggested by several authors (Rezene 1998; Rezene and Kedir 2006). However, being no adequate effort has been made to implement the suggestions; the infestation of the weed has reached at the pick and causing considerable damage on susceptible crops of the regions. Many farmers already have been forced to abandon the growing of pulse crops and the weed free neighboring areas are also potentially under the threat.

The I. cernua and). ramosa are the most prevalent and devastating parasitic weeds in the central rift valley of Ethiopia (Abuelgasim, 1996; Etagegnehu, 2005). The problem of these weeds on solanaceous crops particularly on tomato ('ycopersicon esculentum Mill.) and also on tobacco (0icotiana ta"acum) and eggplant (,olanum melogena) is concentrated where the main vegetable crops are grown in the country.

No one indicated how these parasitic species actually entered the area. They were possibly introduced as contaminant of imported nursery or horticultural plants. Alarming mixed infestation of these parasitic weeds occurred since 1984 (Ahmed and

Mohammod, 1992).The infestation increased from time to time with an invasive nature due to dispersion of the seed via irrigation water, agricultural machinery and tools, movement of laborers and animals, and wind (Stroud and Parker, 1989).

They are threatening both the large-scale farms like Upper Awash Agro-Industry Enterprise and Ziway Horticultural Enterprise farms, and small-scale subsistence farms of the surrounding irrigated areas. Many suitable production fields forced to abandon the cultivation of the solanaceous crops. Besides the direct impact on the producers, the increasingly reduction in farm yields also challenging horticultural sectors like merchants involved on marketing and manufacturing factories like the Merti Processing Plant. These Broomrape species are also a great risk to the weed free broad leafed crops growing low laying irrigated areas along the Awash River basin.

At all intensification of cultivation of the host crops, moisture-deficit, poor soil fertility and lack of awareness on the nature of the parasitic weeds seem the main constraints aggravating impacts of the Broomrapes in Ethiopia. These limitations coupled with the ever increase in population pressure that fasten ecological degradation, and the world climate change are exacerbating the parasitic weeds infestation and impacts year after year.

The host crops cultivation is strongly hampered by the occurrence of these parasitic weeds threatening the economy and livelihood of so many peoples in Ethiopia. Yield losses reach up to 100% depending on the level of infection (Etagegnehu, 2005; Teklay et al., 2013). Besides, when affected by Orobanchethe straw of faba bean with the unique nutritive feed value completely unpalatable to animals due to high degree of parasitism inflicted on the crop plant. In highly infested areas, as a result of the complete devastation caused by the Broomrape plants in many areas of the country, farmers generally avoid growing the host crops resulting in substantial reductions in both cultivated areas and crop production.

The unrestricted continuous spread and dense occurrence of the weeds also have limited the traditional crop rotation practices hindering economic, nutritional and ecological benefits from the diversified cropping systems. Moreover, these parasitic weeds threaten the world export market potential of the country both as a result of reduced crop yield and contamination of the harvested products.

In addition, one should learn from others' experience that the serious infection on the specific host crops in the country today might extend to other related crops in the future as experienced in Mediterranean countries unless possible efforts undertaken to restrict the soil infestation. In general, the harmful condition of these parasitic weeds has considerable negative implication on the farm productivity and on the country's economic development at large.

4. Current farmers' effort in controlling Broomrapes in Ethiopia

Farmers do apply several kind of control measures against Broomrapes as of on other common weeds, but not found effective that the unique nature of the parasitic weeds is unknown to them. This is due to the fact that the weeds arenew introduction to the country mainly due to lack of preventive measures and also there is unclear option in restricting their spread.

Assefa Admasu (2008) reported that almost all farmers in Dessie-zuria district have no knowledge about the life cycle and management of I ro"anche that they only rely on hand pulling for its control in faba bean field. In large scale farms too the only available control option was hand pulling that incurred high cost and considerable mechanical damage on tomato plants (Etagegnehu, 2005).

As a solution, so far limited control methods have been developed through research and adopted, and only marginal successes have been achieved. There is few relatively ineffective control methods implemented in the country inconsistently in reducing the damage. Mekonnen (2016) indicated that farmers have been advised to practice crop rotation over long times and even later on advised to grow resistant cultivar provided by Alamata Agricultural Research Center in highly infested faba bean growing areas. The Broomrapes control efforts that have been widely adopted in the country include hand weeding, crop rotation and also lately to lesser extent growing of resistant faba bean cultivar using improved agronomic practices.

However, the control of these parasites is difficult using these methods because of the multiple reemergence of new flashes within few days and altogether uprooting of crop plants, requirement of several years crop rotation to reduce the parasite seed populations to non-damaging levels, and getting the resistant host plant to grow is at scares to reach most farmers of the country.

In addition, integrated program is practiced only on a small scale by few farmers because of cost and technical problems. Beside other reasons, lack of professionals for technology innovations and active extension staff for transferring available knowledge and information are seen as the main constraints.

5. Broomrapes management technologies

Investigation and experimental results driven available management techniques against Broomrapes in the country can be grouped and discussed under preventive, physical, cultural, agronomic, biological, and chemical control methods and other innovative integrated management systems.

5.1. Preventive:

The preventive measures advocated as effective in preventing Broomrapes are quarantine and phyto-sanitary measures.

i. Quarantine measure:

The prevention of seed distribution and containment of infested areas are the seriously requited practices in parasitic weed management strategies. Beside strict quarantine measures at various ranks- regional and national levels, creation of adequate knowhow among the farming communities helps in preventing the introduction in to the parasite-free areas.

ii. **Phyto-sanitary measure:**

The strength of the parasitic weeds lies in their ability to form a bank of seeds in the soil. Phyto-sanitary measure must aim at reducing this seed bank, while minimizing the production of new seeds and their dispersal to new sites. Though they are valuable measures if implemented consistently in an organized manner, almost they are yet not practiced in our country except by few award farmers.

5.2. Physical control

i. **Soil solarization:**

Mulching soil with polyethylene sheet for several weeks under solar irradiation physicallykills soil born pests including conventional, noxious and parasitic weed seeds in the upper soil layers. Study in tomato fields naturally infested with I. cernua and). ramosa showed that soil solarization using clear polyethylene sheet for two months reduced the parasitic weeds seeds in the soil by greater than 90% and increased considerably the crop yield (Giref et al., 2005).

Requirement for solar pasteurization or success include moist soil, high air temperature and solar radiation, and adequate length of exposure (Habimana et al., 2014). Thus, soil solarization using clear polyethylene sheets can disinfest the soil on seedbed and enable to produce clean seedlings for transplanting. This could also reduce infections after transplanting of the seedlings on infested fields. At 40 ºC in 20 days the parasitic weed seeds can be adequately killed.It is very useful in managing the parasitic weedsin vegetable crop field but tedious, time-consuming and costly.

Under irrigation systems, soil solarization with plastic sheets could be this date much interested measure to effectively reduce the weed infestation without harm on the farming system as has been confirmed in a number of studies elsewhere outside this country. Nevertheless, the adoption of such method is hampered mainly by drawbacks in the subsistence farming systems in tropical and subtropical areas.

ii. **Flooding:**

Flooding for an extended period can kill Broomrapes seed in the soil. This practice proved useful where host crops are planted after rice that the weed infestation drastically reduced in such rotation.

A good suppression of *I. cernua* was achieved by maintaining a continuous flood for about two months prior to draining and planting tomato (Ahmed and Mohammed, 1992). However, the authors suggested that factors influencing success like species, season, length of period, temperature and soil type deserves future detailed study. Though the method seems promising on irrigated fields, it seems no progressive research works done and decisive result achieved regarding this aspect in the country.

5.3. Cultural control

i. Hand weeding:

Hand pulling flowering shoots of Broomrapesis the main control method if the weed found sparsely, and there are adequate human labour and time to do so. In addition, combined with other methods it can also serve to clear the removal even in highly infested areas.This is the only available technique and commonly practiced among small scale farming communities of developing countries like Ethiopia. It is not likely to show any yield increase in the short term but play significant role in reducing soil seed bank (FAO, 2008).

However, Broomrapesstem need to be pulled frequently as possible at late flowering stage but before seed shading. The collected shoots also need to be immediately discarded from fields because they can continue developing flowers and spreading seeds.

ii. Manureapplication:

Broomrapesdense infections tend to be associated with less fertile soil conditions (Trabelsi et al., 2017). However, high levels of composted manure or nitrogen fertilizer showed a suppressive effect (FAO, 2008). A pot study indicated that goat manure at 20 t/ha found effective in reducing). ramosa parasitism and enhancing growth of tomato plants (Etagegnehu and Suwanketnikom, 2004a; Etagegnehu, 2005).

Pre-plant composting fresh manure causes I ro"anche seeds to lose viability within six weeks, and reduces I. ramosa infestation on many vegetables. Fermenting manure in the farm can be easily practiced by subsistent farmer without much input and can aid sustainable farming strategy. There are conflicting ideas among farmers concerning the impact of soil fertility improvement using manure on the parasitic weeds that needs to be reasoned out scientifically. This practice could be a useful asset in high value crops. So, it needs to be realized by farmers on the great value of manure application in improving soil fertility and composting in disinfecting the manure.

5.4. Agronomical

i. Fertilization:

Trabelsi et al. (2017) confirmed that both N and P deficiencies enhanced exudation of strigolactones, the most potent germination-inducing factors for the parasites, in studied I. crenata resistant and susceptible faba bean genotypes.

However, a pot study indicated that Urea (NH_2CONH_2), ammonium nitrate (NH_4NO_3) and ammonium sulfate $(NH_4)_2SO_4$at 207 kg N/ha found effective in reducing). ramosa parasitism and enhancing growth of tomato plants (Etagegnehu and Suwanketnikom, 2004a; Etagegnehu, 2005). In most cases, as nitrogen rates increased the number and dry weight of the weed plant shoots decreased and the yield of tomato increased linearly except for the yield obtained from the highest rates of NH_4NO_3 and $(NH_4)_2SO_4$.

In addition to the toxic effects on Broomrapes seed and seedling, fertilization can protect crop from parasitism by means of down-regulating crop synthesis and exudation of strigolactones (Fernandez-Aparicioet al., 2016b). On the other hand, with an increase in nitrogenous fertilizer application, the extent of broomrape infection on host crops can be decreased. However, in some cases, good crop yield increases have been recorded but in others the crop has been damaged that needs to maintain the correct balance between N and P.

ii. Irrigation:

Under dry conditions, parasitic development with respect to the crop is favored. However, under irrigation in the dry months, high temperature and moisture can induce Broomrapes'seed degradation (Etagegnehu, 2005).

iii. Rotation with trap- and catch- crops:

Trap crops promote seed germination but do not support parasitism. Girma et al. (2005) reported that maize and snap bean as trap crops showed better performance in stimulating germination of Broomrapes seed and raised the germination by 74 and 71%, respectively (Table 1). The trap crops also complementing each other under inter-cropping and soil seed bank of). ramosa and I. cernua depleted by 72.5% per season. In the third season of the study period, yield of tomato significantly increased due to the reduction of the weedsseed bank. Even the rest tested trap crops role on the weed species that is reduction by greater than 60% per season can't be ignored where they are more suitable to be included in the rotation as also reported somewhere else outside this country.

While the catch crops promote seed germination and support parasitism, theyare destroyed prior to the parasitic weeds flowering to reduce the Broomrape seed bank in the soil. Catch crops are usually used either for green pod, forage or green manure before emergence of the parasitic weeds to reduce the seed stock by more than 30% e.g. *rifolium alexandrinum and =rassica campestris.

The crop rotation, in addition to increase in host plant yield, decreases the Iro"anche incidence and seed production. However, it takes several years of trap or catch cropping to reduce the parasite seed populations to non-damaging levels, due to the long life-span of the parasitic seed. At this point knowledge of the host range, germination induction, attachment and tubercle formation are essential in management of the parasitic seed and seedling. It need to understand clearly that germination of parasitic plant seed is stimulated by active root exudates produced by susceptible as well as some non-susceptible plants.

Knowledge of the host range of the differentparasitic plant species is vital for the implementation of the concept of avoidance by practicing growing of the only non-host crops. In addition, growing selected varieties with high inductor potential for suicidal germination of *I. crenata* in rotations introduced in infested soils could also shorten the time required between host crops (Rubiales and Fernandez-Aparicio, 2012).

Table 1. Effects of trap crops on Broomrapesandtomato yield at different locations (after Girma *et al.*, 2005)

Trap crop	Reduction of Broomrapeshoots (%)	Shoot count/plot at different locations			Mean shoot count/plot	Tomato yield (t/ha)
		Melkassa	Ziway	Merti		
Fenugreek	63	87	89	92	89	61
Linseed	67	78	80	84	81	67
Alfalfa	70	76	69	75	73	74
Cotton	66	77	84	86	82	66
Garlic	69	75	74	76	75	71
Onion	70	87	73	59	73	75
Pepper	67	88	79	75	81	66
Snap bean	71	66	76	70	71	78
Maize	74	60	62	63	62	85
Sesame	64	90	79	88	86	62
Tomato	-	145	235	215	198	42
LSD (0.05)		21*	20*	16*	26*	25*
CV (%)		10	14	11	12	17

*=Significant

5.5.Host plant resistance

Plant species not parasitized by a parasitic plant under natural conditions are considered non-hosts, resulting avoidance of parasitism. Whereas, plants capable of supporting parasitic growth to maturity are considered as hosts, and within host species the level of resistance to parasitism can vary (Westwood et al., 2010).

Genetic resistance leads the fight against the root parasitic weeds, but without unequivocal success. There has been little success in finding resistance to most parasitic weeds. Never the less, there are some good successes in developing resistant cultivars against Broomrapes.

In central rift valley of Ethiopia, tomato varieties evaluated for). ramosa resistance in pots revealed that various levels of resistance demonstrated in certain varieties; LE 244, South Africa, CLN 2123 A, Melkashola, Riogrande, Seedathip, LE 180 A, and Cherry with lesser yield losses estimated at 37-45% and number of parasite shoots per plant as of 7-11 (Etagegnehu and Suwanketnikom, 2004b). However, no report on further effort and finding that enabled to recommend resistant tomato variety. It might enable to develop resistant variety that can be putted on production if the selection effort was continued on the varieties which showed promising resistance in naturally infested fields at different locations.

In addition, faba bean genotypes from Morocco, Egypt and ICARDA including susceptible check from Syria and local land race showed various levels of resistance to I. crenata, though the resistance level is not high enough (Teklay et al., 2013). On the same line, study on selected faba bean genotypes stability in Crenate broomrape resistance under diverse environments of the south Tigray, with various infestation severities revealed that genotype originated from Morocco ILB 4358 (+shenge) found resistant with highest seed yield potential at Alamata Agricultural Research Center (Teklay et al., 2015). The work has resulted promising material but its seed is not adequetly available to users.

5.6. Biological control

i. Microorganisms:

This interesting control option investigation tried in our country long years back on *I ro"anche* spp. by M.Sc. student but no progressive work then after (Abuelgasim, 1996). In general, soil-dwelling microorganisms have numerous advantages over aerial bio-agents in the control of the root parasites though yet not reported except some initial activities using *;ungus* and **richoderma* spp (Sauerborn *et al.*, 2007; Mokhtar *et al.*, 2009).

They can provide effective control by attacking the seeds and the early stages of the developing parasite; they are less sensitive to the environmental conditions compared with aerial bio-agents; and they are expected to survive in the soil by producing resting structures at population levels sufficient to provide residual control of the parasitic plant.

ii. Botanicals:

Five plant species engaged pot experiment indicated that leaf powder of *Janthium a"yssinicum* highly interfere the germination of *). ramosa* seeds that resulted an increased tomato fruit yield (Etagegnehu, 2005).However, there is no report on the successful practical application of the result at field level.

5.7. Chemical control

Methyl bromide soil fumigation under polyethylene sheet cover for seven days effectively sterilized the soil from Broomrapes infestation (Ahmed *et al.*, 1990; Beyenesh and Etagegnehu, 1992). The soil fumigation with methyl bromide was effective especially in light soils for suicidal germination, but now out dated.

Glyphosate can be used with a few crops like faba bean if applied in low doses, but the necessary number of applications for an effective control depends on the environmental conditions (Mekonnen, 2016). It is reported that an excellent control of the weed achieved in faba bean field with a single glyphosate application at 60 g ha^{-1}, at the growth stage of the weed when shoot bud already visible or shoot and vestigial roots well developed (Restuccia *et al.*, 2009). However, its selectivity to the host crop is marginal and its use is not widely spread.

Alternatively, the use of chemical like Strigolactones with the ability to stimulate Broomrapes seed germination in the absence of a suitable host can lead to a reduction in the seed bank. This is “suicidal” germination found promising as long as formulated for field application. Moreover, research has shown other functions of Strigolactones in the rhizosphere that they promote hyphal branching in arbuscular mycorrhizal fungi (AMF) and rhizobial nodulation in legume crops (Soto et al., 2010).

Furthermore, the value of herbicide resistant crop varieties has already been demonstrated and near perfect selectivity achieved with different herbicides in correspondingly modified commercial crops. This approach is likely to become an important weapon in the control of Broomrapes.

5.8. Integrated approach

Integrated approach combines different preventive and control measures into a given farming system. No single dependable Broomrapes control method that suggests the requirement of developing integrated management system.

In study conducted in naturally). ramosa infested tomato fields, nitrogen fertilizer at 92 kg/ha and irrigation at four days interval gave effective control of the parasitic weed and high fruit yield of the crop (Etagegnehu, 2005).

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Khalil *et al.* (2004) concluded in their study for resistance of faba bean against *Orobanche* spp. that the use of resistant varieties together with improved agricultural practices is the most economical and safe ways to control the weeds. An approach whereby effective and locally available measures are used in an integrated manner, preferably with different technologies targeting the various objectives of long-term reduction and containment of infestations is most likely the preferable way that parasitic weeds can be effectively and sustainably managed.

According to Fernandez-Aparicio *et al.* (2016a), many of the Broomrapes traits such as achlorophyllous nature, underground parasitism, and the physical and metabolic overlap with the crop or lack of functional roots reduced the efficiency of conventional programs in weed management aimed to their control. Thus, Fernandez-Aparicio *et al.* (2016b) have suggested that successful Broomrapes control should target their underground earlier life stages, prior to attachment or as soon as attach to the host, because of their highest vulnerability at those stages and the avoidance of yield loss in the current crop.

In general, effective and affordable management measures for parasitic weeds are at scarce. Alongside adequate knowledge on their biology, an integrated and sustainable management strategy composed of several possible control methods acting at different life stages of the parasitic weeds is crucial to keep away or minimize the problem for a particular agro-ecology successfully. Looking for host-plant resistance as the major component of an integrated parasitic plants management strategy is acknowledged, being assumed effective, durable, economical and practical for low-input farming systems.

6. Conclusions

In different parts of Ethiopia, the problem of Broomrapes on economically important crops; *Orobanche crenata* on faba bean, and *O. cernua* and *Phelipanche ramosa* on tomato are getting worse. Negligence in implementing preventive measures and lack of knowledge on the biology of the parasitic weeds are responsible for the spread and increase of their problem.

Moreover, moisture stress, poor soil fertility and lack of dependable control measure at farmers' level are main problems aggravating infestation and impact of Broomrapes.Many control methods are not or weakly used by farmers and still in the country no harmonized strategy has been adopted to control the parasite. The existing and also more widening future impacts of the parasitic weedsare the great concern in the country.

Studies concerning the parasitic weeds are very minimal as compared to the serious problems imposed by the parasitic weeds on farming communities of the country. The identity, host ranges, biology and possible management options of these obscure weeds are being overlooked. There is paucity of research activities and recommendation on managing Broomrapes in the country. Preventive measures, land preparation, adjustment of sowing time and depth, biological control and intercropping effect on reducing the parasitic weed problems at all not explored in the country. Even the proven technologies and knowledge that can help to manage the parasitic weeds are not adequately transferred to users. Studies on agronomic and chemical practices are still underway, although the major efforts need to be shifted to genetic improvement of crops, which appears to be the most appropriate and cost-effective control practice.

Species of =roomrapes are listed as prohibited and/or subject to quarantine, in virtually all countries with developed plant quarantine systems.Preventive methods are in general unknown and thus not applicable by farmerscontributing to the dissemination of these parasitic species in this country. Due to increasing global travel and trades, besides the above mentioned deleterious exotic species the number of introduced serious weed infestation and impacts can continue more and more in the future years unless the quarantine actions at ports of the country and also containment of already infested areas strengthened and put in actual actions. The very large weed free areas are at risk of invasion if care not taken to limit their spread by raising awareness of farmers and agricultural experts to be alert for new infestations.

The ability of the parasite to produce a tremendously high number of seeds which can easily disperse, and remain viable in the soil for decades and their intimate physiological interaction with their host plants are the main difficulties that limit the development of successful control measure that can be accepted and used by subsistence farmers. Due to the severe effects of the parasitism on the host crops and the high persistence of the parasite seed bank in agricultural soils, it has been the cause for elimination of important crops cultivation in the respective suitable cropping areas.

The control of these parasitic weeds has proved to be exceptionally difficult. Preventive measures could be effective and the most economical methods to reduce these root parasitic weeds infestations in agricultural fields. Physical methods are very useful to manage the weeds but are tedious, time-consuming and costly. Agronomic control methods and host resistance appear to be the most appropriate measures when available and affordable. The principal conclusion to be drawn is that no single technique provides complete control of Broomrapes, and resorting to some of them is unavoidable. It can be advised that integrated approaches combining several available preventive and control techniques could be more effective.

It is indispensable that the previously made research works and their results have increased individuals knowledge about the weed, host resistance mechanisms and relative effectiveness of the individual weed control methods. Large number of them can be manipulated to better understand the biology of the weed and design integrated weed management system that can offer adequate answer to the parasitic weeds problem and re-introduce the host crops into cropping systems.

7. Future prospects

The scope of inflicting damages due to the parasitic weeds is many and diverse but the extent of attention given and works done to solve problem of the weeds is still very low in Ethiopia. Hence, there is a great demand for strong attention to work on the parasitic weeds research and technology transfer.

The development of future strategy for preventing other species introduction, minimizing impacts on infested areas and checking further dispersal by creation of necessary capacity and knowhow to the grass root levels is paramount importance. Strong community awareness or ownership of the problems and up-to-date quarantine legislations are crucial in successfully avoiding the introduction and spread of the parasitic weeds to high risk areas.

In addition, the identity, distribution, host ranges, detailed knowledge of the specific mechanisms of parasitism, damage caused and possible management options of these obscure parasitic weeds need to be studied in detail. Since no standard integrated management ‘package’ for the parasitic weeds that can be put forward, relevant IM system need to be adjusted to individual cropping systems, local needs and farmers’ preferences. To reduce the elevating impacts of the parasitic weeds infestation, there is a strong need for host plant resistance based integrated management practices that well account host-parasite association, and prevailing socio-economic and ecological conditions.

Formulating national and regional programs against the invader and difficult to control parasitic weeds like proper quarantine and phyto-sanitary measures, cultural, physical and agronomic practices, andresistant cultivars development found more attractive for the successful management in the future. Thus, it can be suggested that to reduce the Broomrapes impact sustainably and boost the respective host-crops productivity, the future research direction and weed management efforts shall be targeted to explore the additive or synergetic effects of two or more applicable control methods for effective and eco-friendly management of the weeds.

Being controlling parasitic weeds is a long lasting struggle looking for resistant cultivars should be given special attention. Expecting wide enough genetic differences among the host plant genotypes, screening with a large number of Ethiopian landraces can be effective in generating high yielding cultivars with reduced number of emerged parasitic plants. There is also a need to make accessible various available technologies and knowledge to growers, and enhance the linkage between research and extension in facilitating effective advisory work and in assisting farmers to assess and adopt an appropriate integrated management option.

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Controlof Water Hyacinth Using Bioagents in Ethiopia

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Abstract

9ater hyacinth UEichhornia crassipes (/art.) ,olmsV remains one of the worst a6uatic weeds worldwide. #n Ethiopia, water hyacinth continues to pose significant economic, social and environmental pro"lems. Experiences worldwide indicate that the use of "ioagents is the most economical and sustaina"le control measure for water hyacinth. #n Ethiopia, the management of this invasive weed using "ioagents is still in an experimental stage. @owever, recently, the use of "ioagents against water hyacinth at the national level has received due attention, and researchers have "ecome engaged in surveys and programmes to introduce and evaluate native, as well as classical, "ioagents. +ccordingly, the mottled water hyacinth weevil (0eochetina eichhorniae 9arner) and the chevroned water hyacinth weevil (0eochetina "ruchi @ustache) have "een introduced and tested under Ethiopian condition. 'a"oratory study on life cycle and development of 0eochetina weevils indicated the two weevils took shorter generation time in Ethiopia than in +rgentina "ut relatively similar to -enya and 3ganda. #n Ethiopia, the two weevils produced four generations per year indicating their successful esta"lishment. ;eeding "y adult weevils and tunneling "y larvae significantly impacted the vigour and reproduction of water hyacinth plants. + her"ivory loads of three pairs of 0. "ruchi and two pairs of 0. eichhorniae showed the highest level of leaf damage and defoliated petioles. *he study also reinforced that the two weevils are sufficiently host$specific.

I n the other hand, 2G fungal isolates were collected during the survey conducted from 2..A to 2.11. =ased on morphological characteri%ation and :0+ se6uencing, 2G fungal species were identified that "elong to nine genera. +lternaria tenuissima, +. alternata, +spergillus niger,)homa sp., <urvularia trifolii, /ucor fragilis, /. racemosus, +. fumigatus, ;usarium oxysporum and ;. e6uiseti were the most common fungi detected. +mong the fungal pathogens, +. alternata, +. tenuissima, ;. oxysporum, ;. e6uiseti and 0eofisicoccum parvum were highly

pathogenic to water hyacinth. +lternaria alternata and +. tenuissima did not cause disease symptoms on ecologically important plant species. /oreover, the study on integrated use of 0eochetina weevils and an indigenous plant pathogen revealed that the two 0eochetina weevils and the fungus +. alternata were together a"le to reduce the vegetative growth and fresh weight of water hyacinth plants considera"ly. *herefore, taking into account the synergy "etween fungal pathogens and the two weevil species, it is advisa"le to augment the large scale release of the two weevils with fungal pathogens.

1. Introduction

Water hyacinth (Eichhornia crassipes [Mart.] Solms) is an invasive, free-floating, alien weed that has spread into different water bodies and wetlands of Africa, Asia, the Western Hemisphere and Pacific regions (Julien, 2001). The weed has been recognized as one of the world's worst invasive water weeds causing various problems to millions of users of water bodies and water resources (Patel, 2012). Although the weed is native to the Amazon basin, its attractive flowers played a significant role in the spread into a number of water bodies throughout the world (Center et al., 2002). It has been established in most of the water bodies with significant impacts on the environment, economic activities and community livelihoods in Africa (CABI, 2015). It is a serious weed, not only because of its rapid growth rate through both sexual and asexual reproduction methodsbut also due to the absence of natural enemies in the introduced habitats (Abdelrahim and Tawfig, 1984).

In Africa, where there is resistance to the use of herbicides, biological control is the most sustainable control option (Cilliers et al., 2003; Mbati and Neuenschwander, 2005). Accordingly, several insect bioagents have been imported into Africa to be used as classical bioagents against the weed (Cilliers et al., 2003; Ajuonu et al., 2007; Coetzee et al., 2011; Tipping et al., 2014). Among these insect bioagents released worldwide, two weevils, 0eochetina eichhorniae (Warner) and 0. "ruchi Hustache (Coleoptera: Curculionidae) have been proven to be most effective (DeLoach and Cordo, 1976b; Center and Van, 1989; Center et al., 1999b). In addition, Shabana et al. (1995a) and Charudattan (2001a,b) indicated that fungal pathogens showed highly effective controlling potential against water hyacinth under experimental (e.g. Egypt, Sudan, South Africa) and field (e.g. Florida, South Africa, Australia) conditions. Positive interactions between insect herbivores and plant pathogenic fungi are potentially useful in biological water hyacinth control. Combined use of biological control agents (bioagents) has been advocated as the best prospect for long-term management of aquatic weeds (Charudattan, 2001a,b; Evans and Reeder, 2001). In line with that, the few attempts made so far to utilize this potential for the management of water hyacinth demonstrated the feasibility and commercial potential of augmenting weevils with pathogens (Moran and Graham, 2005; Martinez and Gomez, 2007).

In Ethiopia, water hyacinth continues to pose significant economic, social and environmental problems. These include hindrance to water transport, disrupting hydro-electric operations, blockage of canals and rivers, flooding, causing human health problems, increased evapotranspiration, interference with fishing, reduction in irrigation efficiency, navigation, livestock watering and biodiversity (Hailu et al., 2004, Kassahun et al. 2004, Senayit et al., 2004, Taye et al., 2009).

The existing management strategy (i.e., manual as well as mechanical clearing and in some spots chemical control) was not effective to combat the various problems. In 2011, efforts were made to control water hyacinth in Ethiopia using weevils. The host-specific weevils Oeochetina eichhorniae Warner and O. "ruchi Hustache have been used already for a long time as biological agents for control of water hyacinth in different parts of the world (Harley, 1990). In Ethiopia, O. eichhorniae and O. "ruchi were introduced from the Biological Control Unit, Namuloge Agricultural and Animal Production Research Institute, based in the Republic of Uganda. Adaptability, host-specificity (ecological as well as economic plant species of Ethiopia) and pre-release impact assessment studies confirmed their suitability for release in the Rift Valley of Ethiopia (Firehun et al., 2015, 2016).In light of the efforts to manage water hyacinth in Ethiopia, studies were also conducted to assess availability of indigenous fungal pathogens for management of this noxious aquatic weed (Stroud, 1994; Samuel et al., 2014; Firehun et al., 2017).

Thus, this paper presents reviewof studies conducted to assess the existing potential to use insects (Oeochetina weevils) and pathogens, their host specificity, and their herbivory/virulence effect against water hyacinth for managing water hyacinth in Ethiopia. The opportunity to use a monitoring tool to evaluate the impact of bioagents in water hyacinth management has also been discussed.

2. Use of *Neochetina*weevils as bioagents of water hyacinth

Among the seven arthropod agents released worldwide (Harley, 1990; Julien et al., 1999, Tipping et al., 2010, 2014), two weevils, Oeochetina eichhorniae (Warner) and O. "ruchi Hustache (Coleoptera: Curculionidae), are the most effective (DeLoach and Cordo, 1976a; Center and Van, 1989; Center et al., 1999b). Oeochetina "ruchi and O. eichhorniae have been released on water hyacinth in 30 and 27 countries, respectively (Center et al., 2002). These weevils are host specific and successful biological agents used for the control of water hyacinth. For example, in Uganda, the impact of the two weevils five years after release indicated that in Lake Victoria there was a rapid build-up of the weevil population that reduced the weed biomass by nearly 80% (Ogwang and Molo, 2004). Similar results were also later obtained on the Kenyan and Tanzanian shores of Lake Victoria (Mallya et al., 2001; Ochiel et al., 2001). Likewise, in Benin, the weevils were shown to reduce water hyacinth cover from 100 to 5% within eight years (Ajuonu et al., 2003). In Egypt, 0. eichhorniae and 0. "ruchi were released in August 2000 on two lakes and by July 2002, water hyacinth on Lake Edko was reduced by 90% (Cillers et al., 2003). There has also been success in other areas of the world including Mexico where 20-80% reduction of the water hyacinth population has occurred within 2-3 years after release of the weevils (Aguilar et al., 2003).

The relative adaptability and success of these weevils in controlling water hyacinth differ from place to place and from country to country. For instance, in Benin, 0. eichhorniae is better adapted than 0. "ruchi (Ajuonu et al., 2003), while in Uganda, 0. "ruchi become the dominant species (Ogwang and Molo, 2004).

Climate matching between Ethiopia and those tropical regions in Africa where the weevils proved to be a success, such as Uganda, Sudan, and Benin, indicated the potential to use these weevils as biocontrol agents of water hyacinth in Ethiopia (Firehun et al., 2013). Accordingly, in the biological control programme of water hyacinth, 0. eichhorniae and 0. "ruchi were imported into the country from the Biological Control Unit, Namuloge Agricultural and Animal Production Research Institute based in the Republic of Uganda. However, to release these weevils into water hyacinth infested and prone areas, it was crucial to generate basic information such as their adaptability, life cycle and developmental stage duration (Firehun et al., 2015).

Firehun et al (2016) had also conducted a pre-release impact assessment study on the potential efficacy and host specificity of 0. eichhorniae and 0. "ruchi with regard to water hyacinth and determined the optimum densities of the two weevils for release in the Rift Valley of Ethiopia. Therefore, this section presents the major findings of the studies conducted in the Rift Valley of Ethiopia.

2.1. Life cycle and development of *Neochetina* weevils

2.1.1. Egg stage

Eggs of 0. "ruchi and 0. eichhorniae were white when first laid but changed to pale orange as they approached to hatching. The eggs were arranged singly or in a group inserted below the epidermal layer of a petiole. The egg hatching period for 0. "ruchi ranged from 4 to 10 (mean = 6.7 ± 2.4) days while for 0. eichhorniae it ranged from 8 to 12 (mean = 9.0 ± 1.6) days at an average temperature of 25 °C. In other studies, the egg stage of 0. "ruchi took a shorter duration (7.6 days) in Argentina at 25 °C (DeLoach and Cordo, 1976b) compared to 11 days in Uganda and Kenya (Nijoka, 2001; Ogwang and Molo, 1997). Similarly, life cycle study on 0. eichhorniae indicated that the egg stage could take 7-14 days in Argentina at 25 °C (Stark and Goyer, 1983) while it took 10 days in Uganda at 20-24 °C (Ogwang and Molo, 1997) and 14 days in Kenya at 21-24 °C (Nijoka, 2001). The number of days reported in Ethiopia was relatively small for 0. "ruchi and high for 0. eichhorniae(Firehun et al.,2015) as compared to the reports of DeLoach and Cordo (1976b) and Stark and Goyer (1983), respectively. The observed differences could be attributed to variation in temperature. In line with this, reports indicated that temperature had a significant effect on egg hatching period of 0eochetina weevils (DeLoach and Cordo, 1976b; Grodowitz et al., 1991; Heard and Winterton, 2000). However, there was no significant difference in the egg to larvae durations between the two weevil species.

2.1.2. Larval stage

Both weevil species had three larval instars. Studies made by Firehun et al (2015) indidicated that the number of days required for the development of larvae showed significant differences ($P < 0.05$) among the three stages and between the two species (Table 1). Larvae of 0. "ruchi took comparatively shorter period (32-38 days, mean 34.4 ± 2.8 days) to complete their developmental stage than 0. eichhornaie. Duration of 0. "ruchi 1st, 2nd and 3rd instars development on average took 11.6 ± 1.3 (range, 10-13 days), 14.9 ± 1.4 (range, 14-17 days) and 8.1 ± 1.2 days (range, 6-9 days), respectively. Whereas, 1st, 2nd and 3rd instar larvae of 0. eichhorniae took on average 17.6 ± 1.3 (range, 16-19 days), 25.1 ± 1.2 (range, 23-29 days) and 13.6 ± 4.4 days (range, 9-20 days), respectively. 0eochetina eichhorniae took 52 to 60 days (mean = 56.3 ± 3.0) to complete their developmental stage. The larval developmental period recorded in Ethiopia was very similar to the works of Ogwang and Molo (1997) in Uganda that indicated larvae of 0. "ruchi and 0. eichhornia took on average 35 and 58 days. The larval duration also took 31 and 57 days in Kenya (Nijoka, 2001), which is similar with the finding in Ethiopia.

It is apparent that the larva causes the most damage to the water hyacinth plant through tunnelling the petioles ultimately leading to the death of the plant. In line with this, observation on larval feeding habit of the two weevils reared under lath house condition in Ethiopia showed that larva of the two weevils fed first within the petiole tissues, and then mined towards the base of the plant. Most of the larvae were found singly, however, in some large larval tunnels 2-4 larvae were observed together. In some cases, though the tunnel length was high, only single larvae had been observed. After completion of the 3rd instar, the larvae came out of the petiole and moved into the root (Firehun et al., 2015; Firehun 2017). This tunnelling potential coupled with the difference in the larval developmental period between the two species indicates the opportunity for combined use of the two species in large scale management of water hyacinth in Ethiopia.

Table 1.Developmental time of 0. "ruchi and 0. eichhorniae from egg to pupal stage (After Firehun et al., 2015).

	Mean duration (day) ± SE		
Developmental Stage	***N. bruchi***	***N. eichhorniae***	**Significance**
Egg to larva	6.7 ± 2.4	9.0 ± 1.6	ns
Larvae	34.4 ± 2.8	56.3 ± 3.0	**
1st Instar	11.6 ± 1.3	17.6 ± 1.3	**
2nd Instar	14.9 ± 1.4	25.1 ± 1.2	**
3rd Instar	8.1 ± 1.2	13.6 ± 4.4	*
Pupae	29.4 ± 3.7	27.4 ± 4.6	ns
Adult longevity	116 ± 7.3	133 ± 9.2	**

Where ns = not significant, * = significant at $P < 0.05$, and ** = significant at $P < 0.01$.

2.1.3. Pupal stage

A study made in Ethiopia by Firehun et al (2015) indicated that there was no significant difference between the two species in the pupation period. Duration of pupal stage ranged from 24 to 34 days (mean = 29.4 ± 3.7 days) and from 22 to 30 (mean = 27.4 ± 4.6 days) for 0. "ruchi and 0. eichhorniae, respectively at a temperature of 25-27 °C, under lath-house condition. Similarly, in Uganda, pupal stage took 30 and 28 days for the two weevils at 21-25 °C, respectively (Ogwang and Molo, 1997). On the other hand, DeLoach and Cordo (1976b) reported that 0. "ruchi required a pupation period of 30 days at 25 °C. In Kenya, this stage took 31 and 28 days respectively for 0. "ruchi and 0. eichhorniae at 21-24 °C (Nijoka, 2001).

2.1.4. Adult longevity

Adult longevity ranged from 80 to 130 (mean = 116 ± 7.3) and 90 to 160 (mean = 133 ± 9.2) days for 0. "ruchi and 0. eichhorniae, respectively for both sexes (Table 1). In India, Jayanth (1988) reported that adult longevity of 0. "ruchi and 0. eichhorniae could take an average of 134 and 142 days. DeLoach and Cordo (1976b) reported a maximum of 87 days for 0. "ruchi. A study conducted in Kenya indicated that the adults of the two weevils would live on average for about 112 days (Nijoka, 2001). Thus, the higher longevity recorded in the present study as compared to Argentina and Kenya indicates the prevalence of conducive climatic condition, which consequently enhanced the potential for use of the two weevils to control water hyacinth.

2.2. Adaptability of *Neochetina* weevils

Adaptability study of 0eochetina weevils in Ethiopia were conducted for three consecutive years as of year 2011 (Firehun et al., 2015). The results indicated that population of 0. eichhorniae and 0. "ruchi increased over time as indicated by adult numbers and corresponding increase in feeding scars per plant (Figures 1 and 2). Adult numbers changed significantly over time (0. "ruchi: $F = 4.79$; $P = 0.0002$, $R^2 = 0.73$ Figure 1; 0. eichhorniae: $F = 3.62$; $P = 0.0014$; $R^2 = 0.82$ Figure 2). For example, the highest number in 2011 occurred three months after release of the well quarantined weevils during the main rainy season with values of mean individuals of four weevils plant^{-1} in October 2011. Thereafter, a significant decrease in adult numbers followed and the numbers continued to decline to November and December. The lowest values for each species (mean = 0.5 individuals plant^{-1}) were recorded between November and

December 2011 following the low temperatures. In January and February 2011, a significant linear increase (**O**. "ruchi: P = 0.0018; R^2 = 0.94; **O**. eichhorniae: P = 0.0088; R^2 = 0.86) of about 4 individuals plant^{-1} month^{-1} species^{-1} (i.e., **O**. "ruchi and **O**. eichhorniae) was noted, respectively. Adult numbers increased more widely during the 2012 and 2013 growing season. Peak populations of approximately 5.6 and 7.4 individuals plant^{-1} were recorded in August 2012 and March 2013 for **O**. "ruchi while 5.9 and 6.9 individuals plant^{-1} were noted in October 2012 and April 2013 for **O**. eichhorniae, respectively. This seasonal variation as well as increment of the weevils population over years would indicate their adaptability to the Rift Valley agro-climatic conditions.

The adaptability study also confirmed that the two weevils produced four generations per year. Accordingly, the first generation of **O**. "ruchi adults emerged in August, apparently from the first acclimatized larvae and pupae as explained by their populations. Later on populations increased gradually in September and October as more adults emerged from pupae. Similarly, the first generation of **O**. eichhorniae occurred in August and extended to October 2011 as more adults emerged from larvae and pupae. The subsequent peak of pupae occurred in January 2012.

The second generation was recorded in January 2012 and increased in February and March 2012. Large populations of larvae were recorded during the months of February and March. The largest pupae population occurred in March 2012 contributed for the large population of third generation of **O**. "ruchi. Finally, the fourth generation of **O**. "ruchi was recorded in May 2012. Similarly, the second, third and fourth generation[1]latD~:737BV:yI

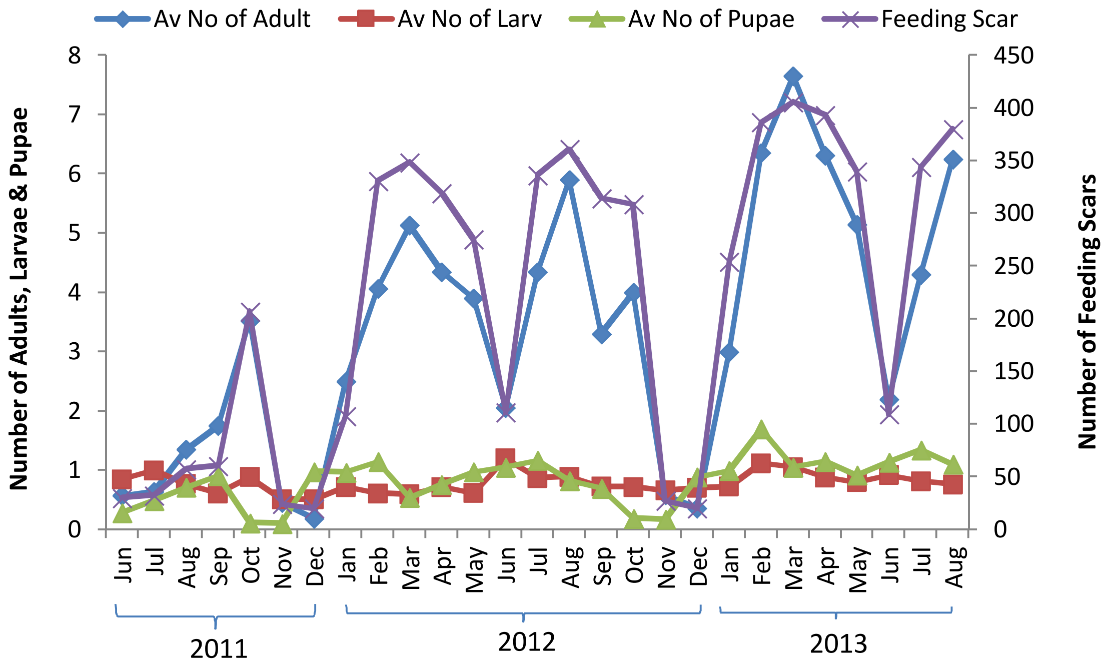

Figure 1. Density of **O. "ruchi** adults, larvae as well as pupae and feeding scars per plant through time at Wonji-Shoa, Rift Valley, Ethiopia. LSD(Average number of adults) = 0.23; LSD(Average number of larvae) = 0.07; LSD(Average number of pupae) = 0.07 and LSD(feeding scars) = 75.41 at $P \leq 0.05$.

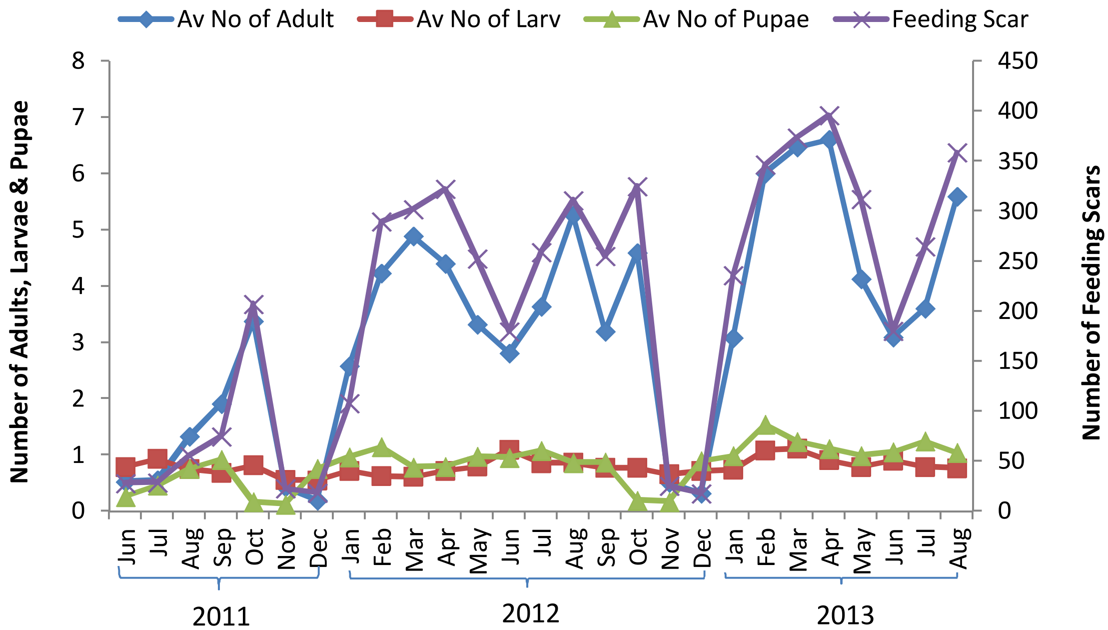

Figure 2. Density of 0. eichhorniae adults, larvae as well as pupae and feeding scars per plant through time at Wonji-Shoa, Rift Valley, Ethiopia. LSD(Average number of adults) = 1.23; LSD(Average number of larvae) = 0.14; LSD(Average number of pupae) = 0.23 and LSD(feeding scars) = 80.11 at P $\leq$ 0.05.

2.3. Host-specificity of *Neochetina* weevils

The host-range assessment study revealed that 0. eichhorniae and 0. "ruchi were restricted to the aquatic plant water hyacinth family (Pontederiaceae). Furthermore, families allied to or very closely related to Pontederiaceae, namely Asteraceae and Commelinaceae, appeared to be not suitable for their development and survival (Table 2). Absence of adult survival and feeding over were recorded on non-Pontederiaceae plants and no progeny was produced on E. natans (Pontederiaceae),)istia stratiotes (Araceae) and =rassica oleracea (Brassicaceae), providing evidence that they are not suitable hosts (Firehun et al., 2016).

0eochetina eichhorniae and 0. "ruchi have been released on water hyacinth in 30 and 27 countries, respectively (Center et al., 2002). Both weevils were subjected to extensive screening and tested against 274 plant species in 77 families worldwide (Julien et al., 1999). The results indicated that both weevils have a narrow host range and they can only complete their pupation stage underwater. The pupation behaviour of these insects, during which they develop a pupal cocoon in the roots of floating water hyacinth, makes it highly unlikely that any substrate rooted plant could serve as a suitable host (Julien et al., 1999; Center et al., 2002; Firehun, 2017).

Moreover, since the release of the two weevils in USA in 1972, there is no report about adverse attacks on non-target plants in any of the countries where the agents have been released. Therefore, the need/relevance of such rigorous confirmatory test particularly on terrestrial crops becomes questionable. Nevertheless, the study conducted in Ethiopia confirmed that **O**. eichhorniae and **O**. "ruchi are sufficiently host specific and therefore, can be safely released in Ethiopian water bodies for the management of water hyacinth without any risk.

2.4. Quantifying the density of the two *Neochetina* weevils required to control water hyacinth

Effects of different densities of the two weevils on water hyacinth growth and plant biomass indicated that weevil herbivory were expressed in decreased leaf and petiole lengths, increased leaf mortality and overall reduction in plant biomass (Firehun et al., 2016). The plants were significantly affected by different densities of the two weevils and their combined application at eight weeks after release of the herbivory treatments (Table 3). Three pairs of **O**. "ruchi resulted in the greatest reduction of water hyacinth plant weight when combined with two or three pairs of **O**. eichhorniae.

Table 2. Results of feeding and no-choice oviposition tests for **O**. eichhorniae and **O**. "ruchi.(After Firehun et al., 2016)

Family	Genus & Species	Common Name	Feeding	Oviposition
Apiaceae	*Daucus carota* L.	Carrot	-	-
	Hydrocotyle verticillata L.	Water pennywort	-	-
Araceae	*Pistia stratiotes* L.	Water lettuce	++	-
Asteraceae	*Guizotia abyssinica*	Noug	-	-
	Lactuca sativa	Lettuce	++	-
Brassicaceae	*Raphanus sativus* L.	Radish	-	-
	Brassica oleracea capitata L.	Cabbage	++	-
Chenopodiaceae	*Ipomea batata* (L.) Lam.	Sweet potato	-	-
Cyperaceae	*Cyperus papyrus* L.	Papyrus	-	-
Compositae	*Carthamus tinctorius* L.	safflower	-	-
Commelinaceae	*Commelina bengalensis,*		++	-
	C. latifolia A.		++	-
Cruciferae	*Brassica carinata* Cobs.	Mustard	-	-
Cucurbitaceae	*Cucumis sativus* L.	Cucumber	-	-
Fabaceae	*Phaseolus vulgaris* L.	Haricot bean	-	-
	Glycin max (L) Merr.	Soy bean	-	-
	Cicer arietinum L.	Chickpea	-	-
	Vicia faba L.	Faba bean	-	-
	Pisum sativum L.	Pea	-	-
	Lens culinaris Medik	Lentil	-	-
	Trigonella foenum-graecum	Fenugreek	-	-
Lileaceae	*Allium sativum* L.	Garlic	-	-
	Allium cepa L.	Onion	-	-
Malvaceae	*Gossypium hirsutum* L.	Cotton	-	-
Pedaliaceae	*Sesamum indicum* L.	Sesame	-	-
Poaceae	*Hordeum vulgare* L.	Barley	-	-
	Sorghum bicolar (L.) Moench	Sorghum	-	-
	Zea mays L.	Maize	-	-
	Eragrostis tef (Zuccagni) Trotter	Teff	-	-
	Saccharum officinarum L,	Sugarcane	-	-
	Triticum aestivum L.	Wheat	-	-
Rubiaceae	*Coffee arabica* L.	Coffee	-	-
Pontederiaceae	*Eichhornia crassipes* (Mart.) Solms.	Water hyacinth	++++	++++
	Eichhornia natans		++	-
Solanaceae	*Lycopersicon esculentum* Mill.	Tomato	-	-
	Capsicum pepper	Pepper	-	-
	Solanum tuberosum L.	Potato	-	-
Typhaceae	*Typha orientalis*	Roscoe	-	-
Umbelliferae	*Cuminum cyminum*	Cumin seed	-	-
Blank Control	*Water but no plant*		-	-

Feeding and Oviposition by the weevils: - absent; + very low; ++ present, +++ abundant, and ++++ very abundant.

Table 3.Effects of different densities (no) of **0**. "ruchi (NB) and **0**. eichhorniae (NE) on mean values of water hyacinth growth and reproductive characteristics at eight weeks after introduction (After Firehun et al., 2016).

NB	**NE**	**No. Ramets (no)**	**No. Leaves (no)**	**Damaged Leaf Area (scale)**	**Petiole length (cm)**	**Defoliated petiole**	**Weight (g)**
NB0	NE0	4.73	8.27	0.00	37.17	0.00	354.00
	NE1	1.73	6.23	3.93	21.39	1.40	153.33
	NE2	1.53	3.27	4.40	20.99	1.53	116.07
	NE3	1.00	3.00	4.93	20.49	1.86	99.83
NB1	NE0	2.03	6.41	3.93	22.34	0.86	169.63
	NE1	1.53	5.43	3.97	21.77	1.40	126.50
	NE2	0.97	2.80	4.13	20.02	1.70	103.65
	NE3	0.97	1.63	4.93	18.51	1.87	93.32
NB2	NE0	1.56	4.90	4.20	20.95	1.43	122.63
	NE1	1.43	4.00	3.93	20.08	1.93	110.26
	NE2	1.03	2.46	4.93	18.65	1.90	89.74
	NE3	0.74	0.70	5.67	16.27	2.65	68.33
NB3	NE0	1.5	4.20	4.40	20.35	1.63	109.16
	NE1	1.5	3.45	5.30	19.34	1.87	98.57
	NE2	0.50	0.40	5.93	15.07	2.80	66.49

NE3	0.44	0.40	5.90	14.49	2.80	64.37
LSD (0.05) NB*NE	0.24	0.43	0.27	0.86	0.11	4.10
Correlation (r)	-0.50	-0.54	0.57	-0.57	0.62	-0.54
Regression (R^2)	0.64	0.89	0.70	0.66	0.87	0.84
Significance (P) alone & interactions[1]						
NB	**	**	**	**	**	**
NE	**	**	**	**	**	**
NB*NE	**	**	**	**	**	**

1 ** indicates significance at $P < 0.01$

Evaluation of the density-damage associations between the weevils and the water hyacinth biomass indicated a curvilinear relationship between its final biomass as a function of increasing levels of herbivory (Firehun et al., 2016). The observed relationship between weevil density and water hyacinth biomass reduction could be well described by a negative log function (R^2 = 0.98). Reduction in water hyacinth's ability to compensate for herbivory was a linear or curvilinear function of insect density, which is a relationship commonly observed between plants and phytophagous insects (Meyer, 1998; Schooler and McEvoy, 2006; Stanley et al., 2007). Similarly, findings in Ethiopia indicated that herbivory loads greater than one weevil per plant were sufficient to cause significant biomass reductions with a maximum recorded at a density of 6 weevils plant^{-1} (Figure 3). In the adaptability study, for both species, more than 6 weevils plant^{-1} have been recorded (Firehun et al., 2015). Thus, assessment of the optimum densities of the two weevil species for release in Ethiopia satisfies the requirements stated by McClay and Balciunas (2005) for a promising biocontrol agent, although a candidate is only justified for release if it has the ability to reduce fitness of its host plant at realistic field densities.

Figure 3. Regression of different densities of 0. "ruchi (NB) and 0. eichhorniae (NE) (#) and final weight (g) of water hyacinth plants at the end of the eight week study period.

Moreover, the herbivory effect evaluation study results indicated that the change in fresh weight of water hyacinth plants was significantly different between all herbivory treatments and the control (Firehun, 2017; Figure 4). However, the extent of change in weight loss varied with densities and weevil species. Change in weight due to the herbivory treatment ranged from -13% by one pair of 0. eichhorniae alone to -67% by three pairs of 0. "ruchi when combined with two pairs of 0. eichhorniae (Figure 8.1). The extent of change in weight observed in Ethiopia was much greater than the losses reported by Del Fosse (1978), who showed changes that ranged between -5 to -50% where weevils were allowed to interfere with water hyacinth. This might be attributed to the use of only single species in that study as opposed to evaluation of combined effects of two mottled weevils studied in Ethiopia.

Figure 4. Changes in fresh weight of water hyacinth plants from Week 1 to Week 8 in the herbivory treatments and the control. Herbivory treatments included densities of 1, 2 and 3 pairs of 0. eichhorniae (NE) and 0. "ruchi (NB). Means compared by one-way ANOVA; those with the same letter are not significantly different (Tukey's HSD, $P < 0.05$). Error bars represent the standard error of the mean.

2.5. Pre-release efficacy of *Neochetina* weevilsas bioagents of water hyacinth

The study by Firehun et al (2015) on the life cycle and development of 0eochetina weevils indicated that the egg hatching period of 0. "ruchi ranged from 4 to 10 days, while 0. eichhorniae took 8-12 days. Larvae of 0. "ruchi took a comparatively shorter period (32-38 days) than 0. eichhorniae (52-60 days) to complete their development. This study also indicated that the intrinsic rate of increase of 0. "ruchi appeared to be 0.060 with a generation time of 74.8 days and a population doubling period of 14.4 days. The intrinsic rate of increase of 0. eichhorniae was 0.046 accompanied by a generation time of 94.8 days and a doubling period of 18.6 days. Moreover, the study about the oviposition behaviour of 0eochetina weevils on water hyacinth under Ethiopian condition indicated that 0. "ruchi and 0.eichhorniae females oviposited a total number of 359 ± 14 eggs and 299 ± 36 eggs during their lifespan, respectively (Table 3).

Table 3.Life history parameters of 0. "ruchi and 0. eichhorniae (After Firehun et al., 2015).

Parameters	**Unit**	***N. bruchi***	***N. eichhorniae***
Net reproductive rate (4_0) *	Female female^{-1}	92 ± 5.6	83 ± 4.3
Gross reproductive rate, GRR*	Female female^{-1}	101± 6.3	85 ± 5.0
Mean generation time (T) *	Days	75 ± 2.3	95 ± 1.6
Intrinsic rate of increase (r_m) *	Head^{-1} day^{-1}	0.060 ± 0.003	0.046 ± 0.002
Doubling time (DT) *	Days	14.400 ± 1.79	18.6 ± 1.84
Finite rate of increase (W) *	Times day^{-1}	1.062 ± 0.011	1.047 ± 0.003
Fecundity for the first 35 days*	Egg female^{-1} day^{-1}	6.800 ± 0.82	6.000 ± 0.740
Fecundity for life *	Egg female^{-1} day^{-1}	3.700 ± 0.73	3.100 ± 0.540

0ote> t$test was performed for all the parameters; X indicate significance at GO pro"a"ility level; n H 2..

Based on the obtained results regarding developmental time, population increase and fecundity factors, in Ethiopian condition, it appears logical to recommend large scale release of 0. "ruchi. However, since (i) the larvae caused the most damage to the water hyacinth and (ii) 0. eichhorniae took a comparatively longer period to complete the larval stage, the research team suspected better larval damage from 0. Eichhorniaethan from 0. "ruchi. The research team, therefore, hypothesized that the difference in the larval developmental period between the two species indicates the potential for combined use of the two species in large scale management of water hyacinth. Based on earlier observations by Center and Dray (1992) and Center et al. (1999), theyalso hypothesized, that the two weevil species respond differently.

In order to address the aforementionedhypotheses, Firehun et al (2016) carried out a pre-release evaluation of efficacy of the two weevil species at different densities. The results revealed that the combined release of 0. "ruchi and 0. eichhorniae showed significantly higher growth suppression as expressed in petiole length and biomass of water hyacinth (both fresh and dry weight) than 0. "ruchi and 0. eichhorniae alone (Figures 5D, E, F).

Among the different combinations, the lowest number of ramets and leaves was recorded in case of three pairs of 0. "ruchi when combined with two pairs of 0. eichhorniae, followed by three pairs of 0. eichhorniae combined with two as well as three pairs of 0. =ruchi(Firehun et al., 2016). However, no difference was observed regarding numbers of remaining ramets and leaves in the combined application of three pairs of 0. "ruchi with two and three pairs of 0. eichhorniae. Leaf number and ramet production are among the most critical growth factors that limit water hyacinth survival (Center and Van, 1989; Heard and Winterton, 2000; Coetzee et al., 2007) and are therefore proper parameters to evaluate the impact of weevil herbivory. Asexual reproduction by water hyacinth is important in the density and spread of water hyacinth populations. Therefore, a reduction in productivity would reduce expansion of water hyacinth mats and reduce its invasive potential (Byrne et al., 2010). The herbivory effect of the combined application on number of leaves and ramets would also affect the plant photosynthetic capacity and its buoyancy capability meaning that combined herbivory effect of the two weevils would reduce the expansion rate of the weed.

In conclusion, the pre-release study revealed that the combined release of the two weevils showed better reduction in the reproductive potential and vigor of the water hyacinth plants in Ethiopia. This could be attributed to the co-existence of the two weevil species in water hyacinth plants as well as the complementary effects of the different growth stages of the respective weevil species (i.e., larvae and adult). Thus, in spite of earlier predictions by Firehun et al. (2015) where 0. "ruchi had greater intrinsic rate of increase, fecundity and plant damage than 0. eichhorniae, it Firehun et al. (2016)strongly recommend the combined release of the two weevils

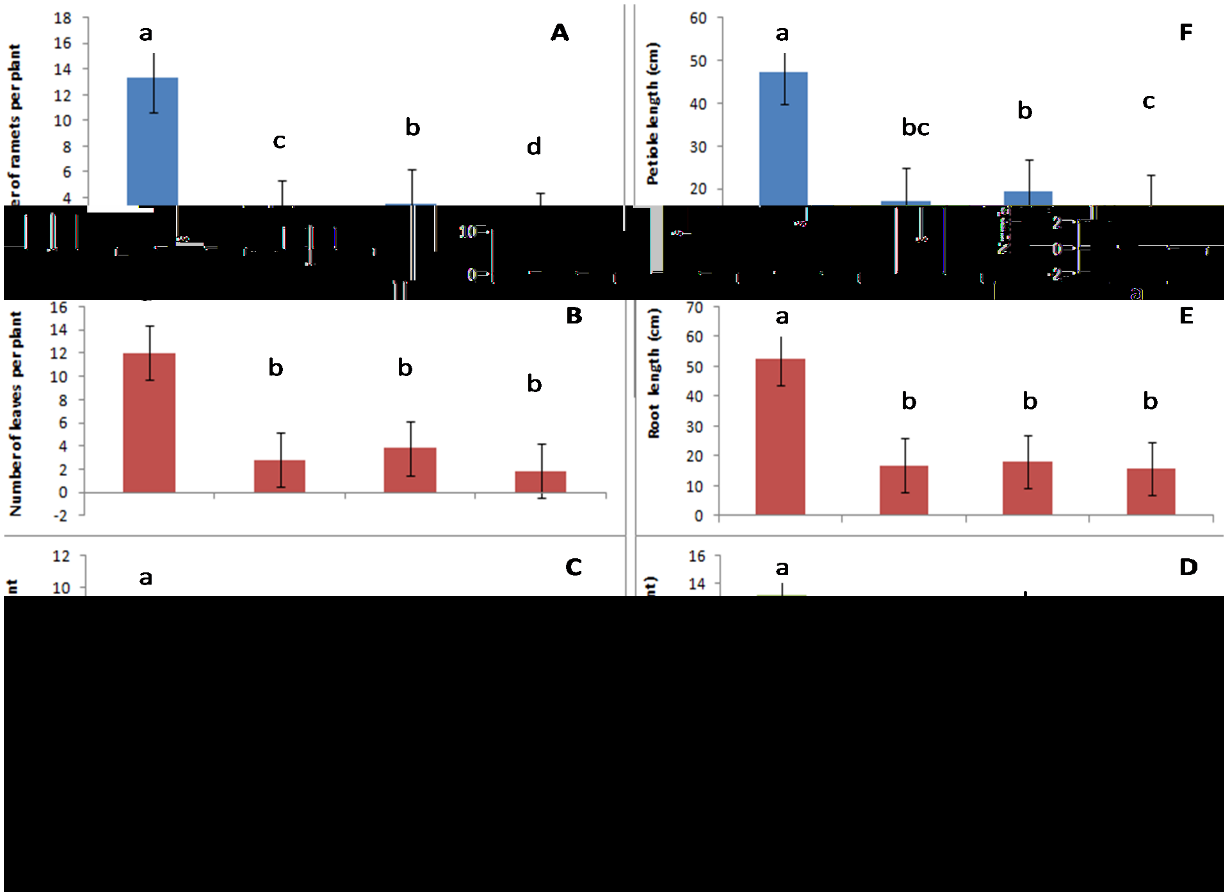

Figure 5. Impact of herbivory by 0eochetina weevils on the mean number of ramets (A), number of leaves (B), number of inflorescences (C), dry weight (D), root length (E) and petiole length (F). Treatments are: None (no herbivory treatment), NB (applying only 0. "ruchi), NE (applying only 0. eichhorniae) and NB+NE (applying both species). Means compared ANOVA; those with the same letter are not significantly different (Tukey's HSD,
P < 0.05). Error bars represent the standard error of the mean.

3. Use of fungal pathogens as bioagents of water hyacinth

Biological control of weeds using plant pathogens has gained acceptance as a practical, safe, and environmentally beneficial weed management method applicable to agro-ecosystems(Charudattan, 2001a). In this regard, several fungal pathogens have been reported to attack water hyacinth worldwide (Shabana et al., 1995a, b, 1997, 2000; Charudattan, 2001b). Various strains in the genera +cremonium, +lternaria, <ercospora, and /yrothecium have been studied intensively as biocontrol agents and shown to be effective under experimental conditions (Shabana et al., 1995a, b, 1997, 2000; Charudattan, 2001b; Martinez and Gutierrez, 2001; Mohan et al., 2003; Praveena and Naseema, 2004). One fungal species, <ercospora piaropi, originally described as <. rodmanii (Conway, 1976a) and patented by the University of Florida (Conway et al., 1978) was developed into a bioherbicide by Abbott Laboratories (Chicago, IL) for water hyacinth management. In Africa, several pathogenic fungi that attack water hyacinth offer great potential to be developed in to mycoherbicides (Bateman, 2001). For example, in Egypt, +lternaria eichhorniae was developed into a mycoherbicide for the control of water hyacinth (Shabana, 2005).

In Ethiopia, the first survey carried out in the Gambella region in the 1970s reported the fungus <. rodmanii as affecting water hyacinth 5-15% (Stroud, 1994). Then after, there was no attempt made to use or assess potential of fungal pathogen for the management of water hyacinth. In 2006, Firehun reported prevalence of ;usarium e6uiseti around Wonji-Shoa significantly affecting growth and development of water hyacinth. As a result, to assess the occurrence of fungal pathogens and their potential as bioagent of water hyacinth, field and laboratory studies were conducted from 2008 to 2012 (Samuel et al., 2009; Firehun et al., 2017).Therefore, this section presents the major findings of these studies.

3.1. Occurrence and diversity of fungal pathogens

In 2008 survey, a total of 23 fungal isolates were collected and identified. These include +lternaria alternata, <ochlio"olus car"onum, ,temphylium vesicarium, +lternaria geophila, +scochyta chartarum, Epicoccum nigrum, ;usarium spp., 3locladium spp,)ythium 3ltimum,)enicillium spp. and /ucor circinelloides(Samuel, 2009; Samuel et al., 2012). Among the isolates, +lternaria was the most prevalent genus which comprised 17.14% of the isolates while 3locladium,)ythium and)enicillium were the least (2.38 %).

Identification result of fungal isolates by Phytomedicine Department of Humboldt University of Berlin, Germany (Appendix table 1) showed that different fungal genera with variable frequency were observed on water hyacinth leaf. Moreover, six isolates were absent on identification report. To have clear understanding of the fungal pathogens found in association with water hyacinth, further assessment were conducted for three consecutive years since 2009 (Firehun et al., 2017). During this survey, a total of 25 fungal isolates have been collected. To confirm the identity of this fungal isolates, molecular characterization was conducted at the Farming Systems Ecology Group Laboratory, Wageningen University, Netherlands.

Both morphological and molecular analyses showed that the fungal isolates belonged to nine genera (Table 4). Among the fungal pathogens, +. alternata, +. tenuissima,)homa sp., +lternaria sp., ;. oxysporum, and ;. e6uiseti were the most common species reported as pathogens of water hyacinth. +lternaria alternata has been described as a pathogen of water hyacinth in Australia (Galbraith, 1987), Egypt (Shabana et al., 1995a, b; El-Morsy, 2004; El-Morsy et al., 2006), Bangladesh (Bardur-ud-Din, 1978) and India (Aneja and Singh, 1989; Mohan et al., 2002, 2003). Despite the occurrence of several fungal species on water hyacinth in Ethiopia, <urvularia trifolii, /. fragilis, /. racemosus, +. fumigatus, =otryosphaeria sp. and 0. parvum have not been previously isolated from water hyacinth. Based on the analysis of data on pathogenicity, host-range, and association with environmental and water factors, +. alternata and +. tenuissima hold promise as possible biocontrol agents of water hyacinth.

3.2. Pathogenicity to water hyacinth

Among the various fungal isolates, ten were pathogenic to water hyacinth, while six were found to be severely pathogenic (showing > 70% severity) to water hyacinth in the study made by Firehun et al (2017)(Table 5). The disease symptoms occurred 8-14 days after inoculation. As the symptoms progressed, they coalesced and covered a larger surface area of the leaves within five weeks after inoculation (WAI), while other isolates showed restricted spread. The pathogenic fungal pathogens observed in this study have also been reported from other countries (Barreto et al., 2000; Charudattan, 2001b; El-Morsy, 2004; Ray, 2006). Although the fungal species 0. parvum was reported for the first time as pathogenic to water hyacinth, it also attacks Eucalyptus spp. and *i"ouchina spp. (Pavlic et al., 2007; Heath et al., 2011).

As indicated in Table 5, severe reduction in plant height (48-55%), root length (45-50%), fresh (53-67%) and dry weight (60-72%) was recorded due to infection by +. alternata, 0. parvum and +. tenuissima, compared to small reductions in plant height (15-18%), fresh (11-15%) and dry weight (20-23%) due to /. fragilis,). macrostomata, and <. trifolii, respectively. Meanwhile fungi such as +lternaria sp., ;. e6uiseti, and ;. oxysporum showed low to moderate reduction (26-50%). These findings indicate that some fungal species may be useful in water hyacinth management since they affected the growth of water hyacinth plants.

Table 4. List of fungal pathogens isolated from water hyacinth, their symptoms and frequencies of occurrence in the Rift Valley water bodies of Ethiopia (After Firehun et al., 2017).

Isolates	Fungal Pathogens	Symptoms and infected plant part	Frequency (%)*
1	+spergillus niger VanTiegh	Leaf spot on leaf	14.5
2 & 21	+spergillus flavus Link ex Fr.	Leaf spot on leaf	8.9
3	)homa sp.	Blight on leaf and petiole	10.4
4	+lternaria sp.	Leaf spot on leaf and petiole	17.8
5 & 7	+lternaria tenuissima (Nees ex Fr.) Wiltshire	Leaf spot on leaf and petiole	23.5
6	+lternaria alternata (Fr.) Keissler	Leaf spot on leaf and petiole	26.2
8	<urvularia trifolii (Kauffman) Boedij	Leaf spot on leaf	11.2
9, 19 & 24	/ ucor fragilis Bull.	Blighting on leaves	11.6
10	/ ucor racemosus Fres.	Blighting on leaves	14.2
11	)encillium sp.	Zonate leaf spot on leaves	6.7
12	)homa macrostomata	Blight on leaves and petiole	7.3
13	0eofusicoccum parvum	Leaf spot on leaf and petiole	7.3
14	+spergillus ory%ae (Ahlburg) E. Cohr	Leaf spot on leaf	11.0
15	+spergillus fumigatus Fresenius	Leaf spot on leaf	12.2
16	;usarium e6uiseti (Corda) Saccardo	Leaf spot on leaf	12.3

17	)homa sp.	Blighting on leaves	7.4
18	;usarium oxysporum Schlechtendal	Leaf spot on leaf	13.8
20	=otryosphaeria sp.	Zonate leaf spot on leaves	6.5
22	)homa sp.	Blighting on leaves	7.4
23	)homa sp.	Blighting on leaves	7.4
25	)homa sp.	Blight on leaves and petiole	7.4

* ;re6uency is the num"er of locations in which a species occurred expressed as a percentage of the total num"er of locations surveyed.

The reduction in plant height and biomass following exposure to fungal pathogens suggests that the number of reproductive and vegetative propagules of water hyacinth and the doubling time of the plant would be prolonged (Firehun et al., 2017). Similarly, Shabana et al. (1995b) and Shabana (2005) also reported reductions in water hyacinth growth and reproduction due to infection by fungal pathogens, reinforcing the potential for pathogenic fungi to play an important role in weed management. Damage by pathogenic fungi to water hyacinth plants results in rotting of the lower petioles, water logging of the crown and gradual sinking of the plant (De Jong and De Voogd, 2003) leaving the water surface clear of the weed.

Table 5. Effect of potential fungal pathogens on different plant parts of water hyacinth (After Firehun et al., 2017)

Fungal Pathogens	Fresh wt at end (g)	Relative reduction (%)	Dry wt (g)	Relative reduction (%)	Plant height (cm)	Relative reduction (%)	Root length (cm)	Relative reduction (%)	DI 4WAI *** (%)	DS 4WAI **** (%)
Alternaria sp.	118.5 de*	47.71	7.13 de	55.33	11.63 e	44.09	17.93 g	41.41	88.7 cd	73.3 c
Alternaria tenuissima	105.8 e	53.31	6.37 e	60.09	10.77 f	48.22	16.83 h	45	91.2 b	74.2 c
Alternaria alternata	73.9 f	67.39	4.39 f	72.49	9.28 g	55.38	15.3 j	50	92.2 ab	80.4 a
Curvularia trifolii	191.7 b	15.4	12.23 b	23.37	16.99 bc	18.32	25.52 d	16.6	89.1 cd	49.5 e
Mucor fragilis	200.4 b	11.56	12.62 b	20.93	17.64 b	15.19	26.71 b	12.71	77.4 f	30.2 h
Phoma macrostomata	196.7 b	13.2	12.38 b	22.43	17.51 b	15.82	26.22 c	14.31	89.5 c	40.6 f
Neofusicoccum parvum	87.9 f	61.21	4.96 f	68.92	9.3 g	55.29	15.61 i	48.99	93.1 ab	78.6 b
Fusarium equiseti	126.5 d	44.17	7.79 d	51.19	12.36 d	40.58	18.12 fg	40.78	75.6 g	71.4 d
Fusarium oxysporum	132.6 d	41.48	7.85 d	50.81	12.19 de	41.39	18.3 f	40.2	87.7 d	70.4 d
Botryosphaeria sp.	173.6 c	23.39	10.33 c	35.28	16.56 c	20.38	23.84 e	22.09	83.9 e	34.7 g
Uninoculated	226.6 a		15.96 a		20.8 a		30.6 a		0 h	0 i
CV (%)	**5.96**		**6.19**		**2.88**		**0.55**		**1.23**	**1.59**
Corr (r) with DI	**-0.57**		**-0.66**		**-0.63**		**-0.71**			
Corr (r) with DS	**-0.93**		**-0.95**		**-0.96**		**-0.97**			

*Means within a column for each week followed by the same letter are not significantly different according to Duncan's multiple range test;

**WAI = weeks after inoculation;

***= DI = disease incidence (percentage of leaves infected); DS = disease severity (percentage severity of infection)

****=DI and DS was determined for each leaf on a scale of 0-9, where 0 = healthy, and 9 = 100 % diseased and finally the DS grouped in to five groups, where "N", no significant damage or infection; "Mild", < 25% of infection; "Low Moderate" 26-50% of infection; "High Moderate", 51-75% of infection and "Severe", > 75% of infection.

3.2. Host specificity of water hyacinth fungi to plants

Among the fungal species, ;. oxysporum was pathogenic to a wide range of plant species, including cabbage, papyrus, mustard, chickpea, faba bean, pea, lentil, fenugreek, sesame and pepper (Table 6). Meanwhile, ; e6uiseti was pathogenic to

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Table 6.Risk Assessment of fungal morphotypes proved to be pathogenic to water hyacinth.

Family	Species and Common Name	ALLAL	ALNSP	ALLTE	FUSOX	FUSEQ	NEOPA
Apiaceae	*Daucus carota* L. cv. unknown; Carrot [a]	_	_	_	_	_	+
	Hydrocotyle verticillata L. Water pennywort [b]	_	_	_	_	_	_
Araceae	*Pistia stratiotes* L.; Water lettuce [b]	+++	+++	+++	+++	+++	+++
Asteraceae	*Guizotia abyssinica* cv. Fogera; Noug [a c d]	_	_	_	_	+	_
Brassicaceae	*Raphanus sativus* L. cv. unknown; Radish [c]	_	_	_	_	_	_
	Brassica oleracea capitata L. cv. unknown; Cabbage [a c]	_	_	_	++	+++	_
Chenopodiaceae	*Ipomea batata* (L.) Lam. cv unknown; Sweet potato [a c]	_	_	_	_	_	_
Cyperaceae	*Cyperus papyrus* L. Papyrus [b]	_	_	_	++	_	_
Compositae	*Carthamus tinctorius* L. cv. unknown; , safflower [a]	_	_	_	_	_	_
Cruciferae	*Brassica carinata* Cobs. cv. Holleta 1; Mustard [a c d]	_	_	_	++	++	_
Cucurbitaceae	*Cucumis sativus* L. cv. unknown; Cucumber [a c]	_	_	_	_	_	_
Fabaceae	*Phaseolus vulgaris* L. cv. Awash Melka; Haricot bean [a c]	_	_	_	_	++	_
	Glycin max (L) Merr. cv. Williams; Soy bean [a c]	_	_	_	_	++	_
	Cicer arietinum L. cv. Chefe; Chickpea [a]	_	_	_	++	_	_
	Vicia faba L. cv. Holleta 80; Faba bean [a c]	_	_	_	++	_	_
	Pisum sativum L. cv. Holleta 90; Pea [a c]	_	_	_	++	+	_
	Lens culinaris Medik *c* v. Chekol; Lentil [a c]	_	_	_	+	_	_
	Trigonella foenum-graecum cv. unknown; Fenugreek [a d]	_	_	_	+++	_	_
Lileaceae	*Allium sativum* L. cv. G-493; Garlic [a c]	_	_	_	_	_	_
	Allium cepa L. cv Shallot; Onion [a c]	_	_	_	_	+++	_
Malvaceae	*Gossypium hirsutum* L. cv. Arba; Cotton [a c]	_	_	_	_	_	_
Pedaliaceae	*Sesamum indicum* L. cv. Adi; Sesame [a c d]	_	_	_	+++	+++	_
Poaceae	*Hordeum vulgare* L. cv. Desta; Barley [a]	_	_	_	_	_	_
	Sorghum bicolar (L.) Moench cv. IS9302, Sorghum [a]	_	_	_	_	_	_
	Zea mays L. cv. Melkassa III; Maize [a c]	_	_	_	_	_	_
	Eragrostis tef (Zuccagni) Trotter cv. Kuncho, Teff [a d]	_	_	_	_	_	_
	Saccharum officinarum L, cv. B52298, Nco 334, N14; S	_	_	_	_	_	_
	Triticum aestivum L. cv. Asasa, Wheat [a d]	_	_	_	_	_	_
Rubiaceae	*Coffee arabica* L. cv. Gesha, Coffee [a d]	_	_	_	+	_	_
Pontederiaceae	*Eichhornia crassipes* (Mart.) Solms. Waterhyacinth	+++	+++	+++	+++	+++	+++
Solanaceae	*Lycopersicon esculentum* Mill. cv. Melka-Shola; Tomato [a]	_	_	_	_	+++	+++
	Capsicum pepper cv. Mareko-Fana; Pepper [a]	_	_	_	+++	+++	_
	Solanum tuberosum L. cv. Awash; Potato [a c]	_	_	_	_	_	_
Typhaceae	*Typha orientalis* Roscoe [b]	_	_	_	_	_	+
Umbelliferae	*Cuminum cyminum* cv. unknown; Cumin seed [d]	_	_	_	_	_	_

[a] plants of economic importance; [b] plants ecologically related to water hyacinth; [c] plants reported susceptible to test fungi; and [d] plants ecologically important. Bayer Code: ALLAL: +lternaria alternata, ALLTE: +lternaria tenuissima, ALLSP: +lternaria sp., ;3,ER:;usarium e6uiseti, FUSOX: ;. oxysporum and NEOPA:0eofusicoccum parvum.Disease reaction from leaf inoculation; - no reaction; + slight; ++ moderate;+++ severe leaf necrosis.

4. Joint Use of fungal pathogens and *Neochetina* weevils as biocontrol strategy of water hyacinth

Taking into consideration the prevalence of host-specific native fungal pathogens and adaptability of the two weevils, Firehun (2017)evaluated the integrated use of Oeochetina weevils and an indigenous plant pathogen (+. alternata) in controlling water hyacinth. The average numbers of ramets, leaves and inflorescences per plant recorded during week 8 were 0.45, 0.63 and 0.10 (Figure 6A, B, C), respectively, in water hyacinth plants treated with both Oeochetina weevils augmented with +. alternata. These values were significantly lower than in plants treated with O. "ruchi or O. eichhorniae augmented with +. alternata as well as in those treated with the combined application of Oeochetina weevils. However, both weevil species restricted flowering in a similar way when combined and when individual weevil species were augmented with +. alternata (Figure 6C). Eight weeks after establishment of insects and pathogens, the number of green leaves per plant diminished by 95% and the number of new ramets was reduced by 97% due to combined application of the two weevils with +. alternata.

Plants augmented with both agents had 85% lower plant fresh weight than in the control (Figure 7). Reduction in plant fresh weight was significantly higher in plants with the two weevils augmented with +. alternata (mean ± SE; 84.6% ± 1.94%) and plants that received only the weevils (75.3% ± 1.49%) compared with plants that received only +. alternata. This indicates that the integrated effects of the weevils and the fungal pathogen plus feeding damage by Oeochetina weevils created satisfactory stress on the plants to cause a very significant reduction in plant size and density. Similarly, Center and Van (1989) indicated that weevil herbivory resulted in a decrease in leaf and petiole length, an increase in leaf mortality and an overall reduction in plant biomass.

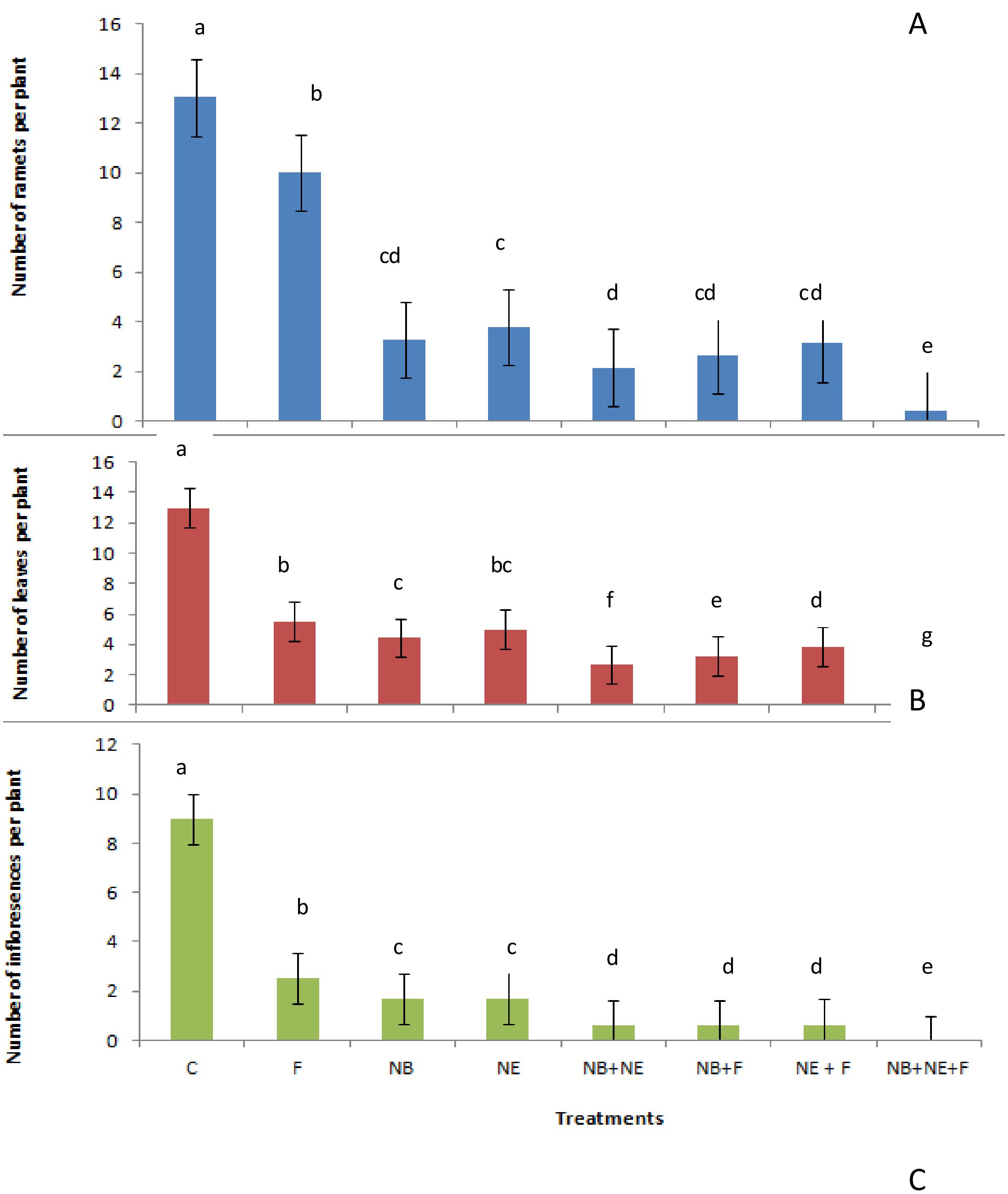
A
Number of ramets per plant
16
14
12
10
8
6
4
2
0
a
b
cd
c
d
cd
cd
e
B
Number of leaves per plant
16
14
12
10
8
6
4
2
0
a
b
c
bc
f
e
d
g
C
Number of infloresences per plant
12
10
8
6
4
2
0
a
b
c
c
d
d
d
e
C
F
NB
NE
NB+NE
NB+F
NE + F
NB+NE+F
Treatments

Figure 6. Impact of herbivory by 0eochetina weevils augmented with the fungal pathogen +. alternata after eight weeks on the mean number of ramets (A), leaves (B), and inflorescences (C). Treatments: C (control), F (applying only +lternaria alternata), NB (applying only 0. "ruchi), NE (applying only 0. eichhorniae), NB+NE (applying both weevil species), NB+F (0. "ruchi augmented with +. alternata), NE+F (0. eichhorniae augmented with +. alternata and NB+NE+F (both weevil species augmented with +. alternata). Means compared by two-way ANOVA; those with the same letter were not significantly different (Fisher's honest, P < 0.05). Error bars represent the standard error of the mean.

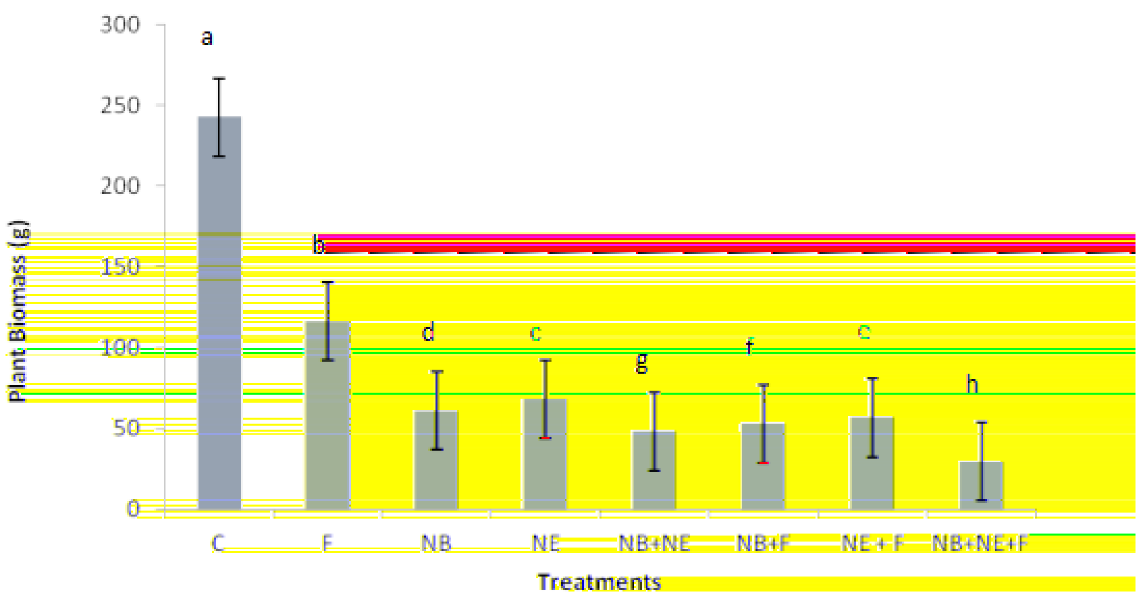

Figure 7. Impact of herbivory by 0eochetina weevils augmented with the fungal pathogen +. alternata on plant biomass. Treatments: C (control), F (applying only +lternaria alternata), NB (applying only 0. "ruchi), NE (applying only 0. eichhorniae), NB+NE (applying both weevil species), NB+F (0. "ruchi augmented with +. alternata), NE+F (0. eichhorniae augmented with +. alternata and NB+NE+F (both weevil species augmented with +. alternata). Means compared by two-way ANOVA; those with the same letter were not significantly different (Fisher's honest, P < 0.05). Error bars represent the standard error of the mean.

5. Significance of *Water-Watch-Ethiopia Application* in monitoring of water hyacinth

Active monitoring and evaluation of measures of invasive water weed control on large lakesare time and resource consuming. However, hyperspectral remote sensing based monitoring and evaluation tools have been effectively used in the past for quantifying spatial and temporal extent as well as the severity of such water weeds (Erin et al., 2008; Kate et al., 2011). From experience on the Lake Victoria, Caravalli et al (2007) used such tools to support and enhance the management of water body resources and for providing an inexpensive way to gather extent of weed infestation and optical parameter linked to the water body status. In light of such efforts "Water-Watch-Ethiopia" Application Tool (https://water-watch-ethiopia.appspot.com/) has been developed by Yalew and Yirefu (2018) and tested to generate preliminary information on Lake Tana (Figures 8 to 10). This application would support to monitor distribution of aquatic weeds and assess impact of management interventions (including use of bioagents) as it covers the entire water bodies (lakes) of Ethiopia.
''Water-Watch-Ethiopia' continuously checks for new satellite images covering a water body of interest submitted by subscribers (such as researchers and local or regional water body managers, etc.). It scans public databases (LANDSAT, MODIS, SENTINEL) images published at Google cloud servers (Moore and Hansen, 2011). Free subscribers and local water body managers can analyze, visualize, and download results of their computations of interest by selecting the water body of their interest. When the tool detects new satellite images from the public databases mentioned earlier covering the lake areasof interest, it automatically notifies local subscribers to check for the most recent status of the aquatic weeds in the lake. Subscribers or local water managers can compare latest satellite images (and associated statistical parameters) with older ones to see effect of a measure or current extent of the weed. Analyzed satellite image showing monthly changes in water weed coverage on any area of a selected water body will be sent via email and SMS to local water managers.

The full-fledged app is planned for release in the second quarter of 2018, but current commits and prototype can be checked via the web address. Some results from the prototype tool applied on Lake Tana are presented below.

Figure 8. Changes in the water body of Lake Tana from1984 to 2017

Figure 8 shows the permanently lost (dried) parts of the Lake in red and other stages of transitions of water loss on all sides of the lake borders (notice particularly the extend in the encircled areas on the figure). The transition to permanently non-water body on side of Gilgel Abbay (lower left) and the Gorgora (upper right), during these years is particularly significant. Based on our computation, about 5% water body area is lost (shown in Figure 9).

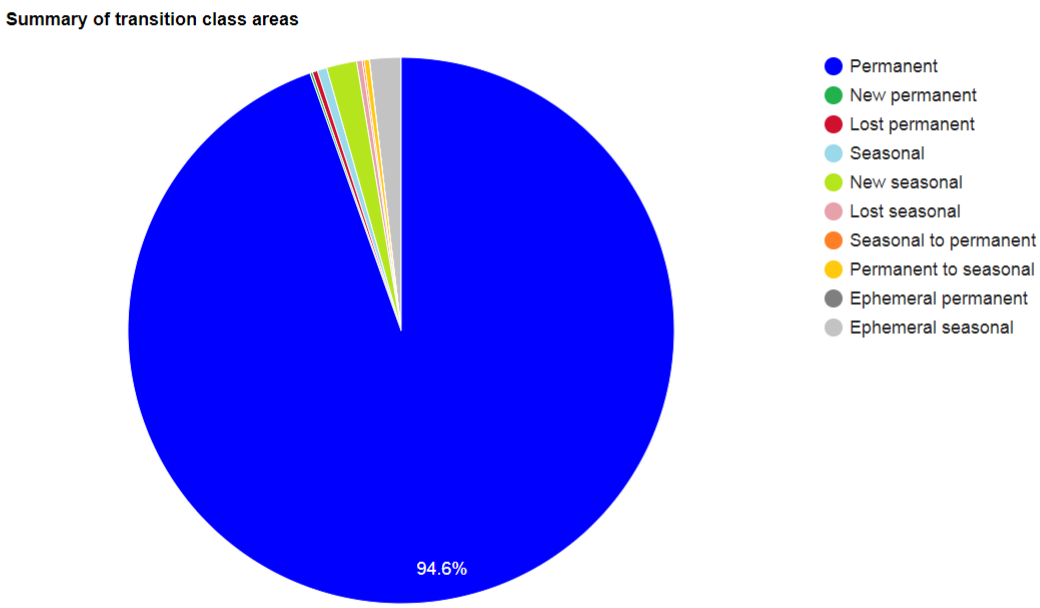

Figure 9. Water body transitions from1984 to 2017

The loss is attributed by several reasons contributing to shallowing lake borders, one of which is likely invasive water weeds. Interestingly, areas that are drying up, particularly on the top right in Figure 8, are locations reportedly highly affected by water hyacinth (check a closer look of the most affected area and the water loss in Figure 10).

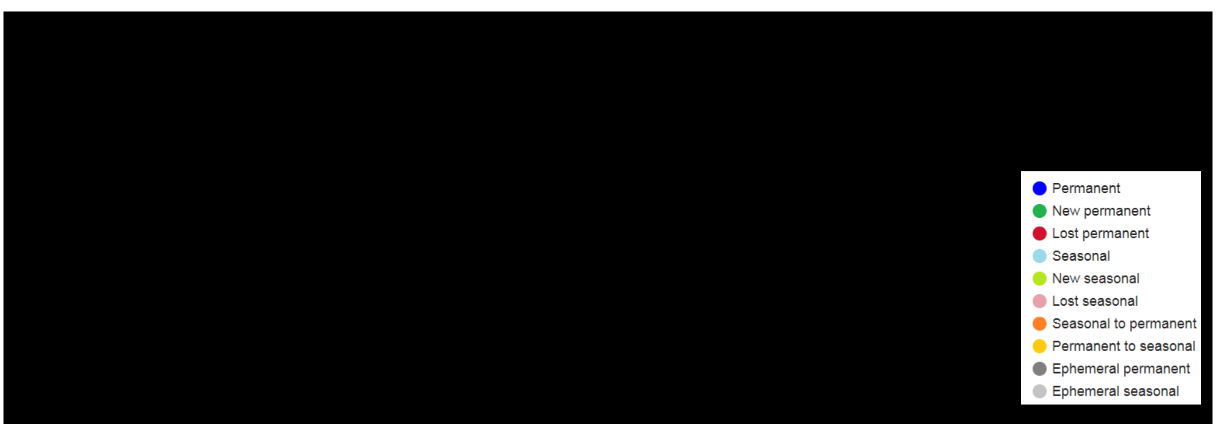

Figure 10. Water body transition from1984 to 2017 on water hyacinth affected part of Lake Tana.

However, there can be no simple parallelism here, so a closer investigation of the vegetation and hyperspectral parameters will reveal the correlations explicitly when the full-fledged Water-Watch-Ethiopia app is up and running.

6. Conclusion

Our review indicated the existing opportunity to use the 0eochetina weevils and indigenous fungal pathogens as bioagents of water hyacinth in Ethiopia. These bioagents (0eochetina weevils and the fungal pathogens) were proved to be host-specific and safe to release for large scale management of water hyacinth in Ethiopia. Moreover, for effective management of this noxious weed, it would be prudent to use the software both to assess the current distribution as well as impact bioagents in water hyacinth affected water bodies. In light of the foregoing's, the following key management actions are proposed to control water hyacinth in a sustainable way using fungal pathogens and weevils as bioagents:

- Among the fungal pathogens, +. alternata and +. tenuissima are recommended as possible biocontrol agents of water hyacinth;
- Both 0. eichhorniae and 0. "ruchi are recommended to be released together in large scale management programs of water hyacinth at herbivory loads of the weevils greater than one weevil per plant;
- Both 0. eichhorniae and 0. "ruchi are sufficiently host specific and, therefore, can be safely released for the management of water hyacinth; and
- Taking into account the synergy between fungal pathogens and the two weevil species it is advisable to augment the large scale release of the two weevils with fungal pathogens.

However, prior to release of these bioagents, it is advisable to understand the level of water hyacinth distribution (using ***Water-Watch-Ethiopia*** application tool) in all affected water bodies. This would enable to extend release of the biaogents in all affected water bodies and assess their impact thereafter.

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Identification of impacts, some biology of water hyacinth (*Eichhornia crassipes*) and

Introduction

Water hyacinth (*Eichhornia crasspies*) is widely recogni%ed as the world's worst aquatic weed. Originally exported from its native Amazonian basin because of its attractive flowers, the species rapidly established and spread throughout tropical, subtropical and warm temperate regions of the world (Julien et. al, 1AAA).It was indicated that this weed forms dense impenetrable mats across water surface, limiting access by man, animals and machinery. Moreover, navigation and fishing are obstructed, and hydropower, irrigation as well as drainage systems become blocked.The weed was first introduced into Africa through Egypt sometimes between 1879 and 1882 (Friend, 1989).It has been recognized as the most damaging aquatic weed in Ethiopia since its first presence in 1965 (Stroud, 1994; Luis et al., 2...; 4e%ene, 2..G).It has been recognized its presence in lake Tana in 2011. (Dereje Tewabe, 2015).Even though several efforts have been made by different parties, its expansion increased year after year.Therefore, there is a need to study some of its biology, impact on water quality, biota and current management options.

Objectives

- To examine some biology and biomass at different periods of a year
- To identify its impact on water quality, fishing activities and over all socio-economic challenges in the community
- To identify current management options and ways taken by the assigned parties and check its effectiveness and identify its drawbacks
- To identify its distribution, area coverage and direction from water hyacinth inception area perspective

Material and Methods

The study was conducted from July, 2013 to July, 2015 in the North-Eastern part of lake Tana. Sampling Sites were chosen from Fogera, Libokemkem and Dembia woreda and two sampling sites were selected from each woreda based on water hyacinth infested and water hyacinth free area Plant sample was collected from infested areas using quadrant and different parameters were recorded using sensitive balance and tape meter.

Measurement of physico-chemical parameters

- Dissolved Oxygen (DO), pH, specific conductance (K_{25}), Total Dissolved Solid (TDS), Salinity (sal) and Temperature (T) were measured in situ using YSI 556 multi-probe system
- Measurements of Ammonia (NH_3-N), Phosphate (PO_4-P), Nitrate (NO_3-N) and Total hardness were carried out using a portable water analysis kit (Wagtech international, Palintest transmittance display photometer 5000). Nutrient analyses were made in the shore area immediately after sample collection using water samples filtered through Whatman GF/C

Plankton sampling

Water samples were collected from each sampling station up to a depth of 1m using a bucket of known volume. Zooplankton and phytoplankton samples were collected by 80µm and 50µm mesh net filtering device. Collected specimens immediately fixed with 4% formalin and were fixed using Lugol's iodine solution respectively. Identification and enumeration of planktons was made using standard procedures. GPS readings, Structured questionnaire, focuses group discussion, rapid rural appraisal, key informants have been used.

Statistical analysis

Descriptive statistics, SAS, Landsat soft ware and Means were compared by means of one-way analysis of variance (ANOVA).

Results and discussion

During dry season sampling in 1m*1m= $1m^2$ there was 13 batches/m^2 area of water hyacinth with in a batch there was 8 individual plants which implies 104 plants/m^2 and 8.216±0.45kg fresh weight/m^2 this equals 82,160kg/ha = 82.16 tones/ha fresh weight can be harvested during the dry season of a year. In the contrary during the wet season with in 1mx1m= $1m^2$ it is found that 55 batches and 27± 0.61kg fresh weight/m^2 was recorded. In each batch there were a mean number of 10.6 plants. 583plants/m^2. 270,000 kg/ha= 270 tones/ha fresh weight can be harvested during the wet season of a year. Dry weight of water hyacinth has been analyzed following the procedures of solar drying system. As a result batches of water hyacinth root, leaf and petioles part has been dried and its dry weight found to be 84.36%, 62.5%, and 92.11% respectively.

The highest plant population count (308 plants/m^2) was recorded in Koka Dam followed by Lake Koka (298 plants/m^2), Lake Ellen (274 plants/m^2), Lake Elletoke (268 plants/m^2), Afer Gedeb (261 plants/m^2), Tare and Awash (211 and 186 plants/m^2) according to (Firehun et al., 2014).

Trends of water hyacinth coverage

Area coverage of water hyacinth has been increased in alarming rate. It's coverage at the inception period in 2011 was about 80ha to 100ha (Dereje Tewabe, 2015). After a year it can able to cover about 20,000ha (BoEPLAU, 2012). Even if tremendous amount of human labour, time and money has been exerted each year by both surrounding community and government it's coverage continues to escalate up to 50,000ha in the subsequent years ((Wassie Anteneh et al., 2014). This may probably due to lack of knowledge about the biology of the plant as a result failed in complete clearance including individual plant fragments tissues and lack of appropriate site selection for deposition of the biomass.

The input of fertilizer drained from the catchment area from crop cultivated land and homestead fuels water hyacinth to over dominate other floras in shore areas of the lake which would be important for fish breeding grounds and livestock forage source in the vicinity.

Fig.1. Water hyacinth infestation coverage was ca. 80-100 ha during 2011 in Lake Tana. (Dereje Tewabe, 2015)

Fig. 2. Map showing water hyacinth infestation during July 2012 estimated ca. 20000 ha (source: BoEPLAU, 2012)

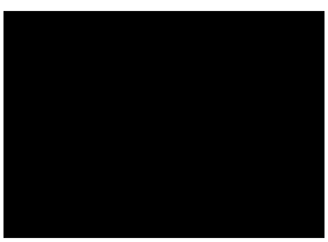

Fig. 3. A map showing the 50 000 ha water hyacinth infestation kebeles and woredas during August 2014 survey (Wassie Anteneh et al., 2014)

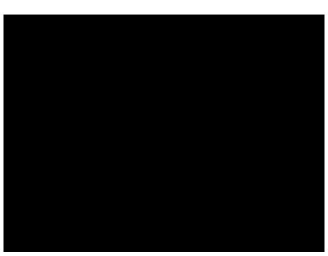

Fig. 4. Water hyacinth infestation current status on the shore of Lake Tana estimated to be ca. 34500 ha (May, 2015)

Table 1. Root, leaf and petioles measurement of water hyacinth during dry and wet seasons of a year

Period	**Different plant part measurements**						
	Root mean length (cm)	Root mean weight (gm)	Leaf mean length (cm)	Leaf mean width (cm)	Leaf mean weight (gm)	Petioles mean length (cm)	Petioles mean weight (gm)
Dry season	76±2.12	222±6.11	9.5±1.23	12.3±3.32	48.5±5.43	19.6±1.19	287.6±1.55
Wet season	58±3.21	1840±7.62*	8.7±2.33	12.1±2.23	172±4.22*	17.1±1.13	725±12.62*

* $P<0.05$

Table 2. Physico-chemical analysis

parameter	Weed Infested site	Non-infested site	
	Mean±SD	Mean±SD	P value
Temp (^{0}C)	25.57±3.4	24.12±1.95	0.346
PH	7.64±0.56	7.61±0.34	0.915
DO(mg/l)	5.34±0.87	5.99±0.67	0.140
S.Cond. (K_{25}) (µs/cm^3)	168.57 ±43.7	138.7±44.6	0.230
TDS(g/l)	0.109 ±0.03	0.092±0.03	0.306
Sal.(g/l)	0 .0757 ±0.022	0.064±0.022	0.356
PO_4 (mg/l)	1.31±1.25	0.46±0.39	0.184

NO_3(mg/l)	1.49±0.65	1.53±0.51	0.908
NO_2(mg/l)	0.0066±0.005	0.0196±0.023	0.210
TH(mg/l)	92.5±21.1	91.2±43.9	0.950
SO_4 (mg/l)	3.83±2.9	2.4±1.3	0.351
H_2S (mg/l)	0.030±0.014	0.023±0.024	0.578
Alk.(mg/l) as Ca CO_3	87.5±29.4	74.0±32.6	0.489
NH_3(mg/l)	0.046±0.076	0.096±0.14	0.469

Phytoplankton

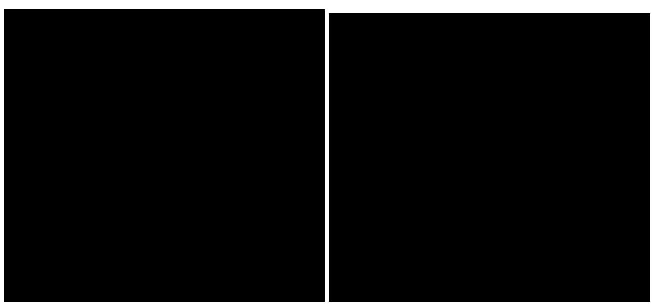

Fig. 5 Higher species diversity was observed in non-infested sites, while in the weed infested site, higher density of the majority of identified phytoplankton taxa.

Zooplanktons

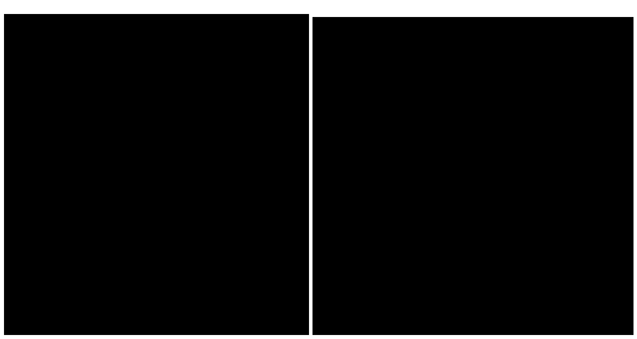

Fig.6 Rotifers contributed 65% in the non-infested sites followed by copepod and cladocera, but, in the weed infested sites copepod contributed 51% followed by Rotifer and Cladocera

Socio-economic impacts of water hyacinth

- There are benefits and costs that result from the presence of water hyacinth
- Costs are associated with:
    - Preventing
    - Managing or eradicating, and
    - Ecological impacts of those actions
- In agreement with a study by (kateregga & sterner, 2009) the most direct impacts are:
- Access for fishing ground and fish catch ability
- Navigation and recreation; and
- Difficult to pump water for recession agriculture

Fig. 7 Thick mats and wide coverage of water hyacinth at its blooming period blocks all access to open water of Lake Tana (October, 2017)

Impacts of water hyacinth on fishing

- Water hyacinth provides highly complex habitat structure by restricting the growth of other submersed macrophytes.
- modification at the surface of the water adds habitat complexity that likely affect fish assemblage (meerhoff et al., 2003).

- Cost of controlling water hyacinth infestations is a function of:
    - The rate of removal
    - Cost of labour
    - Cost of equipment and the frequency of treatment.

	N	Min.	Max	Mean	Std. Dev.
Extra hour for detaching from the gear and boat	20	1	12	5	3.528
How much you incur for fishing gear damaged	16	200	5000	1721.7	1470.072
Birr you allocate for purchase animal feed	18	300	5000	1240	1223.461
How much you incur for cow medication	20	50	200	120	63.509
How many times you clean your farm land for sow Teff	20	1	5	2.7	.946
Labour required to clean "timad" of land per day	20	4	60	19.2	17.651

- ✓ Water hyacinth can greatly affect fish catch rates because mats of water hyacinth:
    - Blocks access to fishing grounds
    - Clogging and damaging eye of net, and
    - Increasing costs (effort and materials) of fishing
    - Furthermore, water hyacinth tear gillnets and damage boat's motor which accrue to cost of fishing.

- ✓ Fishers invest extra time on detaching water hyacinth parts from gillnet after catching.
- ✓ Fishers put gillnet in non infested area but when the wave starts the fishing gear becomes covered by water hyacinth== loss gillnet
- ✓ Additional labor and fuel cost for finding their fishing gear and repair damaged gillnet.
- ✓ In the area of severe infestation fishing is difficult especially around the shore area
- ✓ This could strongly affect fishers that use artisanal fishing boat.
- ✓ In general area infested by water hyacinth reduces efficiency of fishing

Fig. 8 water infested by water hyacinth that hinders swimming and boats

Impacts of water hyacinth on livestock

- ❖ The study areas are known by potentially rich dairy cattle breeds known as fogera breeds.
- ❖ The shore area of Lake Tana was reach in submersing grass (including hippo grass) which feeds lots of cattle.
- ❖ But now a day due to expansion of water hyacinth, the submerging grasses becomes devastated. These affects benefit obtained from cattle.
- ❖ According the study, some respondents are purchasing supplementary feeds for their livestock
- ❖ After the freely grazing land have been infested by water hyacinth and devastated.

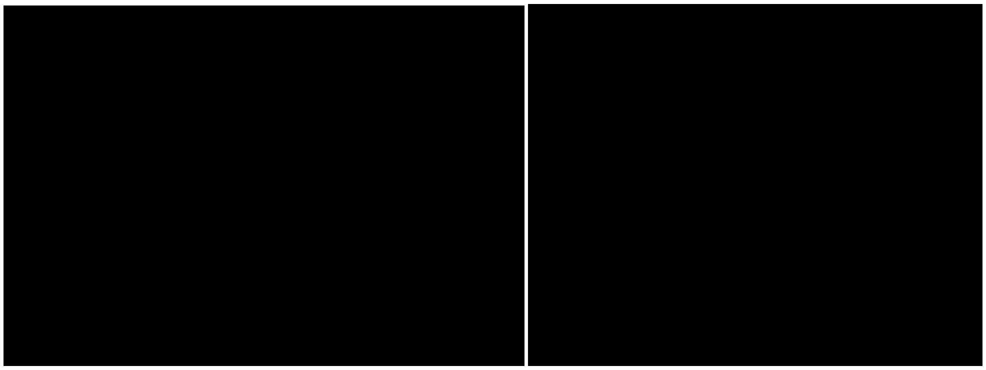

Fig.9 **Grazing land and shore side of a lake infested by water hyacinth**

Impacts of water hyacinth on crop production

- ✓ The collected water hyacinth (heap) has noticeable effect of farm management because of they took large place and make the farmland fragile.
- ✓ Farmers in the study areas sow crops when the water starts to shrink with simple adjustment of the plot.
- ✓ Unlike the last five years, managing the farm lands for cropping becomes labor intensive
- ✓ After the water become shrunk water hyacinth stay on the farm by penetrating its long root to the ground.
- ✓ Therefore, farmers clean their farm land for planting crop by family and employed laborers.
- ✓ Based on the survey, 19 laborers in average are required to clearing 0.25hactare of land.
- ✓ The other challenge associated with infestation of water hyacinth is where to put the collected water hyacinth???
- ✓ Farmers put the collected water hyacinth as a terrace from many places
- ✓ Makes the plot fragile and makes the plot difficult to manage.
- ✓ In addition, mat of water hyacinth and azolla during flooding and wave time makes rice production frustrating by totally covering the rice.
- ✓ Most of the interviewed farmers agree that water hyacinth makes the farmland more compacted by its long root

- ✓ Difficult to plough the farm land

Fig.10 farmlands overcrowded by heap of removed waterhyacinth

Ecosystem impacts

- Restricting the growth of other submersed or emergent macrophytes. Loss of native habitat
- Affect diversity, distribution and abundance of life in aquatic environments.
- Lead to de-oxygenation of the water, thus affecting all aquatic organisms.
- It is known that a dense cover of water hyacinth enhances evapo-transpiration
- The death and decay of water hyacinth vegetation in large masses create anaerobic conditions and production of lethal gases.

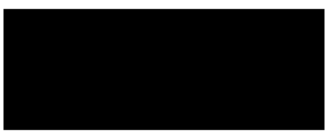

Fig.11 Burning collected and dried water hyacinth

Conclusion

Water hyacinth which was ca. 80-100 ha in 2011. Eventually, it spread into eastern part of the lake and reaches ca. 50,000 ha. The impact of water hyacinth on water quality was not significant.The present assessment also noted that no major management strategy had been employed in the infested water body areas, despite many efforts had been applied by the community and the government. Eichhornia crassipes remains a major lake Tana ecosystem problem, especially in fisheries, irrigation, transportation, hydropower and ecotourism sectors.

Recommendations

- Multidisciplinary research should be carried out on:
    - Their effects on the aquatic systems
    - Potential benefits to both humans and other organisms;
    - Relationship with submersed vegetation, cattle health and farm productivity
- Control strategies should take into account the potential effects on the flora and fauna found in the water body.
- Harvested water hyacinth have to put into valuable way
- Manual control method which currently applied should be revised based on the biological nature of the plant.
- Integrated approach has to be implemented such as manual, mechanical, chemical and biological methods through scientific procedures
- There is need for improvement of land use management in the catchment and along the rivers so as to reduce silt and nutrient loads

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General papers

Status of Plant Health Regulatory and Pest Management Service in Ethiopia

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BACKGROUND

Although undocumented, pest management in Ethiopia has been going on for ages by traditional farmers who have been depending on the use of their indigenous knowledge and practices to manage pests of crops including insect pests, plant diseases, weeds, invasive species and vertebrate pests such as birds and rodents. Nevertheless, in general, before the 1950s in Ethiopia agriculture was diversified and follows old custom trends in most of the country and farms used to experience extensive crop losses due to pests' damages. In the 1950s the Ministry of Agriculture made great strides in plant pest control and started giving increased attention to other important pests besides the desert locust, which was taken as number one pest affecting crop production in general (PMSS, 2015).

With the effect of increased occurrence of pests, a permanent plant protection section to handle study of crop pest problems, demonstration of modern equipment and pesticides, and training personnel and performing import, export and domestic plant quarantines has been established by Ministry of Agriculture (USDA, 1958). Moreover, basic plant pest law which was developed in 1971 under which the Ministry of Agriculture could carry out control programs and operate and enforce plant quarantine regulations was proclaimed in 1992. National plant protection laboratories were established in 1977 with the objective to provide effective crop protection laboratory and technical support services furnished with adequately equipped, staffed and organized laboratories to provide plant protection support services.

Organizational structure revision was made the mid-1980s and it was raised from division to a department level. Nevertheless due to the widening service need the capacity of the national plant protection support system was found inadequately equipped in terms of both support facilities, such as laboratory services, and trained manpower, either to monitor endemic and epidemic situations of insect pests, plant diseases and weeds effectively or undertake and promote control measures at the national and local levels. Because of this further institution building activities were carried out between 1987 and 1992 which resulted in revision of the organizational setup the Crop Protection and Regulatory Department as subdivided into two Divisions: Crop Protection and Plant Quarantine. Crop protection Division gives extension service on migratory and regular pests and the Plant Quarantine Division had units for handling policy and regulations on the import and export of plant materials, operations, and technical aspects of quarantine. By 1992 it was confirmed that the crop protection and regulatory department was rated competent with respect to insect pests, disease causing pathogens, weeds, and vertebrate pests monitoring, surveys, surveillance, identification, and extension and training and in certain cases it was able to provide advice on control (UNDP/FAO, 1993).

Another reorganization underwent and the department in merging with the crop production department from which the crop production and protection technologies and regulatory department was formed after 1992. The crop protection was regressed and organized at division level by merging the different units in the two divisions and forming three teams: crop protection team, crop protection laboratories and quarantine team and pesticides registration team (MoANR, 2000 and Merid Kumssa, 2004).

As he Ministry of Agriculture was again reorganized in 2004 and was renamed Ministry of Agriculture and Rural Development, crop production and protection technologies and regulatory department was also dissolved and the crop protection and plant quarantine was put under a new directorate, Crop Protection and Regulatory Directorate. The mandate of the directorate was revised and made to include all measures necessary to: conduct quarantine controls on plants, seeds and prevent outbreaks of plant diseases and insect pests

In 2008 there was a total shift in the thinking and direction of the Ministry of Agriculture and Rural Development on the ways and how of providing pest management support services in the country at large. In line with this, the crop protection and regulatory directorate was subdivided and the pesticides registration and control, migratory pest control support and the pest regulatory components were maintained within the newly formed Animal and Plant Health Regulatory Directorate (PMSS, 2015).

Quarantine pests management support service Addressing pest regulatory issues using the countries system and procedures are very apparent at the federal level but it is focused only on promoting or facilitating the export and import of mainly raw agricultural produces' using the defined procedures in the regulatory guideline and the support documents such as the quarantine pest checklist, which spanned several decades without being updated. On the other hand, the pest management of regular pests is majorly undertaken by regional agricultural bureaus whereas the coordination and backstopping for migratory pest controls are supported by the federal ministry of agriculture and natural resources.

Revision and up grading of phytosanitory measures and procedures that are in use to meet international phytosanitory standards and to tackle emerging phytosanitory problems has not been done for many years. Thus, enforcement of phytosanitary measures has been constrained by a number of things such as shortage of enough trained personnel, physical capacity, and lack of phytosanitary law. Moreover, the regulatory directorate has not been organized in a way it can give rapid response to arising plant quarantine related problems. Moreover, there are no enough resources to do pest risk analyses as needed due to lack of well documented check list of quarantine pests to Ethiopia and expertise to do the job as needed.

CURRENT STATUS OF PLANT QUARANTINE AND PEST MANAGEMENT SERVICE IN ETHIOPIA

PEST MANAGEMENT

Currently, due to climate change, increase of agricultural investment, global trade, expansion of irrigation, poor agronomic practices, weak survey, monitoring and early warning system recurrent pests upsurge and introduction of new pests are increasing year after year. Due to loose link of federal and regional bureaus and absence of Plant protection process owner in organizational structure of region bureaus of agriculture status of major economic pests have not been routinely surveyed, monitored and their seasonal situation not properly documented and communicated; informed pest management control decisions have not been taken rather the system has been responding to emerging problems in a tactical rather than strategic manner. Since migratory pests survey and management is owned by Federal Ministry plant protection directorate in collaboration with region bureaus of agriculture, regular pests management has been largely left for farmers to handle by their own mainly by using generic pesticides, except technical assistance given by district plant protection experts and rural extension agents. Moreover, pest management tactics aside from synthetic organic pesticides have not been receiving sufficient attention from users. Due to these, there has been upsurge of regular pests, establishment and spread of new pests, misuse and abuse of pesticides resulting in the development of pesticide resistance in major economic pests, and pests, which had local importance have turned national problems such as sweet potato virus diseases, bacterial wilt of potato and pepper, late blight of tomato, maize stalk borer.

As clearly shown in the current situation described above, undertaking a strong capacity building in the areas of plant protection will allow plant protection support services to provide as required and ensure transfer of plant protection technologies and knowledge to farmers. Therefore, special attention should be given to the federal plant protection laboratories and the plant health clinics (PHCs) as they were developed to provide the service of pest management in coordination. Strengthening the national plant protection laboratories will help the country prevent new pests from establishing, to take rapid response to eradicate intercepted new pests; manage regular, sporadic, invasive alien plant species and migratory pests. Moreover, strengthening the PHCs and increasing their number will help the country successfully carry out routine pest surveillance, survey and monitoring and technically support farmers to decide to control pests only when it is found appropriate and also to coordinate actions to control pest outbreaks.

PLANT QUARANTINE ESTABLISHMENT AND SERVICE IN ETHIOPIA

The International Plant Protection Convention (IPPC) is an international treaty in force since 1952 to prevent the introduction and spread of pests of plants and their products and promote appropriate pest management measures. Where deemed appropriate provisions of the IPPC may be extended to articles capable of harboring or spreading plant pests, such as soil, packaging, conveyances and storage facilities. As of May 2016, 182 countries are signatories to the IPPC (93% of the countries in the world), which recognizes that phytosanitary measures should be scientifically justified, transparent and applied so as not to constitute disguised trade barriers. The IPPC provides a framework for the development of international phytosanitary standards and the application of phytosanitary measures. Parties to the IPPC agree to cooperate on information exchange and on the development of standards and to fulfil the objectives of the IPPC in their own countries according to their competencies. They also agree to promote the provision of technical assistance to other contracting countries, especially those representing economically disadvantaged areas, to facilitate the implementation of the IPPC. Provisions for settling disputes concerning phytosanitary quarantines and measures are also provided.

The governing body of the IPPC is the Commission on Phytosanitary Measures (CPM), membership of which includes all contracting parties. The CPM is supported by a secretariat which resides with the Food and Agriculture Organization of the United Nations (FAO). The Secretariat assists the CPM in reviewing the state of plant protection in the world and the needs for phytosanitary actions. The CPM establishes its work program and adopts International Standards for Phytosanitary Measures (ISPM). It also establishes non-binding procedures for settling disputes among contracting parties. Subsidiary bodies may be established by the CPM to perform other tasks as may be necessary for the proper fulfilment of the objectives of the IPPC. It also cooperates with other relevant international organizations on matters covered by the IPPC and adopts guidelines concerning the establishment of regional plant protection organizations (RPPOs).

IPPC being a body at international level has a power to organize different regional plant protection organizations established at different regions of the world: European and Mediterranean Plant Protection Organization (EPPO) established in 1951, Inter-African Phytosanitary Commission (IAPSC) established in 1954, Organismo International Regional de Sanidad Agropecuaria (ORSA) established in 1955, Plant Protection Committee for the South- East Asia and Pacific Region (SEAPPPC) established in 1963, Near East Plant Protection Committee (NEPPC) established in 1963, Comite Interamericano de Proteccion Agricola (CIPA) established in 1969, Organismo Bolivariano de Sanidad Agropecuaria (OBSA) established in 1969, Caribbean Plant Protection Commission (CPPC) established in 1969, Near East Plant Protection Organization (NEPPO) established in 2012 and COSAVE in 1980.

The IPPC obligates each contracting party to identify its official NPPO. Of course, countries that are not parties to the IPPC may also have official plant regulation and protection agencies. Ethiopia became signatory of IPPC after issuing plant protection decree No. 56 of 1971 and proclaimed plant Quarantine regulation No. 4/1992 which specifies Ministry of Agriculture which is now renamed Ministry of Agriculture and Natural Resources as an organization mandated to operate activities of Plant quarantine centrally. In addition, as countries are also encouraged to become members of their local regional plant protection organization (RPPO) to get different advantages to undertake their activities in the area of plant health, Ethiopia became a member of Inter-African Phytosanitary Council (IAPSC). Membership of these bodies imposes certain organizational obligations described in IPPC and in the regional cooperation. The operations are: first, according to IPPC Article VIII a single central government authority is required the establishment of an official NPPO. And the IPPC (Article VIII) also require the designation of an enquiry or contact point for the dissemination of information on plant pests and national phytosanitary regulations. For these, it is sensible to satisfy requirements with a single government post or office, which normally would be a part of the administrative sector of the NPPO. Based on the requirements, Ministry of Agriculture and Natural Resources designated Plant Health and Quality

Regulatory Directorate which was formerly called Crop Production and Protection Regulatory Department as a responsible NPPO and the head to it as a focal person.

PESTICIDE REGISTRATION, USE AND HANDLING

Power to control registration, use and handling was given to the Ministry of Agriculture on provisions of Special Decree No 20/1990 and Pesticide Registration in Ethiopia was started in 1996. With some important modifications and revisions, this proclamation was replaced by Pesticide Registration and Control Proclamation No. 674/2010 which was effective since August 25/2010. Although pesticide regulation based proclamation was not issued and in progress, pesticide registration, use and handling activities are still undertaken.

In this regard, pesticide registration goes through application for registration upon submission of samples for efficacy trial and dossier evaluation done in the ministry of agriculture and natural resources by different professionals and forwarded for pesticides registration national committee.

In the process of pesticide registration, shortage of trained man power, Lack of awareness on pesticide related legislations Illegal and low quality dossier are some of the problems encountered.

Lack of laboratory to conduct quality control of imported pesticides, repeated request to import pesticides manufactured before 6 months (in opposing Article 17 sub-article (3)(a) of the proclamation, release of pesticide consignments from customs without inspection and issuance of import authorization by the Ministry ((in contradiction with Article 17 sub-article (3)(c) of the proclamation), tendency to import un registered pesticides and Illegal importation are some of the import control problems.

Misuse of pesticides, Poor storage, transportation and stock management - both in public and private sectors, illegal labeling, diversion of pesticides from flower forms to illegal retailers, accumulation of obsolete pesticides and contaminated materials, Abuse of empty pesticide containers and unsafe disposal are the major Pesticide Use and Handling constraints.

LEGISLATION CONCERNING PLANT PROTECTION IN ETHIOPIA

In Ethiopia, the importation and exportation of plants, plant products and other regulated articles and plant pest control in the country is controlled under the Plant Protection Decree of 1971 (No. 56/1971) which gives the Minister of Agriculture powers to prohibit, restrict and regulate the import and export of plants and plant products and any other regulated article which is liable to carry pests. In specific the decree gives the Minister powers like that require import permits for importation of plants; require inspections for imports and exports; issue phytosanitary certificates for exports; treat imported plants and plants for export; treat conveyances which may be infested; specify ports of entry; quarantine or detain plants to be imported as they are suspected infested or infected and prescribe precautions to be taken; require phytosanitary certificates and other documents from the country of origin to accompany plants to be imported. Concerning plant pest control in the country, the decree gives the following powers: to take appropriate measures for the prevention and control of attacks by or the spread of plant pests; in specific, to treat destroy and dispose of any plant, plant products, or other articles infected or infested or likely to infect or infest any plant, plant product or other articles; to prohibit, restrict and regulate the removal or transport of any plant, plant products or other articles from one area to another; to control and destroy any plant pest; to prohibit, restrict and regulate the movement, cultivation and harvesting of any plant in any specified area; to require the reporting of the occurrence of any specified plant pest; to require the collection and transmission of specimens of any specified plant pest or infected plant; to specify the methods of planting, cleaning, cultivation, harvesting and movement to be taken for the prevention or control of attack by or the spread of plant pest within Ethiopia; to issue any revoke licenses and to inspect nurseries in which plants are reared for the purpose of sale or barter and to regulate the sale or removal of plants, whether in the nurseries or not; to require treatment of any building or conveyance known or suspected to have been for the storage or transport of anything likely to infect or infest; to quarantine infected or infested area and to prohibit, restrict and regulate the tapping of and infected or infested plants.

To put the points stated under article 3 of the decree formulated in action, Plant Quarantine Regulation No. 4/1992 of the country was proclaimed and it comprises the following points: all imported plants and plant products which can carry pests and diseases are subject to quarantine as stated in Article 3; No person shall import into Ethiopia any plant and other articles as specified in Schedule I unless he/she is in possession of an import permit duly issued to him by the Minister; Application for such permit shall be made to the ministry on the relevant form prescribed and provided by it as stated in article 4, any plant or other articles as specified in Schedule I of the regulation which is to be imported into Ethiopia shall be accompanied by a phytosanitary certificate; any plant or other articles being exported from Ethiopia shall be accompanied by a phytosanitary certificate, if such is required by the importing country as stated in article 6. Whereas, points specified under article 4 of the decree concerning plant pest control within the country were not made actionable in terms of regulation or any other means.

PHYTOSANITATION IN RELATION TO ETHIOPIAN SYSTEM

Phytosanitary system and regulation depends on three main areas of activity: policy formulation and coordination; scientific and technical advice and related research; and inspection and enforcement. These three disciplinary sectors must be represented in any efficient NPPO, but within the organization can be combined or separated to varying degrees, depending on national circumstances (Ebbels, 2003). It is usually beneficial for these three areas to be under a unified command, but sometimes historical factors make this difficult to achieve. Nevertheless, it is frequently possible to make arrangements for operation, which create a similar effect. For example, a unified control of the budget for all three sectors, or provision of inspection or scientific services under contract, can often allow the head of the NPPO to exercise effective control. The Ethiopian quarantine services majorly focus on inspection and enforcement which partially or totally lacks the other two areas of activity. The policy formulation and coordination, scientific and technical advice and related research to phytosanitary service are not exiting, if ever there, are under totally separate command and the results expected are confusion, particularly in areas such as prioritization of tasks and allocation of resources. This can be counterproductive, encouraging unnecessary administrative complications and unhelpful rivalry. It also will contravene the international obligations to which the country is signatory. Each of the three sectors has firm links to each of the others and a strong unified or coordinated service should result from mutual support.

POLICY AND ADMINISTRATION

As in most areas of government, well-considered and technically justified policy decisions are the key to efficient programmes and services. This administrative activity benefits by being part of core government in order to reflect current government policies and to ensure that the NPPO is regarded as an integral part of the government of the day, with consequent authority. Although there are examples where the delegation of phytosanitary policy to peripheral government agencies or government-sponsored bodies works well, such an arrangement may lay it open to undue or inappropriate sectoral influence, which usually detracts from its effectiveness and may encourage neglect by core government, both administratively and financially. There are as many styles of policy making and organizational structure as there are governments, and different styles can be equally effective. However, to avoid impractical policies and waste of resources, policies need to be based on up-to-date and reliable information.

This Operation of NPPOs can be obtained by close cooperation with both the other sectors of the NPPO and by effective consultation with interested stakeholders (such as the relevant parts of the agricultural and forestry industries, traders, and appropriate environmental groups) before important decisions are taken or new initiatives started.

Besides policy formulation, policy units often also undertake routine administrative tasks, such as international contacts and liaison with other parts of national government. Negotiations and discussions, both international and intranational with various interest groups, occupy much effort in the day-to-day operation of phytosanitary services. The lead in these is normally taken by the policy and administrative sector, but as scientific and practical problems or concepts are frequently considered, support by specialist scientific or inspection personnel is often essential. This is particularly so when major initiatives on surveys or eradication campaigns are being planned.

The essential administration of the service may be undertaken by a central group, perhaps attached to the central policy unit, or by the operations part of the service. It may include the administrative supervision of eradication campaigns, the issue of permits and licenses, the administration of healthy stock schemes, making notification reports, compilation of statistics and maintenance of records. The administration often also acts as facilitator in making arrangements for provision of services for other parts of the service, For example, in arranging for translation of foreign regulations before they can be interpreted scientifically. All the above activities to be undertaken by the policy and administration section and sole part to give efficient accomplishment is absent in Ethiopian phytosanitary system.

SCIENTIFIC ADVICE AND RESEARCH

The main tasks of the scientific part of NPPO are: to provide laboratory services for identification of harmful organisms in support of phytosanitary inspections, surveys and surveillance; to provide advice on and interpretation of the scientific aspects of national and international legislation or other regulations; to carry out pest risk analyses which only be undertaken upon request; to provide scientific support, training and advice to other parts of the NPPO during negotiations, or when planning policy or executing initiatives such as surveys or eradication campaigns; and to advise on the scientific aspects of certification schemes and issue of licenses and permits.

Ancillary but complementary to these tasks is the need to carry out related research to improve testing or identification procedures, to investigate pest biology where necessary to help in assessing threats and developing effective eradication measures, and to keep up to date with scientific advances in relevant disciplines. In the scientific advice and research area no activity is being undertaken in the Ethiopian phytosanitary services. As this area is key for improvement of the system, special attention by the government and professional should be given.

INSPECTION AND ENFORCEMENT

This area of activity is usually covered by specialized personnel of phytosanitary inspectors, forming a phytosanitary inspectorate, under Ethiopian condition where the activity is arranged under Plant health and Quality inspection Directorate in the ministry of agriculture. Plant quarantine inspectors are responsible for import and export inspection of any unprocessed and semi processed agricultural products, pesticides and fertilizers. In some countries, especially in those with very limited resources, there is a temptation for the duties of phytosanitary inspector and agricultural advisor to be combined as in the Ethiopian case where an inspector undertakes inspection of agricultural products and inputs and also where the responsibility of inspection is given to extension officers. However, this should be avoided wherever possible as it inevitably leads to conflicts of interest and detracts from the reputation and efficiency of both services. Phytosanitary inspectors need to have good basic scientific and agricultural qualifications, as well as training in the more specialized aspects of the work, such as the phytosanitary legislation, techniques for inspecting various plants, plant materials and other objects under very varied circumstances, and in the recognition of plant pests. This was done based on the human resource requirements and job description of the ministry used during recruitment session but induction and continual training of inspector which is very important is not part of the session. They need to be familiar with current horticultural, agricultural and forestry practices and, as they are usually the public face of the NPPO, they need to be able to carry out their duties in a friendly but firm fashion.

On the other hand, depending on large area of Ethiopia, there may need to be more senior inspectors responsible for organizing and coordinating inspection work over larger areas or in certain sectors of activity. Whatever organizational structure is adopted, the phytosanitary inspectorate should be responsible to the head of the NPPO and should have good and rapid means of communication, and both within its own organization and with other parts of the service and these are partially fulfilled in the Ethiopian system.

FACILITIES AND EQUIPMENT

The administrative arm of an NPPO requires normal office facilities and the scientific arm requires scientific laboratories for biological work. For the Ethiopian NPPO and out reached stations, the office facilities were fulfilled, but the laboratory and its facilities do not exist. In principle, where such laboratories dedicated to phytosanitary work are not established within the public service, this work is sometimes contracted operation of NPPOs out to university departments or other institutions in the activities are networked. Although such equipment may be more or less sophisticated according to the budget available, the scientific equipment and facilities required for phytosanitary work are not particularly specialized, except for quarantine containment for plants or pests. The phytosanitary inspectorate also requires good quality equipment and appropriate facilities to produce high quality and reliable results, and this must not be overlooked.

Even though the transportation facilities for the service are inadequate under Ethiopian condition, phytosanitary inspectors need to be mobile and able to travel immediately and quickly to deal with potential problems at places of plant production or points of import, so they must have ready access to dedicate and reliable motor transport. In the Ethiopian phytosanitary system, much of the necessary equipment consists of protective clothing of one kind or another, including waterproof jackets, trousers and headgear, rubber boots, overalls, are delivered to the inspectors at a regular bases but, safety helmets for use where heavy items are being lifted are not in the list of such protective clothing.

Upon establishment of central identification phytosanitary laboratory, disposable Overalls and Overshoes which will frequently be used and appropriate disinfectant for use on footwear and utensils may need to be available. For inspectors working at station, a good-quality folding knife and a hand lens, equipment for sampling and lifting plants which include garden forks and spades, trowels, knives, pruning secateurs, polypropylene bags of various sizes together with fasteners, marker pens, labels and reliable torches (flashlights) should be available; among which some are in use by the inspectors in the country. Other equipments which are necessary but not available are: suitable augurs, cheese scoops or trowels are needed and more specialized equipment necessary for many tasks such as sampling seed and grain, for which mechanical or manual sampling spears and riffles for mixing and subdividing into official samples.

BORDER INSPECTION POSTS

Border inspection posts activity is practical under Ethiopian context that inspectors are assigned to different Plant Quarantine station distributed throughout the country. Settings of stations started in early 1980s in southern at Moyale; Eastern at Dire Dawa; North Western at Humera Western at Metema at central at Nazareth and before dismantling of Eritrea at Asmara, Massawa and Assab. But as international movements of agricultural products increases Modjo and Gelan Dry ports , Mekele, Gonder, Kombolcha, Bahir Dar, Mehoni, Assossa, Gambella, Jigjiga, Mile Dry port and Shire were proposed to be opened, among which Modjo and Gelan dry ports, Gonder, Mehoni and Kombolcha are functional.

MAJOR PLANT HEALTH REGULATORY AND CONTROL ACTIVITIES UNDER ETHIOPIAN CONTEXT

REGULAR PESTS MANAGEMENT SUPPORT SERVICE

In the last about one decade, the pest management support service that has been given by the MoANR to smallholders was declining and significantly reduced in the last about five years and has reached its lowest point since the pest management support service was started with the control of desert locust more than six decades ago. This is due to a number of reasons including: the repeated reorganization the pest management support service underwent, the weak organizational structure adopted in the latest past years, lower emphases given to pest management by decision makers, limited budget allocated, staffs assigned and facilities developed, which have been affecting the conduct of surveillance, survey and monitoring of regular pests, hence, resulted in loosely regulated pesticides use by farmers and the free movement and utilization of plant materials with unknown health and quality. The above challenges were clearly identified in the strategy document to be resolved but still not fully addressed.

IMPORT AND EXPORT NSPECTIONS

Ethiopia exports different types of agricultural products since long time ago. These are pulse crops like beans of different types, chickpeas, Lentils, Horse beans, Peas, Lupines, Pigeon pea; Oil crops like Sesame, Niger seeds, Cotton seeds, Peanut, Rape seeds; Cereals like maize sorghum, Wheat, Barley; Fruits like banana, orange papaya; Vegetables like tomato, potato, onion; Spices like cumin seeds, coriander, cardamom; Stimulants; flowers and herbs. In export control system, due to absence of traceability of product and analysis at accredited laboratories several interception reports on non-compliance have been sent to the NPPO. Causes of non-compliances are pesticide residues above acceptable limits, aflatoxin and presence of quarantine pest in the consignment.

The objective of a phytosanitary import regulatory system is to prevent the introduction of quarantine pests or limit the entry of regulated non-quarantine pests with imported commodities and other regulated articles. An import regulatory system should consist of two components: a regulatory framework of phytosanitary legislation, regulations and procedures; and an official service, the NPPO, responsible for operation or oversight of the system. The legal framework should include: legal authority for the NPPO to carry out its duties; measures with which imported commodities should comply; other measures (including prohibitions) concerning imported commodities and other regulated articles; and actions that may be taken when incidents of non-compliance or incidents requiring emergency action are detected.

In operating an import regulatory system, the NPPO has a number of responsibilities that have been identified in Article IV.2 of the IPPC (1997) relating to import including surveillance, inspection, disinfestation or disinfection, the conduct of pest risk analysis, and training and development of staff. These responsibilities involve related functions in areas such as: administration; audit and compliance checking; action taken on non-compliance; emergency action; authorization of personnel; and settlement of disputes. In addition, contracting parties may assign to NPPOs other responsibilities, such as regulatory development and modification. NPPO resources are needed to carry out these responsibilities and functions. There are also requirements for international and national liaison, documentation, communication and review.

In Ethiopia importation of agricultural products for consumption and as planting materials and growing media is radically increasing every year. Due to the failure of effective import control service system as a result of lack of reliable identification service and qualified personnel to provide efficient quarantine service a number of pests have found their ways to newer areas in different parts of the country and have been causing significant economic damage to different crops. This include cotton mealybug, Phenacoccus solenopsis Tinsley (Hemiptera: Pseudococcidae), South American tomato moth, Tuta absoluta (Meyrick) (Lepidoptera: Gelechiidae), Citrus woolly whitefly, Aleurothrixus floccosus (Maskell) (Hemiptera: Aleyrodidae), white mango scale, Aulacaspis tubercularis (Hemiptera: Diaspididae), and the fall armyworm, Spodoptera frugiperda (Smith), Larger grain borer, maize lethal necrosis disease, garlic rot caused by Sclerotium cepivorum Berk., bacterial wilt of ginger, Ralstonia solanacearum and new races of wheat stem rust, Puccinia graminis f. sp.tritici, Faba bean galls, Olpidium viciae Kusano.

Plant species that are invasive and were introduced into the country at different times and have been affecting the country significantly include the invasive species: parthenium weed, Parthenium hysterophorus L. (Asteraceae); water hyacinth, Eichornia crassipes (C. Mart.) Solms (Liliales: Pontederiaceae; mesquite, Prosopis juliflora (SW) DC (Fabacea) and the parasitic weed crenata broomrape, Orobanche crenata Forskal on faba bean and the semi parasitic species witchweed, Striga hermonthica (Delil) Benth. (Orobancheace) on sorghum, noxious grass weed species Avena species, Bromus pectinatus, Snowdenia polystachiya, Setaria species and Phalaris paradoxa in major wheat and barley growing areas of the country .

Although regulating the movement of plant materials across the country was long recognized as an important activity, to date there is no domestic quarantine system I the regional states were put in place to regulate the movement of plant materials across the country.

PEST SURVEY AND SURVEILLANCE

The collecting and recording of pest information is fundamental to justify their phytosanitary measures on the basis of pest risk analysis and for the establishment of pest free areas. The implication is that National Plant Protection Organizations (NPPOs) should be in a position to validate declarations of the absence or limited distribution of quarantine pests.

To do so there are two major types of surveillance systems: general surveillance and specific surveys. General surveillance is a process whereby information on particular pests which are of concern for an area is gathered from many sources, wherever it is available and provided for use by the NPPO. Specific surveys are procedures by which NPPOs obtain information on pests of concern on specific sites in an area over a defined period of time. The verified information acquired may be used to determine the

presence or distribution of pests in an area, or on a host or commodity, or their absence from an area (in the establishment and maintenance of pest free areas).
Each signatory country to IPPC has a responsibility to establish plant protection service for the purpose of survey and surveillance of occurrence of new pest or to establish lists of Quarantine Pest and Regulated non-Quarantine Pests. To undertake such activities, although it is the responsibility of the NPPO, in Ethiopian plant quarantine service, no any coordinated pest survey and surveillance program is in place.

However, for the purpose of control of migratory pest (desert Locust, army worm and grain eating birds), Information collection, Monitoring, forecasting and Early Warning activities are being undertaken. The activities are done at Regional Level Forecasting (DLCO-EA), National Level Forecasting (PHRD, MOA), Community Based Armyworm Monitoring, Forecasting and Early Warning Program (Front line villages and Target Districts). Monitoring and collection of information is done through utilization of Pheromone traps, lures that are located at national sites and Community based front line Districts and villages and the information are conveyed through mobile SMS by forecasters.

Concerning monitoring of grain eating migratory birds (quelea quelea), survey and follow up is done by District and PHC staff and information on population of birds that remained from current control in areas where grass seeds, grain and water are given to the ministry and regional bureaus through telephone communication. Following early warning given to region bureaus of Agriculture for preparedness and upon confirmation of Sites of birds roost and population density control measures are executed.

CAPACITY BUILDING

One of the main focuses of the MoANR had been the provision of trainings based on assessment of pre- and in-service training needs of field staff, preparation of training programs and materials and also conducting of the trainings. Technologies, information and knowledge that have been generated by the research system have been compiled into crop production packages' components and have been delivered to users in different training fora. Production and distribution of training materials and provision of trainings to development agents has been followed by the MoANR for more than six decades, i.e., years before the start of the "Minimum Package Program" in 1971 to the present date.
Crop protection recommendations on economic pests are normally incorporated in the crop production packages, however due to the low emphasis given to pest management in the packages, the following gaps were created during practical implementation of acquired knowledge: failure by trainers to communicate the full picture of economic pests and the corresponding management information, miscommunication of crop protection related information to users, misidentification of pests and wrong

recommendations provided to farmers who sought technical support on pests causing significant economic damage on their crops, and development agents are prevented from getting sufficient knowledge on pest management strategies and tactics. Because of these, there is insufficient current knowledge transfer in pest management to the actors involved at all levels of the agriculture development.

In pest management system of regular and migratory pests, trainings for locust scouts, forecasters and experts working at different levels are being delivered. Training of locust scouts and community elders is undertaken annually in collaboration with DLCO-EA in Eastern and North eastern Ethiopia (Somali, Oromia, Dire Dawa, Afar and Amhara regions). Moreover, theoretical and practical training to regional plant protection experts selected from Locust and Armyworm prone Districts, Zones and PHCs on biology, survey, information collection, survey equipment application and reporting is done regularly.

Besides training activities, budget support for Airstrips maintenance, survey and control operations as well as purchase of pesticides from different donors are obtained and given to the regional bureaus of agriculture.

Phytosanitary inspectors need to have updated good basic scientific and agricultural qualifications, as well as training in the more specialized and specific aspects of the work, such as the phytosanitary legislation, techniques for inspecting various plants, plant materials and other objects under a varied circumstances, and in the recognition of plant pests. Until 2008 Induction training for newly recruited inspectors and on job and continual training in the technical aspects and related fields were being delivered. But until very recent years no sustainable training was undertaken but in 2014 and 2015 training on different topics was given to all inspectors.

PEST RISK ANALYSIS

The objectives of a pest risk analysis (PRA) are, for a specified area, to identify pests and/or pathways of quarantine concern and evaluate their risk, to identify endangered areas, and, if appropriate, to identify risk management options. Pest risk analysis for quarantine pests fo,:nIU17DHU,:tI7:oI.K7WB:sID137:oI,13W3BB:fIHD177V3:: I0H,7:apIH17VBUU:pIU

POST ENTRY QUARANTINE SERVICE

Confinement of a consignment of plants in a Post Entry Quarantine (PEQ) station may be an appropriate phytosanitary measure in cases where a quarantine pest is difficult to detect, where it takes time for sign or symptom expression, or where testing or treatment is required.

For a PEQ station to function successfully, its design and management should ensure that any quarantine pests that may be associated with consignments of plants are suitably confined, and do not move or escape from the station. The PEQ station should also ensure that consignments of plants are held in a manner that best facilitates observation, research, further inspection, testing or treatment of the plants. PEQ stations may consist of a field site, screen house, glasshouse and/or laboratory, amongst others. The type of facility to be used should be determined by the type of imported plants and the quarantine pests that may be associated with them. PEQ stations should be appropriately located and comply with physical and operational requirements based on the biology of both plants and quarantine pests that may potentially be associated with the plants. The impact of such pests should also be considered.

Operational requirements for PEQ stations include policies and procedures relating to staff requirements, technical and operational procedures, and record keeping. PEQ stations should have systems in place to detect and identify quarantine pests and to treat, remove or destroy infested plant material and other materials that may harbor these pests. The NPPO should ensure that the PEQ station is audited on a regular basis. The plants may be released from the PEQ station at the completion of the PEQ period if they are found to be free from quarantine pests.

However, in Ethiopia to undertake such activities, post entry quarantine system is not established or no follow up observation of imported materials at the premises or farms is done. Consequences of this result in the emergence of new pests in the country.

CHALLENGES AND GAPS

The Ethiopian phytosanitary service has several challenges and gaps among which:

1. Insufficient facilities and equipment and manpower

Lack of central or regional identification laboratories and appropriate laboratory facilities, green houses for follow up of detained imported or exported quarantine materials, at all stations and headquarters limit the activity to only document and visual inspection of import as well as export consignments. Even though, large export consignments are treated with necessary chemicals at the premises of exporters by certified agencies, fumigation premises and chamber for imported consignment if found infested are absent in the system of phytosanitary of the country. If the consignments are found infested and/or infected during inspection, it is a mandatory to avoid by burning. However, lack of facility like incinerator hinders the activity to be undertaken.

Test of imported material against genetically modified organism is currently becoming mandatory requirements, but to undertake such test is not possible due to absence of facilities and laboratory. Currently, even if facilities and equipment are fulfilled, manpower that can use the facilities and equipment are insufficient or lack in some specialized work areas.

2. Absence of Post Entry Quarantine and pest free area system

A post entry quarantine service is a place or green house for detention of any imported materials necessarily pass through serious observation of specific professionals. The materials detained in such away may be given to the importer as offspring or avoided not to enter in to the country. To undertake such activities, post entry quarantine system is not established or no follow up observation of imported materials at the premises or farms of the importer is done. This results in the emergence of new pests in the country.

3. The need to carry out pest survey and surveillance

Each signatory country to IPPC has a responsibility to establish plant protection service for the purpose of survey and surveillance of occurrence of new pest or to establish lists of Quarantine Pest and Regulated non-Quarantine Pests. Although there is too old quarantine pest list of the country, there is no any coordinated pest survey and surveillance program is in place.

4. Insufficient training for the phytosanotary personnels

Phytosanitary personnels need to have good basic scientific and agricultural qualifications, as well as training in the more specialized aspects of the work, such as the phytosanitary legislation, techniques for inspecting various plants, plant materials and other objects under very varied circumstances, and in the recognition of plant pests. Induction training and continual training in the technical aspects and related fields as well mentoring and monitoring of trained and qualified inspectors should be mandatory requirements.

5. Absence of proper plant quarantine policy

Policy units of plant quarantine, often undertake routine administrative tasks, such as international contacts and liaison with other parts of national government. Negotiations and discussions, international, regional and intranational with various interest groups, occupy much effort in the day-to-day operation of phytosanitary services. This helps in gearing of national crop protection and agricultural policy towards advancement based on the technology progress and change in trade relation of importing countries. However, in Ethiopia, there is no any section for such a responsibility and way designed to guide upgrading of the system.

6. Revision of plant quarantine regulation

Plant quarantine regulation of 1992 is a secondary legislation that described implementation of the primary legislation of 1971 which was not amended during all these years. Several research results of survey shown that new plant pests emerged at different location, on economically important crops in different times. Moreover, crop pest which were in the category of prohibition are now widely distributed in the country while specific plant diseases which are not found in the country were not included. Therefore there is a need to revise the regulation.

7. Poor importation control

Different institutions and individuals are involved in importation of plant materials without securing plant importation permit from the Ministry. On the other hand coordinated inspection activity from arrival at port to place of production is not in place import control, survey, surveillance and pest risk analysis. Moreover, strong cooperation must be established between and with different stakeholders of the Ministry in order to have sustainable information flow on occurrence and control strategies of pests.

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Evolution and Role of Plantwise Community-based Plant Clinics in Ethiopia: *Lessons, prospects and challenges*

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Introduction

Agriculture remains the mainstay of the Ethiopian economy and the source of livelihood for the vast majority of the population. The growth of this sector is largely related to the performance of the crops sub-sector. This sub-sector is however faced with numerous challenges. In particular, plant pests have become increasingly a major threat to efforts made to boost productivity of the sector. Citing previous studies, Shiferaw et al (2016) reports that in Ethiopia pre-and post-harvest losses due to insect pests, diseases, weeds and vertebrate pests range between 30% and 50%. Mitigating such challenges and enhancing productivity and food security among smallholder farmers requires access to appropriate and effective advisory and other support services (Negussie et al. 2011). However, provision of advisory services on plant health problems could not keep pace with the ever changing and increasing crop pest problems (Negussie et al, 2017). In Ethiopia, provision of pest management services has only been carried out whenever there are large scale outbreak and commonly in the form of seasonal campaign works (MoANR 2016). In describing a similar situation in Uganda, Danielsen et al (2014) highlighted that public crop protection measures are mainly restricted to border control and sporadic field inspections with hardly any services to deal with farmers' day-to-day crop health problems. Widespread and misuse of agro-chemicals has also been causing serious economic, environmental and health concerns. Moreover, the country is also lacking effective mechanisms for promptly detecting, identifying and responding to newly emerging plant pest problems. The challenges posed by the rising incidences of pest/disease problems and the gaps in the conventional extension approaches necessitate the search for innovative and complementary ways to deliver effective plant health advisory services to farmers in a timely manner. The Plantwise community-based plant clinic initiative offers such vital approach, which allows provision of regular and low-cost plant health advice to farmers. This paper discusses the Plantwise community-based plant clinic approach, its evolution and lessons drawn from its implementation in Ethiopia and suggests ways forward.

Genesis and expansion of the Plantwise community-based plant clinics

Plantwise (www.plantwise.org) is a CABI led global plant health programme, implemented on the ground by national and local organisations, such as the Ministry of Agriculture and Natural Resources of Ethiopia and Regional Bureaus of Agriculture and Natural Resources. The Plantwise Programme has evolved out of the former Global Plant Clinics (GPC), which introduced and experimented with the concept of community-based or mobile plant clinics since 2003. The plant clinics draw from lessons of human and animal health where primary healthcare constitutes the first point of contact between the patient and a health practitioner. The development of procedures for plant clinic operations has taken place through experimentation and iterative learning (Danielsen and Kelly, 2010). The initial pilots of plant clinics under the GPC were introduced in Bolivia in 2003, and followed by Bangladesh (2004), Nicaragua (2005), Uganda (2006), Nepal (2008) and other countries (Danielsen and Kelly, 2010;

Boa, 2009). Early promising results have inspired other countries in Africa and Asia to set up plant clinics as a means to meet farmer demand for plant health advice and to help bridge the gap in diagnostic capacity (Boa, 2009; Danielsen and Kelly, 2010). Drawing on lessons and experiences gained under the GPC, the Plantwise Programme was launched in 2011. The programme currently operates in 34 countries across the globe (Africa, Asia and Latin America), out of which 12 are in Africa.

The Plantwise initiative aims at increasing food security and food safety, and improve rural livelihoods by reducing crop losses due to plant pests and other factors. This is achieved through the implementation of networks of community-based plant clinics (CBPCs) which deliver practical advice to farmers when their crops are affected by pests/diseases and other agents. Plantwise plays an important role in stirring linkages among key actors and in strengthening plant health system. By promoting standards of good practice on pest management, Plantwise also contributes to improved food safety and compliance with market requirements (CABI, 2014). Community-based plant clinics are public services that are usually run by frontline extension workers, who serve as primary plant health care workers, known as with the unofficial title 'Plant Doctors (PDs)', who receive systematically designed hands-on Plantwise training courses. These include module 1 and 2 trainings which provide methods to identify crop problems brought to the clinics and how to operate plant clinics, and providing appropriate recommendations to manage the problems. These allows them to diagnose and give advice on the most common plant health problems (Boa, 2009); but their ability to resolve more complex problems is limited (Danielsen and Kelly, 2010). Plant doctors' training courses build on the extension workers' existing knowledge, skills and experiences. CBPCs are set-up and run in locations easily accessed and frequented by farmers such as Farmer Training Centers (FTC), Cooperative centers, local market, etc. Farmers bring samples of affected plants for identification and often get on-the-spot advice on how to manage the problems. Samples and problems are analysed with basic equipment and materials: for example, a knife to cut open the plant, magnifying glass, photo sheets of common symptoms and diagnostic field guides and reference books on pests and diseases (Boa, 2009). For the problems they could not to diagnose instantly at the CBPCs, plant doctors seek further advice and support from plant health experts, while the most difficult problems can be sent to local laboratories or to CABI's Plantwise Diagnostic Service in the UK.

The plant clinic data recorded during each consultation (which includes information on the farmer, crops brought, the diagnosis of the problem and the recommended management advice) are entered into a data-base. These when analysed and shared provide valuable information to various plant health stakeholders – such as extension, regulatory, research, policy and input suppliers. Plant clinics are reinforced by the Plantwise Knowledge Bank (KB) (http://www.plantwise.org/KnowledgeBank/Home.aspx) a comprehensive online resource that collates detailed, high-quality historical data and up-to-date plant health information from a wide range of sources (CABI 2014; Finegold et al. 2013/14). The KB also provides interactive step-by-step diagnostic support and guidelines, mapping and analysis tools, pest news, and home page with country specific information.

Evolution and distribution of Plantwise community-based plant clinics in Ethiopia

In response to the increasing plant pest problems, Plantwise community-based plant clinics were launched in the Oromia region of Ethiopiain2013throughtheestablishmentofeightpilot clinics.The pilot activity focused on areas with serious pest problems, those with irrigation and year-round intensive farming activities (Table 1). This number has increased steadily as a result of the encouraging results recorded during the initial years, and additional clinics were established in Oromia, Amhara and Tigray regions since then, and more recently (in 2017) in SNNP region. In addition to the plant clinics launched through the direct support of Plantwise, some of the Regional Bureaus of Agriculture (e.g. Tigray) and other organizations (e.g. Self Help Africa) supported establishment of additional plant clinics. To date, Ethiopiahas 107 community-based plantclinicsoperatingin 36 woredas ofthefourregional states (Table 1). In addition, preparation is underway to launch 40 new CBPCs in 2018 in the current four regions. In Ethiopia plantclinicsrunondifferentdayseitherweekly or fortnightly at FTCs, in rural market, on the way to market, at irrigation sites or other places in the villages.

Table 1. Distribution and number of CBPCs launched in the four regions of Ethiopia

Region	**Zone**	**Woredas**	**Number of plant clinics**
Oromia	West Showa	Toke Kutaye; Illu Gelan	5
	South West Showa	Wolliso; Wenchi	4
	West Arsi	Shashemene	2
	East Showa	Dugda; Ada'a	4
	North Showa	Degem	2
	Arsi	Ziway Dugda	2
	Bale	Agarfa	2
Amhara	SouthWollo	Kalu; Ambassel	5
	South Gonder	Libo Kemkem; Fogera	6
	West Gojam	Mecha	2
	North Wollo	Kobo	2
	North Showa	Basona Worana	2
Tigray*	Eastern zone	Kilte awlaelo	2
	Southern zone	Raya Azebo; Ofla; Alamata	5
	South Eastern zone	Seharti Samre	2
Tigray**	Central zone; Eastern zone; West Northern zone	Laelay Maychew; Adua; Merebe Leke; Ahferom; Gulomekeda; Ganta Afeshum; Kilte Awlaelo; Hawzien; Asgede Tsimbla; Tahtay	50

		Adiabo	
SNNP	Gurage	Meskan; Sodo; Mareko; Gumer; Abshege	10
Total	18	36	107

*Initiated with direct support of Plantwise; **Scaled out by Tigray regional government resources

Reports obtained from 52 CBPCs initiated by Plantwise show that as of December 2017 about 3,100 clinic sessions were conducted and served 15,604 farmers since the start of Plantwise in Ethiopia, with an average 5 queries per session. Activities of the recently established clinics and those established by Tigray region have not been included, and these may also claim more or less similar reach. In addition to visits made to plant clinics, Plant doctors' reach out to farmers with advice on plant health issues in different ways, including on other agriculture related meetings, through farmers' development group, one-on-one meetings on farm or at FTCs outside of the clinic hours. According to an assessment conducted in 2017, in addition to the plant clinic sessions plant doctors reported reaching 500 farmers, on average, through community meetings, extension fora, etc. to raise awareness on plant health. This brings the total number of farmers reached through non-clinic activities by plant doctors operating the 107 plant clinics approximately to over 50,000. Interviewed plant doctors and experts also report further spill-over effects and farmer-to-farmer clinic information sharing. However, other complementary methods of extension such as plant health rallies have not yet been implemented in Ethiopia. Thus one of the focus areas in the future should be enhancing reach through other complementary approaches such as plant health rally and mass extension approaches.

Capacity building and complementary activities

One of the areas where the initiative has significantly contributed is in terms of capacity building for extension and crop protection personnel who have received various systematically designed and hands-on Plantwise training courses. Records show that atotalof 487 development agents and experts at various levels haveundergone18differenttraining programmessince the inception of the programme. In particular, about 303[1] field-based, woreda and zonal crop protection/extension staff have been trained on Plant Doctors' Modules 1 and 2 (Field Diagnosis, how to set-up and run plant clinics and giving safe and practical recommendations) in 9 rounds of training sessions. In addition, other training courses on extension materials production (Pest Management Decision Guide and Fact Sheets), Data Management, E-plant clinic (use of tablets) training, Monitoring Plant Clinics Performance and quality assurance have been provided to extension staff and relevant experts. National trainers were trained on Training of Trainers on Modules 1 and 2, which would help the country/regions in the move towards training plant doctors using own experts and expand plant clinic operations. In addition, various reference materials, which include 67 Pest Management Decision Guides and Fact Sheets have been developed for use by plant doctors. Cluster exchanges across regions and intra-regional or intra-district cluster meetings and reviews are also extensively used as an important monitoring, experience and lesson sharing and capacity-building tools.

Though the introduction of Plantwise community-based plant clinics is a recent phenomenon in Ethiopia, the number of clinics so far established is somehow comparable to those established in some other African countries, which relatively adopted this concept earlier. The number of farmers reached so far in Ethiopia through CBPCs is also commendable as compared with the countries with a relatively longer experience with the approach. However, considering the size of Ethiopia, plant clinics are currently thinly spread in the country, which calls for further expansion within the current regions as well as to other regions of the country. As shown in the below table, one of the apparent gaps in Ethiopia is transferring clinic query data to computer, which has hindered its sharing and use. As can be seen in the below table, the bulk of the data captured at plant clinics in Ethiopia remained on paper forms.

Table 2: Comparison of reach and coverage of CBPCs in selected African countries (as of beginning of 2018)

Country	Year CBPCs introduced	Number of CBPCs at present	Number of farmers served by CBPCs	Number of queries entered into computer
Kenya	2010	143	34,178	50,304
Rwanda	2011	66	9,578	13,019
Ghana	2012	153	23,796	30,667
Ethiopia	2013	107	15,604	1400

Contributions and merits of the Plantwise CBPCs approach under the Ethiopian context

One of the key advantages of this approach is that it offers the opportunity to effectively reach out to farmers with appropriate advice on plant health problems. Danielsen *et al* (2011) noted that plant clinics are simple and relatively cheap solution to the long standing outreach problem. Unlike other conventional extension approaches that attempt to push pre-packaged technologies to farmers, CBPCs provide demand-driven service that responds to farmers' priority problems (Negussie *et al*, 2017). Based on Ugandan experience, Danielsen *et al* (2014) noted that in addition to adding value to extension by expanding service coverage, plant clinics have the potential to improve regular collection of pest and disease information at the farmer field level. Danielsen *et al* (2014) underscored that the early results convinced senior managers within the Department of Crop Protection of Uganda that the dual-purposed plant clinics could help improve national responsiveness to pest and disease risks by providing the much needed plant health advisory services to farmers and strengthening pest alertness on the ground. The approach works through and builds on existing local structures and system which facilitates its integration into existing structures/system and services. More importantly, the approach provides substantial capacity building activities for extension/crop protection staff. A study conducted in 2017 in the Oromia and Tigray regions by an external consultant reported improvements in the plant health system performance and responsiveness, in particular the farmer advisory services and diagnostic services, as a result of the Plantwise intervention. According to this study before the introduction of Plantwise, the extension officers were not addressing plant health issues mainly due to lack of adequate knowledge on pest identification and management and the inherent focus on distribution of inputs and promoting agronomic practices (e.g. row planting), and watershed management (e.g. constructing terraces). Respondents of the study indicated major changes in availability of information and the service delivery approach compared to the situation prior to the introduction of CBPCs and the accompanying trainings. Respondent plant doctors and experts testified that their knowledge, interest and confidence in providing advice on plant health management have shown substantial improvements.

The Plantwise approach is guided by IPM practices and promotes safe, economical and practical pest management options. By recommending IPM technologies plant clinics endeavour to reduce pesticide use (Danielsen et al., 2011). Provision of prescription-based advisory services minimizes the malpractices and risks associated with the use of pesticides (Negussie et al., 2017). Farmers confirmed these improvements at local level and reported notable changes in the use of pesticides. In the words of Mr Haile Hafitu (a clinic client farmer from Wargiba village, Raya Azebo of Tigray), "Before the arrival of the)lantwise plant clinic, we were having pro"lems in properly diagnosing and identifying our cropsL pro"lems. +s a result, we used to heavily rely on the "est guess and suggestions of agro$ dealers, who at times operate without integrity and sound "usiness ethics. 0ow there is no conflict of interest; we get our pro"lems diagnosed "y plant doctors and then go to the agro$ dealers with prescriptions. *his has helped us to get the right type and amount of pesticide at the right time, and saved our money and our crops". Mr Tilahun Asefa and Mr Hassen Ali, farmers of Robit village of South Wollo zone share similar views. They said &9e came to clearly understand what type of pesticide should "e used for which type of pestDdisease; when and how to spray pesticides, the conse6uences of using similar chemicals repeatedly; the need to and possi"ilities of managing pests using non$chemical control measures such as cultural practices and "otanicals.+s a result, our health, the health of our "ees and livestock has "een protected''. In affirming some of the recent changes in pesticide use, Mr Hayelom Ale and Mr Hagos Bata (clinic client farmers from Wargiba village of Raya Azebo) said "We used to carelessly dispose empty pesticide containers in our farms. =ut following the awareness raising and education we have received from the plant doctor, we have stopped such practices. #n addition, we are now aware of proper application time, fre6uency and pre$harvest interval, as well as the critical importance of using proper))E during spraying''. Some plant doctors also started making commendable efforts in linking plant clinic activities with agro-dealers and local spray service providers. For instance, based on the experiences gained under Plantwise, Raya Azebo district of Tigray is now moving towards making all pesticide supply in the district prescription-based. By creating various fora, the approach also stimulates interaction and linkages amongst key plant health stakeholders. Furthermore, the network of CBPCs has the potential to serve as a community-based pest vigilance and early detection mechanism (Negussie et al, 2017).

The network of CBPCs generates useful information which can be of great use to a variety of stakeholders in the plant health system.Plant clinics data can be analyzed and used in numerous ways by different stakeholders – policy, extension, research, regulatory and agro-dealers (Finegold et al. 2013/14). These include information on the following crucial aspects:

- Geographical distribution of plant clinics
- Pest/disease distribution
- Number and gender of clinic service user farmers'
- Regularity of plant clinics
- Most common crops brought to the clinics
- Common plant health problems brought to the clinics
- Types of recommendations given by PDs
- Need for agro-inputs,
- Quality of diagnosis and quality of advice given by PDs, etc.

Such data thus provide useful information on priority area for research, extension, agro-input supply, etc. It also provides useful information on the quality of service and gaps in the knowledge and skills of PDs, which help in designing and providing targeted trainings. It also provides useful information for regulatory body on new pests and the trends of existing pests. In discussing the experience in Uganda, Danielsen et al (2014) indicated that the plant clinic records of farmer queries revealed a potential to become a multipurpose tool that could be used both for assessing service quality and supporting decision making at local and central level. In order to be put into effective use, clinic data has to be properly managed and shared. However, at present plant clinic data management and use is one of the areas with critical gaps in Ethiopia. Most of the information captured at CBPCs remained on paper forms due to time constraints (regional experts facing) in entering the data into the database. As indicated in Table 3, most of the data generated by plant clinics in other African countries have been entered into computers. In countries like Kenya data from all the districts running plant clinics were analyzed by the Ministry of Agriculture and used for various purposes. Experts and statisticians from universities, research institutions, pesticide regulating bodies and inspection agencies also played roles in the data analysis and quality assurance (Fingold et al., 2013/14). Such practices of demonstrating its benefits or various uses to key actors and involving multi-stakeholders in the management and processing of data can be adopted in Ethiopia. Going forward it is likely that data will be collected and entered in the local languages to ensure that the data are more useful to partners. Moreover, fully moving away from paper-based data recording form to apps on tablets and smartphones would substantially facilitate data sharing and use.

Opportunities and Prospects

Experience gained in piloting the initiative and assessments of the national context reveal that Ethiopia has a fertile ground and unique opportunity to effectively implement, institutionalize and sustain community-based plant clinics and associated activities. These include the existence of a large pool of extension workers on the ground, FTC (manned by 3 Development Agents), Regional PHCs[2], decentralized extension structures, favourable policies that support the agricultural sector and government's renewed interest to revitalize crop protection. Moreover, the presence of various complementary agricultural projects and non-governmental initiatives provide another opportunity in this respect; i.e. to link to and harness resources. As outlined in the preceding section and in the below SWOT analysis table the approach and its implementation under the Ethiopian context have notable strengths and benefits. These among others include being demand-driven approach; provision of services on any crop; low initial and operational costs; building on and working through existing structures and system; high commitment and interest at the ministry level and among PDs; efforts of some regions/woredas to integrate it to their work plan and reporting; enhanced local capacity and improvement in outreach of extension staff (Table 3).

Table 3: SWOT analysis of Plantwise community-based plant clinics operation in Ethiopia

Strength (and advantages)	Weakness (limitations)
• It is demand-driven approach • Provides services to any farmer on any crop • Requires low initial and operational costs • Builds on and works through existing structures and system; can be embedded to regular extension service. • Enthusiasm among PDs to provide improved advisory services to farmers • High commitment and interest at the ministry level - CBPCs is being considered as part of the regular crop protection activity. • Regions/woredas have started integrating to their work plan and reporting - focal persons have included in their BSC.	• Limitations in the technical capacity of plant doctors (local extension staff); affecting quality of service • Lack of adequate awareness and commitment at different levels; limitations in taking plant clinics as a regular extension tool; tendency to view it as external project; weak monitoring and follow up • Performance of plant clinics at times relied on the interest and commitment of individuals; change/transfer of such champions appeared to affect its performance • Limited publicity – some farmers come without samples, low attendance at some places • Lack of effective linkages to other

[2]*CBPCs can be effectively linked to the Regional PHCs and help them to widely reach out to the farming community. Likewise, the Regional PHCs can provide technical backstopping and diagnostic services to CBPCs.*

• Enhances local capacity – ToTs, reference materials, linkages among stakeholders, etc. • Enhances outreach of extension staff • Can serve as vigilance, early detection and rapid response mechanism • Generates useful information that can be used by various actors	services such as agro-dealers, diagnostic labs, etc. • Limitation in data management and use; Paper-based data recording and prescription
Opportunity	**Threats (and challenges)**
• Presence of regional PHCs, FTC, large number of frontline extension staff, research centers, universities, decentralized structures, farmers development groups, various agricultural development projects/programs • Presence of pro-agriculture government development policy. • High demand (among farmers) for support/advisory services on crop health problems – rising diseases/pests problem • Presence of ToT trained staff	• High turnover of plant doctors and trained experts (and even officials – causing gaps in information, knowledge and commitment); • Workload due to competing/overlapping seasonal agricultural activities and campaign works, interrupting clinic sessions • Farmers tendency to prefer chemical control options; undermining the effectiveness of non-chemical management options • Farmers expect CBPCs/PDs to provide chemicals

Challenges and gaps

Despite an increasing demand for services provided through this innovative approach, implementation of CBPCs in Ethiopia was not without its challenges. The major challenges and threats to effective operation of CBPCs include high turnover of plant doctors and trained experts; workload due to competing/overlapping seasonal agricultural activities and campaign works (interrupting clinic sessions); and farmers tendency to prefer chemical control options. In explaining the situation in Nicaragua, Danielsen et al (2011) noted that the development of the national plant health system was constrained by existing work cultures that limit the scope of individual and institutional innovations. They went on the underscore that although good progress has been made in consolidating effort and defining a vision of a nationwide plant health system in Nicaragua, obstacles to learning and institutional innovation persist. Notable weaknesses in the Ethiopian context include limitations in the technical capacity of plant doctors (local extension staff), lack of adequate awareness and commitment at different levels; limitations in taking plant clinics as a regular extension tool; weak monitoring and follow up and limitations in data management and use. Moreover, performance of plant clinics at times relied on the interest and commitment of individuals; change/transfer of such champions appeared to affect its performance.

Limited publicity, low attendance at some places, and lack of effective functional linkages to other services such as agro-dealers, diagnostic labs, etc are also among the gaps.

Linkages and complementarities with other structures

As indicated in table 4, existing Regional PHCs and Plantwise community-based plant clinics have their own strengths and limitations. Forging and strengthening linkages with Regional PHCs can help CBPCs to receive technical, diagnostic and quality assurance supports from their experts as well as can serve as an interface between the later and higher level diagnostic facilities. CBPCs in turn can provide Regional PHCs with the opportunity to more regularly interact with the farming community. Information generated at the clinic can aid the later to plan surveillance activities as well as inform them on priority problems and farmers' needs (Negussie et al, 2017). In particular, the challenges facing the regional PHCs in widely reaching out to the farming communities could be overcome by forming a strong functional linkage with the community-based plant clinics. However, as shown in figure 1, the current linkage between the two structures is rather weak and ad hoc.

Table 4. Comparison of Regional PHCs and CBPCs in Ethiopia

Type of plant clinics	Number (coverage)	Initiation	Mandate (Primary activity)	Key strength	Weakness (limitations)
Regional PHCs	16	1980s and 1990s	- Conduct regular pest surveys - Prepare reference collection of pests for identification & training - Prepare manual& organize training - Provide technical advisory service	- Better technical/ diag. capacity - Better linkage to other structures - Relatively stable structure and staff (though lack motivation)	- Thinly spread - Poorly equipped - Under-resourced - Limitations in reaching out to farmers
Community-based plant clinics	107	After 2013	- Diagnostic and advisory service to farmers	- Close to farmers - Better outreach	- Limitation in diag. capacity - Gaps in

			- Complementary support to experts (e.g. KB)	- Demand driven; rapid response	quality of advice - Issues of regularity

Likewise, community-based plant clinics benefit from linkages with other structures and service providers. For instance, linking CBPCs with FTCs and Regional PHCs has the potential to increase the effectiveness and sustainability of the approach (Negussie *et al*, 2017). In fact most of the CBPCs are operated from FTCs by the development agents assigned to run these centres. In addition, CBPCs would greatly benefit from linkages and interaction with research and universities. In general, for community-based plant clinics to deliver effective and sustainable advice to farmers, all relevant actors and stakeholders in the plant health system have crucial roles to play. Other organizations also derive various benefits by forming strong linkages with CBPCs. National Plant Protection Organisations benefit from the regular, community-based surveillance that clinics can provide, helping to create more accurate and comprehensive lists of pests and diseases (Boa, 2009). They are first and foremost a community-based plant health service for farmers, but if properly connected to other institutions and services, the synergies with surveillance, quarantine, research, other advisory services and input suppliers can be quite substantial (Danielsen and Matsiko, 2016).The plant clinic approach represents a shift from a 'vertical' (single crop or single pest) to a 'horizontal' approach (any problem in any crop). Community-based plant clinics have proved to be a valuable entry point for strengthening plant health (Ibid). Results from pioneer plant clinics in Nicaragua 2005–2007 demonstrated the clinics' potential to create synergies between different actors in plant health, thus making better use of existing resources (Danielsen *et al*. 2013, cited in Danielsen and Matsiko, 2016). The Nicaraguan experience fostered a broad 'plant health system' idea, which recognises that attainment of plant health outcomes requires functional linkages among key actors: farmers; extension services; regulatory bodies; education and research institutions; agricultural input; and information suppliers. These functions exist in every country, but rarely operate as a coherent system (Danielsen and Matsiko, 2016). The recently developed Pest Management Support Service Strategy of Ethiopia recognizes that due to poor linkages between Regional PHCs, Extension, PHRD and research, the crop production packages provided to development agents and farmers were incomplete and hence contributed to a number of regular pests to cause significant economic damage on the crops of their choices (MoANR, 2016). Figure 1 attempts to show the current nature and strengths of linkages between CBPCs and other key institutions and pinpoint areas that need to be further strengthened.

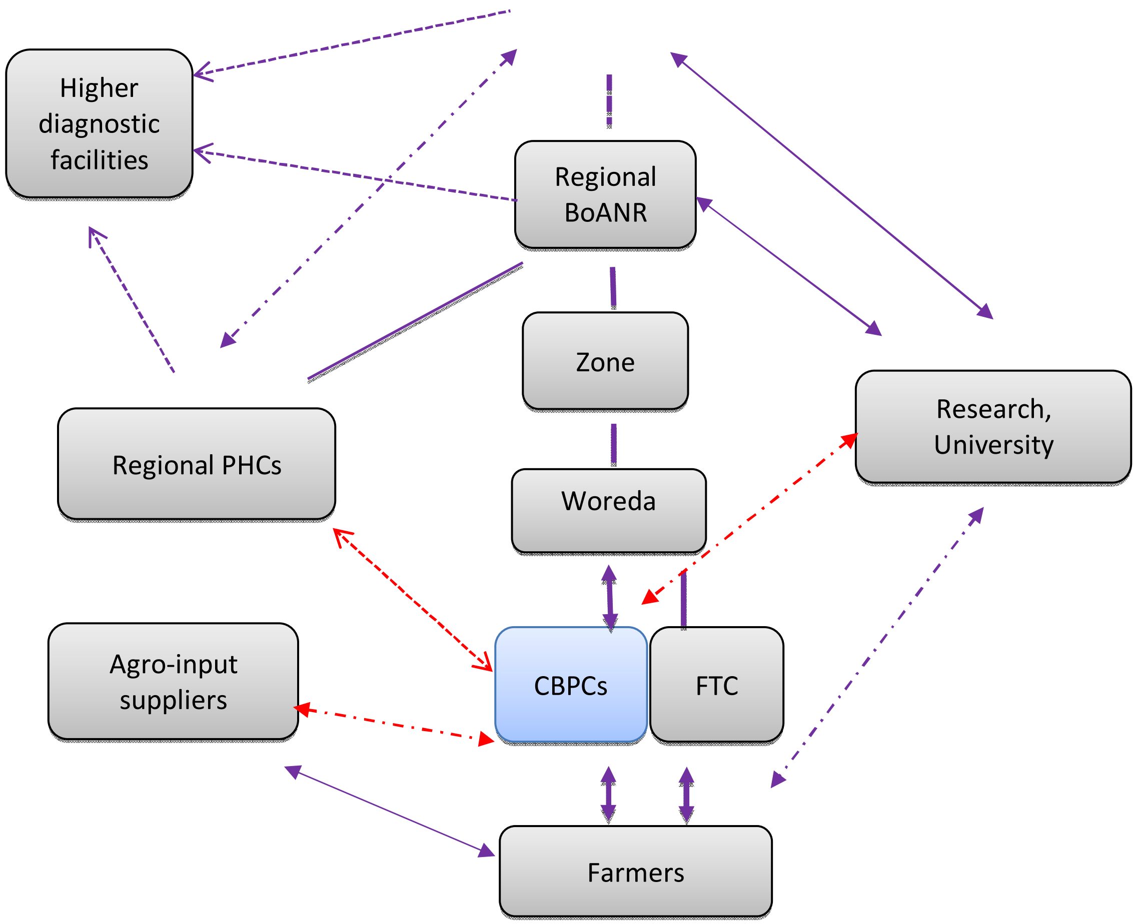

Figure 1. Linkages of CBPCs to other structures and services

Lessons for scaling up and institutionalizing CBPCs in Ethiopia

Experiences show that one of the drawbacks in some countries such as Nicaragua is attempting to pilot and scale up the initiative at the same time. This is mainly due to lack of enough mechanisms to ensure ongoing learning and programme adjustments; and fixed programme designs and high work pressure tend to undermine otherwise promising interventions by squeezing the space for learning and reflection (Moore, 2009; cited by Danielsen et al, 2011). In this regard, assessment of Plantwise implementation in Ethiopia shows that the initiative has attained the requirements for finalizing the pilot and consolidation phase and ready for scaling up/out. Experiences so far gained demonstrate that such a community-based initiative has the ability to effectively reach and address the problems of the farming community in a timely manner. In discussing the experience of Nicaragua, Danielsen et al (2011) pointed out that what began as a small experiment with a few plant clinics became a wider plant health initiative. It was quickly evident that the plant clinics filled a gap in existing services. Organisations saw the advantage of clinics in reaching more farmers with better services and at low cost. The plant clinics filled a gap: they were the 'missing link' between farm families, extension workers and specialists. Early results show that there are increasing demands from different regions of Ethiopia to get access to such services. As outlined above, in Ethiopia there are various opportunities and fertile ground to scale up, institutionalize and sustain this community-based initiative. The Plantwise community-based plant clinic initiative was introduced to Ethiopia at the right time when the challenges posed by the increasing pest problem and demand for such service became apparent. Above all, it complements existing government programmes and services as well as perfectly aligns with the national development strategy and plan. Thus they can easily be integrated into existing extension and crop protection activities. The establishment of a national plant health system in Nicaragua with the support of previously disconnected parties was a ground-breaking achievement that shifted the focus from 'implementing IPM projects' to 'delivering permanent plant health services to farmers' (Danielsen et al, 2011). Similarly, the Ugandan Government, as part of its agricultural development strategy, adopted plant clinics to improve plant health extension for farmers and to contribute to strengthening disease surveillance (Danielsen et al, 2014).

The performance and results demonstrated through the pilot initiative has encouraged the national and regional governments to give serious consideration in taking up this tool as an important approach to reach out to smallholder farmers. The Plant Protection Directorate hasalready included scaling up the Plantwise programme in the annual plan and budget of 2017/18 and intends to aggressively scale up to major crop growing regions. Deliberate efforts are also underway to mobilize resources from other projects such as Agriculture Growth Programme (AGP) and Participatory Small-scale Irrigation Development Programme (PASIDP). In addition, Regional governments in Tigray and Oromia have shown commitment to replicate the Plantwise model to more districts. Tigray region has already set up additional 50 plant clinics with local resources and plan to reach 100 clinics in the coming three years. Moreover, Self Help Africa (SHA) recently signed an agreement with MoANR and CABI and supported launch of 10 plant clinics in the SNNP region in 2017.

Enhancing awareness and securing strong buy-in particularly from regional officials is one of the critical activities in the efforts to embed and sustain CBPCs. Such commitment would particularly facilitate integration of this concept into their regular activity plans, budget, reporting and performance assessment. The pilot Plantwise plant clinics can serve as a model and learning fora for the new clinics to be launched. Another important activity in scaling-up and-out the initiative is provision of more ToT for local trainers and backstopping by CABI and national trainers. Making use of electronic record forms and reference materials would also minimize the costs of printing as well as facilitate sharing of the same. Another important issue is the need for extensively negotiating with regions/woreda officials to minimize transfer of PDs and trained key support staff/experts. Moreover, there is a need to conduct other complementary extension approaches to enhance outreach, which may include making increased use of mass media to raise awareness and publicity. It is also critical to facilitate interactions and experience sharing among regions and between clinics as their commitment, performance and experience do vary. Moreover, in the long-run housing the service in small fixed structure such as community-based plant health clinic post and provision of the service during all working days of the week should be considered, or alternatively one room can be put aside at FTC for such service, and. Such small structures can be built with the participation and contribution of the local communities. With the aim of facilitating and guiding the scale up efforts, a three year (2018 – 2020) Medium-term Plantwise Strategy has been developed for Ethiopia. This needs to be widely introduced to and promoted among key partners so as to create strong ownership.

Concluding remarks

This paper suggests that the Plantwise CBPCs offer an effective complementary approach that can bridge the gaps in the existing advisory services on plant health problems. Despite some challenges, better opportunity and favourable ground seem to prevail in Ethiopia as compared with other African countries. However, given the geographical size of the country, CBPCs are currently thinly spread in Ethiopia. It is thus imperative to devise mechanisms to scale up/out into other areas and increase its coverage. Effectively linking with existing structures and creating synergy particularly with the Regional PHCs, FTCs and other development programmes could ensure sustainability of the initiative.Incorporating plant clinics into the Plant Protection Directorate work plan and budget demonstrates commitment at the ministry level and is a positive move towards its institutionalization. However, the irregularities and gaps observed in its implementation at the local level need to be addressed. In particular, frequent change of officials and staff in key partner institutions appeared to severely affect its implementation. This calls for a strong and continuous awareness creation activities and negotiations to secure better institutional commitment and buy-in at different levels. Strengthening the support networks, backstopping and supervision by experts, implementing quality assurance mechanisms and offering some targeted technical training are other critical areas for the future. Addressing technical and logistic obstacles to data management and improving its flow, analysis and use is another area of focus. One of the possible solutions could be moving away from paper-based data recording to digital/ICT assisted data management; i.e. digitize data capturing and transfer (using tablets and smart phones). It is also crucial to carry out systematically designed rigorous impact study to assess adoption of plant clinic advice and its resultant impacts. More importantly, effective implementation of such initiatives requires active participation and collaboration among various stakeholders in the plant health system. Thus all relevant stakeholders need to team up and work together to effectively scale up/out and sustain the Plantwise initiative in Ethiopia.

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Recent Surges of Migratory Pests in Ethiopia: The Case of Desert Locust

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Abstract

:esert 'ocust, ,chistoserca gregaria ;orskal (Irthoptera, +crididae) is considered the most damaging of all migratory pest species in the world. :esert 'ocust plagues occur after a series of events in which locust num"ers increase. *his starts with the normally calm period of recession, followed "y locali%ed out"reaks and upsurges from which a plague may develop and eventually decline, returning to a recession period. *here have "een six ma!or plagues of :esert 'ocusts in the 1A..s, one of which lasted almost 1 D1G years. *he area in which plagues occur covered a"out 2A million km² which is nearly twice as large as the recession area, and can extend across GC countries. *he most recent :esert 'ocust emergency in 2.. $2..G occurred when an upsurge developed into a regional plague in 2..2 affecting mainly 9est +frica in the ,ahel and more than B million people were affected. Ethiopia is one of the frontline desert locust invasion areas suita"le for locust "reeding and gregari%ation in eastern +frica. #n the last two decades, there were a"out ten desert locust out"reaks and upsurges (1AB7, 1ABC, 1ABB, 1AA , 1AAB, 2..G, 2..C, 2..B, 2..A K 2.12) and almost CGO of the out"reaks started from eastern Ethiopia.;or more than five decades different institutions have "een actively involved to reduce the magnitude and fre6uency of out"reaks, upsurges and plagues through the implementation of capacity "uilding programmes focused on systematic desert locust monitoring, survey, control and reporting system which are valua"le decision tools for early detection and early intervention. *oday, locust$affected countriesL a"ility to detect, respond to and contain :esert 'ocust out"reaks has improved as a result of advances in technologies related to geo$positioning, spatial analysis, remote sensing and early warning. *his document aimed to show the severity of desert locust infestation and the efforts which have "een made to "ring the locust situation where it is now.

-ey words> :esert 'ocust, recessions, out"reaks, upsurges, plagues, early warning system and locust information service.

Introduction

The migratory pests that are registered by the Government of Ethiopia and whose management is being fully supported by the government are Desert Locust, ,chistoserca gregaria Forskal (Orthoptera, Acrididae), Armyworm, ,podoptera exempta Walker (Lepidoptera, Noctuiidae) and Red Billed Quelea (Grain eating Bird), Ruelea

6ueleaethopica(Vertebrata, Aves). Ever since man first started to practice agriculture Desert Locust has been a menace to his crops. Until the early 1940s, man's efforts to save crops from damage by Desert Locusts were organized on a national basis. As this pest often breeds in remote, sparsely populated areas and swarms easily move across national frontiers, it is not surprising that these national efforts were frequently hampered by unexpected invasions from outside (Linda Huddleston, 1978). Such invasions of Ethiopia have occurred at least twice in the past ten years, most recently in April 2009 and 2014.Desert Locust can reproduce rapidly, migrate long distances and devastate crops and pasture. A Desert Locust adult can consume roughly its own weight in fresh food per day that is about two grams every day. Desert Locust threatens livelihoods, food security, the environment and economic development in more than 65 of the world's poorest countries in Africa and Asia.

Under optimal environmental conditions that are in warm temperatures and after unusually heavy rains the Desert Locust has the ability to reproduce rapidly and increase some 20-fold within its three-month lifespan. After six months, there can be up to 500 times more locusts. In response to the habitat, a Desert Locust will change its behavior and appearance, transforming itself from a harmless individual, solitarious locust to part of a collective mass of gregarious insects that form a swarm. Desert Locust swarms can cross continents and seas in a matter of days or weeks, and quickly destroy a farmer's field and his entire livelihood in a single morning.

Solitarious locusts are found in low numbers scattered throughout the deserts of North Africa, the Near East and Southwest Asia. This arid area of some 16 million km² includes about 30 countries and is called the recession area. During a plague, swarms can invade other adjacent countries to the north, south and east of the recession area. This is referred to as the invasion area and equivalent to about 20% of Earth's land surface (FAO, 2015).

Since 1860, there have been nine major plagues (Symmons & Cressman, 2001). Ethiopia was affected by each of these plagues with the 1950–1963 plague lasting for 13 consecutive years in the country. The plagues caused widespread hardship and famine because there was no effective defense. In 1931, the First International Anti-Locust Conference held in Rome invited all governments to cooperate in the control of Desert Locusts by sending regular reports to the Anti-Locust Research Centre (ALRC) in London so that the Centre could give warnings of possible invasions by swarms (Adefiris, 1979). Since this time, countries in the Desert Locust area have collaborated to detect, monitor and control this pest. During the1960s, the strategy of Desert Locust management had shifted from suppressing plagues to implementing plague prevention (DLCO-EA (2), 2012).

In 1978, the Food and Agriculture Organization of the United Nations (FAO), assumed the centralized information and early warning role that was initiated by ALRC. FAO's Desert Locust Information Service (DLIS) remains to this day the key monitoring and early warning element in preventing Desert Locust plagues from devastating farmers' fields in Africa and Asia. DLIS operates an early warning system that monitors weather, ecological conditions, and locust infestations in the potentially affected area on a daily basis(FAO, 2015).

Recessions, Outbreaks, Upsurges and Plagues

Symmons & Cressman, 2001, described below how the Desert Locust behaves during recession, outbreak, upsurge, plague and causes of decline. The factors that trigger these phenomenons globally are analyzed as well.

Desert Locust plagues occur after a series of events in which locust numbers increase. This starts with the normally calm period of recession, followed by localized outbreaks and upsurges from which a plague may develop and eventually decline, returning to a recession period. Since 1860, there have been nine major plagues and ten major upsurges, interrupted by periods of recessions and localized outbreaks (Fig.1& Table 1). These lasted from several months to several years or more

Figure 1. Plague and recession periods of the Desert Locust, January 1860 to

December 2000.

Recessions

The area within which these populations are confined and move around within is referred to as the recession area. It covers about 16 million km2 and includes some 30 countries. The Desert Locust is normally present at low densities in semi-arid or arid areas, away from major agricultural zones. Desert Locusts do not cause significant crop damage, and hopper bands and swarms are rare or completely absent.

Table 1.Locust plagues, upsurges and recessions from 1860 and 2017 (modified from FAO, 2001)

Recessions	Upsurges	Plagues	Plague Years	Declines	Status of Ethiopia
-	-	1861-67	7	-	
1868	-	1869-81	13	-	
1882-88	-	1889-1910	12	-	Affected
1911	1912	1912-19	8	1917-19	Affected
1920-25	1925-26	1926-34	9	1932-34	Affected
1935-39	1940-41	1940-48	9	1946-48	Affected
1948	1949-50	1949-63	13	1961-63	Affected
1964-67	1967-68	1968	1	1969	Affected
1969-72	1972-74	-	-	-	
1975-76	1977-80	-	-	-	Affected
1981-85	1985	1986-88	3	1988-89	Affected
1990-92	1992-94	-	-	-	Affected
1995	1996-98	-	-	-	Affected
1999-2003	2003-2004	2004-2005	2	2005	Affected
2005-present	-	-	-	-	

Outbreaks

The transition from a recession situation to one of plague is characterized by outbreaks and upsurges. An outbreak occurs when there is an increase in locust numbers through concentration, multiplication and gregarization, which takes place over several months. While an outbreak is often localized and restricted to certain habitats, it can lead to the formation of bands and swarms unless it is controlled.

The early stages of an outbreak are often unobserved. Hoppers may be concealed in the vegetation and easily missed during surveys. Similarly, adults may be present in such small numbers that few, if any, are found. Alternatively, adults may be brought in from a wide area by the low level convergent wind flow, which is likely to be associated with the rain required for the first successful breeding of the sequence.

Upsurges

Upsurges are a result of successful breeding over a number of generations by an initially small population. With successive generations, the proportion of the total population in bands and swarms increases until few scattered locusts remain; the total number of locusts increases as does the size and coherence of the bands and swarms. Several outbreaks that occur at the same time followed by two or more generations of transient-to-gregarious breeding can lead to an upsurge. This situation is dependent upon a series of substantial and widespread rains of which at least the earliest rains occur in the normally arid recession area. Many upsurges die out without leading to a major plague. For example, of the five upsurges that have occurred since 1970, only one has led to a plague. This may result from a combination of several factors such as a failure of the rains, causing unfavourable breeding conditions, the migration of adults to an area in which they die shortly upon arrival without laying, or control operations.

Plagues

There are periods of one or more years during which there are widespread and heavy locust infestations, the majority of which occur as bands or swarms. These are referred to as plagues. A plague can occur when favorable breeding conditions are present and control operations fail to stop a series of local outbreaks from developing into an upsurge that cannot be contained. A major plague exists when two or more regions are affected simultaneously. Plagues are separated by recession periods during which bands and swarms are rare or completely absent, and most of the locusts are present at low densities. There have been six major plagues of Desert Locusts in the 1900s, one of which lasted almost 13 years. The area in which plagues occur covered about 29 million

km^2 which is nearly twice as large as the recession area, and can extend across 57 countries.

Declines

Plagues usually decline as a result of a combination of natural factors and human intervention. One natural cause is failure of the rains in an area where successful breeding usually occurs. For example, the short rains in the Horn of Africa failed in 1955, which led to the first break in gregarious populations since 1950. Another cause is migration to areas from where either the adults or their progeny cannot return. A spectacular example is the trans-Atlantic swarm migrations of October and November 1988. Human intervention through control operations also plays a significant role in bringing plagues to an end

Recent surges of Desert Locust

West Africa

The most recent Desert Locust emergency in 2003-2005 occurred when an upsurge developed into a regional plague in 2004 affecting mainly West Africa and, to a lesser extent parts of northeast Africa and the Near East. In 2004, more than 8 million people were affected by locusts in the Sahel of West Africa. Up to 100% of the cereal crops, 90% of the legumes and 85% of the pastures were lost in certain areas due to the Desert Locust. Some 60% of the household heads in Mauritania became indebted, 45% in Mali and 33% in Burkina Faso. At least US$ 90 million was spent on food aid to West Africa in 2004. FAO and donors spent nearly US$ 400 million to bring the upsurge under control and to improve the capacity of control organizations to introduce safer pesticides and safeguard the environment (DLCO-EA (2), 2012).

Ethiopia

Ethiopia is one of the frontline Desert Locust invasion areas suitable for locust breeding and gregarization in eastern Africa. The northern, eastern, southern and southwestern lowland areas of the country host key areas for locust survival and development. Historically, invasions arose from local sources or from neighboring Sudan in the west, Somalia and across the Arabian Peninsula in the east. Since the 2003-2005 regional plague, there have been numerous outbreaks, most of which originated along the Red Sea coast.

In mid-March 2007, a few Desert Locust swarms from northwest Somaliland invaded five districts of the Somali Administrative Region in Ethiopia. The invasion caused substantial concern and triggered survey and control actions in Ethiopia to prevent a further escalation that could threaten other parts of the country. This was particularly critical because the swarms were taking advantage of the suitable environmental conditions caused by the short rains and greening vegetation in Shinile Zone of NW Somali Region where they matured and laid eggs.

The survey teams established from plant protection experts of Crop Protection Department (MoARD), Somale regional state, Dire Dawa Administrative Council, Harar Plant Health Clinic and DLCO- EA DireDawa base office constitute the two teams identified four egg fields covering an area of 9 km2 (900 ha) in Shinile District, Hare village. The first generation of hoppers from the invading swarms started hatching in early May. Accordingly, the main task of the teams became undertaking survey and control operation against the initial generation of hoppers, which was accomplished successfully by spraying 1,409 liters of pesticide on an infested area of more than 1,928 ha until 18 June 2007. DLCO-EA provided two aircraft, 5-YBCJ and 5-YBCK (3^{rd} April up to 3^{rd} June 2007) and intensive survey was conducted by air over 60,000 square km in 6 hrs flights.

Several very mobile immature and maturing swarms that breed in South Yemen from July to September 2007 crossed the Gulf of Aden and rapidly moved through Djibouti to Eastern Ethiopia across Northern Somalia. This locust persisted in Northern Somalia and slowly matured and moved south to Burao, Galkayo then in to Ogaden in October, 2007. They laid eggs in November around north of Warder (0658N/04520E).

Another swarms were also arrived to eastern Ogaden from other adjacent areas of Somalia. These swarms moved west and south and by the end of October a few swarms reached Fik area (0808N/4218E) in the west and South of Kebridehar (0644N/4216E) near Kelafo (0524N/4410E) and Shebele River. DLCO-EA aircraft that was deployed at Kebridehar (0644N/4216E) on November 9, 2007 with a ground team had been conducted aerial and ground survey on 60,000 and 1000ha respectively. The survey team was found a mature flying swarm with medium density at Gode (055451N/433224E) and high density of third and fourth instars hopper bands that covered about 1625 ha and controlled by aerial and ground operation by using 739liters of pesticides. Later at the first week of January, 2008 5^{th} instars hopper bands and fledgling had formed immature swarms along Shebele River near Gode (05557N/4333E) and these were also controlled by aerial and ground operation on 800 and 600ha respectively.

The locust outbreak from eastern Ethiopia in Somali region had been spread further west to south and Southwestern Ethiopia where immature swarms were moved to

Borena, Bale, and Eastern Hararghe zones of Oromia and South Omo, Gamo Gofa, Konso and other Southern Nation and Nationalities Peoples Region (SNNPR) zones bordering Borena. Accordingly the aerial and ground survey and control operation was conducted until the end of January, 2008 on 2070 ha by using 1127lites of pesticides (Table 2 & Fig.2).

Table 2. Summary of Desert Locust invasion and control in 2007-2008

Region	Treated area (ha)	Pesticides used (liters)
Somali	1928	1409
Oromia	520	515
SNNPR	1170	1140
Afar	35	35
Total	**3653**	**3099**

Figure 2. Map of Desert Locust invasion and situation in 2007-2008 (The Gambella case was African Migratory Locust)

Another Desert Locust invasion occurred during April 2009 in eastern Ethiopia from Somaliland and continued until August by spreading to northeast Ethiopia, reaching North Gondar. In mid-October, scattered populations of Desert Locust were reported in North Wello by Amhara Region. The infestations covered seven Administrative Regions, namely Somali (Shinile and Jijiga Zones), Dire Dawa (all villages), Harari, Oromiya (East and West Hararge zones), Amhara (South and North Wello, North Shewa, South and North Gondar, and Oromiya Zones), Afar (Zone three and five – Gewane area) and Tigray (South Tigray – Alamata area) (Fig.3).

Control operations were undertaken by DLCO-EA aircraft and on the ground, treating about 3495 ha of swarms and swarmlets with about 5,600 liters of pesticide. An FAO emergency project provided funds to support the survey and control operations, and supplied some of the necessary equipment. In addition, the project vehicles with mounted sprayers and another vehicle from MoARD served in the Somali Region until the control operations ended. The MoARD sent 790,000 Birr to the locust-affected regions. More than 11,000 liters of pesticide was purchased in the summer by the Federal Government. The affected regions were also supplied with survey and control equipment, consisting of at least three GPS for each region, ULVA+ hand-held sprayer, AU8000 and other vehicle mounted sprayers, personal protective equipment, survey equipment (compass, anemometer, hygrometer, vibratak, hand lens, stopwatch), siphon pumps, batteries, computer and digital camera (only for Somali region), andhard copy sets of theFAODesert Locust Guidelines.

Figure 3. Desert Locust invasion in 2009

The 2014 Desert Locust invasion of eastern Ethiopia was the most extensive in 47 years. An estimated 35 immature small to medium-sized Desert Locust swarms crossed to eastern Ethiopia from Somaliland and moved further west and southwest towards the northwestern and eastern highlands of Ethiopia into Somale, Oromia, Dire Dawa, Amhara and Tigray regions. Although the extensive scale of the infestation and the mobile nature of the swarms over a difficult terrain made survey and control operations difficult, much effort was made by the MoANR, DLCO-EA and the regional states to bring the infestations under control. Aerial and ground spraying were conducted against 30 swarms to reduce the potential egg laying population. More than 10,000 liters of pesticide purchase was effected by the Federal Government and was transported to the Dire Dawa DLCO-EA base store. In all, more than 6,600 ha were treated during the control campaign.Few swarms managed to escape from the assault area, however. One of them, on 14 May 2014, composed of mature and maturing adults appeared over the Addis Ababa sky in after more than 50 years and created a lot of havoc to the city dwellers.

Figure 4. Desert Locust swarm over Addis Ababa on 14th May, 2014.

Figure 5. Desert Locust swarm in Eastern Ethiopia on April, 2014 with a man scaring the locusts by waving his close.

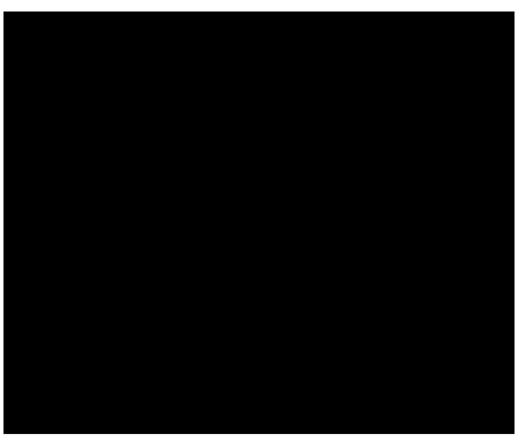

Figure 6.Desert locust Swarm resting on Vegetation in Eastern Ethiopia May, 2014

The Desert Locust situation was calm in 2015 throughout Ethiopia. In August 2016, a small mature swarm emigrated from Yemen and local breeding took place in Ayasha, Shinile and Harmukale districts of the Somali region. Solitarious Desert Locust adults laid eggs in Afar region (Teru, Kuri and Bidu districts), giving rise to increased locust densities. Ground control operations treated 217 ha.

Institutions Engaged in Desert Locust Control Interventions

1. **Desert Locust Control Organization for Eastern Africa (DLCO-EA)**

Clive Elliott, 2012 wrote the history of DLCO-EA establishment in the Book of "DLCO-EA Celebrating 50 Years of Service to Member Countries, 1962-2012" as follows.

After a succession of locust plagues, international concern about the Desert Locust rose in the 1910s that lead to the first International Anti-Locust Conference which was held at the International Institute of Agriculture (the forerunner of FAO) in 1920. After further Desert Locust plagues developed in Africa in the 1920 during which the British, collected and mapped reports from many different countries, Italy Organized another International Anti-Locust Conference which was held in Rome in 1931. The meeting agreed that all the governments involved in locust control should send their reports to the Anti-locust research center in London. The British established a forecasting system Center. Field stations were created in the Arabian Peninsula and East Africa under the quasi-military Middle East Anti-locust Unit, which had its headquarters in Cairo. After the Second World War, the unit was replaced by the Desert locust Survey (DLS).

In June 1961, at a locust meeting, the Director-General of FAO, noting that political independence was arriving in East Africa, called for the establishment of regional body to supplement national locust control efforts and to replace the DLS. Meetings between representatives of the concerned countries continued over the next year, tasked eventually with developing a Convention for the new body. The Convention was signed formally in Addis Ababa, in 1962 by representatives of the government of Ethiopia, Somali Republic and Tanganyika, and by Kenya and Uganda acting with the consent of the UK. DLCO-EA was born. A sixth member country joined a few weeks later when France signed the convention on behalf of Djibouti. The last director of the DLS, Prof. Vernon Joyce (UK) became the first director of DLCO-EA. He was appointed to the post at the First Council Session in October 1962. All the equipment, vehicles and air craft (three Beavers, an Aero Commander and Cessna) of the DLS were handed over to DLCO-EA. At its inception, DLCO-EA's mandate was exclusively concerned with Desert Locust and had three major components:-

to reduce Desert Locust population in eastern Africa to, and maintain them at, a level of economic insignificance;

to direct research on Desert Locust to elucidate the problems inherent in achieving this; and

to train national staffs in Member Countries to take over the control and research components (DLCO-EA (2), 2012).

The organization has passed through different phases to modernize its air unit and its capability and preparedness for an immediate aerial intervention (survey & control) when required as demonstrated in previous & recent locust outbreaks. Since its establishment DLCO-EA have worked in collaboration with Commission for Controlling the Desert Locust in the Central Region by provision of aircraft service for aerial survey and control; in 1972-1974 to assist upsurge control in Saudi Arabia and in 1976 in Saudi Arabia, PDR Yemen and Yemen Republic (Christian Pantenius and Munir Butrous, 2017).

Figure 7. DLCO-EA Aircraft deployed for Aerial Survey andControl at DireDawa Airport, 2007

DLCO-EA is also involved in early detection through efficient and relatively accurate forecasting of locust outbreaks in the horn of Africa for early intervention before widespread invasion occurs. In addition, the organization is providing regular TOT on Migratory Pests Biology and Management for National Focal Persons of each member country.

DLCO-EA has collaborated with national and international institutions to investigate the introduction of Insect Growth Regulators (IGRs) and bio-pesticides into locust control. The Organization has also helped to evaluate and register Metarhizium (Green Muscle) which uses spores of a locust fungal disease as a bio-pesticide. Both products are considered well suited to preventing outbreaks and the early stages of upsurges and in sites far from crops ((DLCO-EA, 2012)

2. **Regional Desert Locust Commissions**

There are three FAO regional Desert Locust commissions, which are administered by FAO with secretariats in Algiers, Cairo and Rome:

Commission for Controlling the Desert Locust in the Western Region (CLCPRO) – covering Northwest and West Africa

Commission for Controlling the Desert Locust in the Central Region (CRC) – covering the Red sea and Arabian countries

Commission for Controlling the Desert Locust in South-West Asia (SWAC) – covering southwest Asia

As it is well documented in the CRC 50th Anniversary Book (Christian Pantenius and Munir Butrous, 2017)the first regional Desert Locust commission, SWAC, was established in 1964. Later, the second commission, CRC was born on 21 February 1967 and its' mandate is to promote cooperation and coordination of anti-locust activities within the region. It is expected that the Commission pays particular attention to capacity development related to survey and control and that it assists national locust programmes with equipment as required. The Commission is also tasked with encouraging joint activities and regional programmes and to promoting cooperation and exchange of experience with other regional entities. At the heart of the Commission's efforts was, and still is, to ensure regular locust surveys and the dissemination of locust reports.

Various regular activities are being conducted by CRC in order to fulfill the objective of its Establishment Agreement. Accordingly, it supports and strengthens the National Desert Locust Control Organizations with a focus on the frontline countries that harbor the most important breeding areas and are regularly being confronted with desert locust outbreaks.

Since 2012, CRC has been conducting a workshop on Environmental Health Standard that was developed by Commission for Controlling the Desert Locust in the Western Region with the aim of improving environmental and human safety before, during and after desert locust operation. The Commission is encouraging member countries to adopt and implement the standard as soon as possible so that they could be able to monitor and reduce human health and environmental risks associated with the use of chemical pesticides.

Ethiopia is a member of CRC and have been receiving continues support in order to build the national capacity of locust management in general. Following the 2003 desert locust outbreak in Western Africa, an EMPRES and CRC have been provided continues capacity building support to Ethiopia. The program was focused on national and international short term trainings on desert locust biology, survey, control and contingency planning preparation and implementation have been conducted and over 300 plant protection experts from all desert locust prone areas of 10 administrative regions were trained. In addition, advanced diploma long term trainings have been awarded for 4 experts selected from Northern, central and Eastern regions of Ethiopia. One MSc student who had been working his dissertation paper on plant species composition, abundance and distribution in solitary Desert Locust habitat in Eastern Ethiopia was also sponsored. As a result, the capacity of national migratory pest management unit in particular the early detection and preventive strategy of desert locust is strengthened through provision of office and field equipment including two field vehicles.

3. Emergency Prevention System for Transboundary Animal and Plant Pests and Diseases in the Central Region (EMPRES/CR)

The Desert Locust component of EMPRES was initiated in mid-1994. Its purpose was to strengthen the locust management capacity of locust affected countries with the aim of minimizing the risk of Desert Locust plagues development. It was designed as a collaborative program in which affected countries, regional organizations, donors, and FAO, participate in the development of improved preventive control strategies (FAO, 2003). The overall program goal was re-defined in February 2000 as: “To strengthen the capabilities and capacities of the national, regional, and international components of the Desert Locust management system to implement effective and efficient preventive control strategies based on early warning and timely, environmentally sound and early control intervention."

Since then the EMPRES/CR activities have focused on five main areas: Early detection, early reaction, Research, Campaign Planning and Contingency Arrangements, and Capacity building.

The launching of FAO/EMPRES/CR program significantly promoted the national locust unit at the Ministry of Agriculture and Natural Resources (MoANR) survey, monitoring, capability for early detection and ground control by providing survey equipment such as GPS and eLocust2 for efficient and quick reporting with the development of remote sensing techniques and data management system.

4. FAO Desert Locust Information Service: FROM MAP reading to GPS

FCC-EMPRES Information Sheet No 1 (FAO, 2015) discussed as follows the importance of Desert Locust Information Service for early detection and control of this dangerous pest and how the Information Exchange Technology is advanced through Desert Locust management history.

The first records of Desert Locust plagues date from Pharonic Egypt and have been documented throughout history. During the first 60 years in the 20th century, there were five major plagues, lasting up to 14 years. Since 1963, there has been a dramatic decline in the frequency and duration of plagues, and now plagues occur perhaps only once every 10 to 15 years and rarely last more than three years.

Today, locust-affected countries' ability to detect, respond to and contain Desert Locust outbreaks has improved as a result of advances in technologies related to geo-positioning, spatial analysis, remote sensing and early warning. The reduction in the frequency, severity and duration of Desert Locust plagues and their associated food losses has been possible thanks to the adoption of a preventive control strategy relying on early warning and early reaction by locust-affected countries and FAO.

FAO Desert Locust Information Service (FAO DLIS) is the key monitoring and early warning tool in preventing Desert Locust plagues from devastating farmers' fields in Africa and Asia.

Since 1978, FAO DLIS has been operating an early warning system that has been monitoring weather, ecological conditions, and locust infestations in the potentially affected areas on a daily basis. After 75 years of systematic Desert Locust monitoring and collaboration between locust-affected countries and DLIS, today's FAO DLIS has revolutionized the process.

In the past three decades, the system has shifted from camels to four-wheel drive vehicles, from telex to email, from map reading to GPS, from narratives to handheld data loggers, from manual plotting to GIS, and from weather station reports to satellite-based rainfall estimates and greenness maps.

GPS, RAMSES (Reconnaissance and Management System of the Environment of Schistocerca) and SWARMS (Schistocerca Warning and Management System) GIS, the Internet and eLocust3 (Android-based tablet) have replaced the traditional tools of paper, colored pencils, maps and telephone.

DLIS-FAO manages an internet-based group of some 25 national locust information officers, a simple mechanism to keep national officers in contact with each other and share information every day. The primary and most important source of information are survey and control reports from affected countries. Each key country has a Locust Information Officer who is responsible for collating, analyzing and transmitting data to DLIS by email. DLIS, in turn, analyses the data and keeps countries informed of the current situation and expected developments.

DLIS issues a monthly bulletin in three languages (English, French and Arabic) to locust-affected countries, the international donor community, researchers, institutes, and other interested parties that summarizes the current situation and provides a six-week forecast on a per-country basis. During periods of increased locust activity, the bulletins are supplemented by updates, warnings and alerts.

DLIS spends considerable efforts to strengthen the capacities of nationally designated locust information officers. New tools are continually developed to facilitate the collection, transmission, management and analysis of data. Annual workshops are held for English and French speaking information officers as a forum for informal discussions on the use, problem-solving and improvement of various tools (eLocust3, eLocust2Mapper, RAMSES, remote sensing, social media) used by the officers.

This global early warning system, based on new advances in technologies, can be a model for other migratory pest early warning systems throughout the world (FAO, 2015).

Ethiopian Government role on Desert Locust management

The Government of Ethiopia has identified three migratory pests and their management is fully supported in all logistics and coordinated by Plant Health Regulatory Directorate (PHRD) of the Ministry of Agriculture and Natural Resources through the Migratory Pest Management Unit in collaboration with Regional Agricultural Bureau at all level and partner organizations who directly are involved on Desert Locust Management (DLCO-EA and FAO/CRC). Major roles of PHRD are:-

- Assignment of National Locust Information Officer and Regional DL Focal Person
- Recruitment of DL scouts- 28 Desert Locust Scouts are recruited for 6 months every year)
- Involve community elders and chiefs on desert Locust Monitoring and Reporting
- Train Locust scouts and Community elders
- Conduct Annual Refreshment training to national and Regional experts
- Purchase of Pesticides, Personal Protective Equipment (PPE) and Sprayers based on forecasts
- Carry out regular ground survey in breeding seasons
- Coordinate control operation of Desert Locust outbreak
- Prepare monthly bulletin to show country status
- Give early warning to regions based on forecasts from DLIS and DLCO-EA

Lessons Learned

The implementation of advanced technologies for monitoring, early detection and timely information exchange on migratory pests for timely control decision is very crucial to bring Desert Locust populations at manageable level under the capacity of each country.

The collaboration between Desert Locust prone countries on reporting and control effort that has been made even at low population of Desert Locust resulted on the reduction in the frequency and severity of this historically dangerous pest.

Present challenges in Fighting Locusts

1. **Insufficient data collection and transmission in some frontline countries.** Given that the D**esert Locust preventive control strategy** is implemented across a large geographical area, it is crucial that all countries involved contribute with data collection and transmission. Failure of all locust affected countries to provide continuous collaboration will compromise the effectiveness of the system to provide meaningful, accurate and timely early warning.
2. **Locust behavioral challenge.** It is puzzling that locusts seem to be attracted more to problem areas that are often inaccessible either because of bad terrain or presence of conflicts that have been making survey and control difficult.
3. **Inaccessibility and remoteness of Desert Locust habitats** with no or poor road access requires experts to travel on foot long distances (often ≥15 km/day)
4. **Armed conflicts** (tribal or otherwise) causes insecurity and hampers the ability to conduct routine survey and control operations freely
5. **Unpreparedness** to deal with the scale of locust outbreaks due to limited number of experienced personnel, limited resources and poor planning continues to hinder prevention and timely response despite continuous training and capacity building programs.
6. **Maintaining well-trained staff**, including Regional Desert Locust Focal Persons,who can use eLocust3 remains a significant challenge, especially during calm and dry periods when there is little locust activity and few surveys are undertaken.
7. **Poor logistics** as the operation requires mobilization of large quantities of resources in which scarcity of resources is not uncommon.
8. **Shortage of appropriate transportation** means such as 4WD vehicles significantly reduces the ability to conduct survey and control operations in all areas.
9. **Lack of effective environmentally-friendly control alternatives** for Desert Locust.

Recommendations

1. Increased regular survey and monitoring of locusts and their habitats with more regional and international collaborations;
2. Training of experts, development agents and locust scouts on locust survey, control and reporting;
3. Promoting community participation by raising their awareness and participation to assist when appropriate in locust survey, control and forecasting and consider them as important stakeholders;
4. Improving locust survey, monitoring, reporting and data management through the use of latest technologies such as remote sensing techniques for more accurate forecasting and consequently early intervention in order to protect the livelihoods of the communities living in locust prone areas and to reduce any negative impacts on the environment;
5. The timely and regular allocation of sufficient funds is required not only when there is an outbreak but also during times of recession to fully support regular survey and monitoring activities for early detection and timely interventions;
6. Encourage experts to use the survey, monitoring and reporting technologies (eLocust3 and RAMSES) at all levels and provide them with continuous refresher training, so that locust officers do not forget how to correctly use these tools;
7. Encourage researchers and higher education institutions to work on Desert Locust alternative control methods;
8. Bring on board all stakeholders to adopt and strictly implement the Environmental Health Standard (EHS) of Desert Locust control to reduce and monitor any risk associated with the use of chemical pesticides while controlling Desert Locust.

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Pesticide Use Practices, Trends and Challenges in Ethiopia; - A Review

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Abstract

+griculture is the most important sector for Ethiopian economy. <ogni%ant of the importance this sector many effort have "een geared towards improving production and productivity crop production. :espite the many efforts the achieved agricultural production and productivity remained very low even "y +frican standard. ,everal factors are known contri"uting to the poor performance of the Ethiopian agriculture. *he ma!or factors contri"uting to this poor performance is low level of access to improved crop production and protection technologies. #n this regard different agricultural research centers and higher learning institutions have demonstrated enormous research activities and achievements in availing solutions to the ma!or agricultural production constraints. Enhancement of agricultural productivity has "een considered through provision of improved technologies and information.)esticides are considered as one of the most important agricultural inputs in crop production processes. *he uses of pesticides to control plant diseases other pests and weeds have "een widely recogni%ed. *he use of pesticides as component of agriculture systems has ena"led an increased in crop yields and food production. @owever the use of pesticides "y small holder farmers is fre6uently accompanied "y different misuses leading to acute poisoning of users and health defects and pesticide residues in food and drinking water. ,everal studies have indicated the environmental and health effects of pesticide use in Ethiopia. @owever, the issue of human health and environmental risks has emerged as a key pro"lem for developing countries in general and Ethiopia in particular. *herefore, this article reviews the main issues related to pesticide use practices, potential "enefit and ha%ard to the famersL, environment and possi"le consideration as pathways for enhanced food production and safety in Ethiopia.

Introduction

Agriculture is one the most important economic sector of Ethiopia as it provides fundamental instrument for poverty alleviation, food security, and economic growth. Recent economic development of the country indicate that the real gross domestic product (GDP) grew at an average annual rate of 10.7 percent, while real per capital GDP grew at an average annual rate of 7.9 percent during 2004/5-2013/14 (Fantu et al. 2015). The agricultural sector grew at an average annual rate of 7.6 percent (Fantu et al. 2015). Over all the agricultural sector has accounted for 47 percent of real GDP over the last decade, and it was the largest contributor to GDP until the services sector took over in 20010/11. Currently agriculture is also given special emphases and considered as engine for economic development for second growth and transformation plan (GTP II). The growth of agriculture in the last decade in Ethiopia happened partly with an expanded cultivated area and the remaining from intensive use of other inputs, increased efficiency, or a combination of these factors (;antu et al. 2015). Accordingly, crop production statistics indicate that a total of 236,0076, 624.38 Quintals of cereals, 26,718,344.34 quintal of pulses, 7,600,993.24 quintals' of oil crops, 5954,004.03 quintals of vegetables, 54615,540.22 quintals of root and tuber crops, 7,066485.72 quintals of fruits and 4,199,801.56 quintals of coffee, are estimated being produced annually (CSA 2015). Despite an increased in production and productivity, the achieved agricultural production and productivity remained very low, even by African standard. Several factors are known contributing to the poor performance of the Ethiopian agriculture. The major factors contributing to this poor performance is low level of access to improved crop production and protection technologies. Biotic agents including disease causing pathogens, insect pests and parasitic weeds have been considered as the most important crop production constrains in the world in general and in Ethiopia in particular. As indicated in Table 1, recent assessment of crop production constraints that contribute for reduction of crop yield in Ethiopia indicate diseases and pests mentioned as the second most important factors next to rain fall (Minot and Sawyer 2013). These biotic agents have been known as a major source of crop and plant damage that can be caused by a number of plant pathogenic (disease causing) organisms, insect [redacted] today, despite the advances in agricultural sciences, [redacted] range from 10 to 90 %, with an average of 35 to 40 %, [redacted] crops (Abang et al., 2014).An increase in production and [redacted] (1).expansion of crop acreages, (2) improved methods of [redacted] zation and soil management, (4) use of improved [redacted] irrigation, and (6) improved crop protection. However, [redacted] crops, however, is often associated with higher [redacted] ling to increasing absolute losses and loss rates (Oerke et [redacted] ent yield losses caused by pests, pathogens and weeds [redacted] ural production (Oerke and Dehne, 2004). Therefore, [redacted] en more important in an intensive agriculture, where [redacted] lly uniform high-yielding varieties, increased irrigation, [redacted]

[redacted] yield by crop in Ethiopia

[redacted]	Other chemicals	Soil degradation	Pests or disease	Other	Total
[redacted]	2	16	5	3	100
[redacted]	0	10	11	2	100
[redacted]	0	8	6	4	100

Other cereals	64	6	0	0	8	16	5	100
Faba/horse bean	51	2	3	0	4	31	9	100
Field peas	52	1	1	0	2	31	14	100
Haricot beans	55	16	3	2	5	14	5	100
Chick-peas	58	0	3	1	6	31	1	100
Grass peas/vetch	59	3	1	0	6	29	2	100
Other pulses	55	0	14	0	6	24	0	100
Neug	42	5	8	1	22	20	2	100
Sesame	59	1	4	0	5	28	3	100
Other oilseeds	66	4	0	0	2	23	4	100
Cabbage	58	0	0	2	3	36	0	100
Red peppers	51	3	1	0	7	35	3	100
Other vegetables	21	0	24	0	3	50	1	100
Onion	38	1	2	1	5	43	10	100
Potato	79	1	3	0	3	13	2	100
Taro/godere	87	0	0	0	11	2	0	100
Other root crops	59	6	10	0	12	13	0	100
Banana	63	0	0	0	19	18	0	100

Other fruit	43	0	0	0	4	21	32	100
Chat	88	0	4	0	1	6	1	100
Coffee	43	1	1	2	13	37	4	100
Hops	62	0	0	0	1	15	22	100
Enset	41	0	0	0	12	44	3	100
Other permanent	85	0	1	1	8	2	3	100
Total	62	5	3	1	9	16	4	100
N=	3,607	418	234	55	584	1,266	341	6,505

Source: Minot and Sawyer 2013.

A large number of insect pests, diseases and weeds have been recorded on major crops in Ethiopia ,but only a few of these are considered to be of economic importance (Abraham 2008 and 2009). Enhancement of agricultural productivity has been considered through provision of improved technologies and information. In this regard during the last five decades different agricultural research centers and higher learning institutions have demonstrated enormous research activities and achievements in availing solutions to the major agricultural production constraints. The use of pesticides to control plant diseases and other pests had been, for many years since themid–1950s, increasing steadily at an annual rate of about 14% (Agrious, 2005). In similar manner, the uses of chemical pesticides have been considered as an integral part of management of different crop diseases, insect pest and weeds in Ethiopia (Abraham 2008 and 2009). The issues of making agriculture more productive and profitable in the face of rising costs and rising standards of human and environmental health the use of the best combination of available technologies has been one approach (Popp, et al., (2013). Much of the increases in yield per unit of area can be attributed to more efficient control of (biotic) stress rather than an increase in yield potential.

Plant protection products (pesticides) mainly fungicides, herbicides and insecticides are important inputs of agricultural production and enable farmers to control disease, insect pests and weeds when producing a crop (Kateregga 2012; Skevas et al. 2013; Jansen and Dubois 2014). The intensity of crop protection has increased considerably as exemplified by a 15–20-fold increase in the amount of pesticides used worldwide (Oerke, 2005). Despite the great role pesticides have been played in boosting agricultural production and productivity its use also associated with negative side effects such as hazard to human, animals and the environment (). The continuing dilemma with pesticides is that they opened up many possibilities for improving agriculture and public health on one hand but they closed other doors by creating extreme dependence on them. The increase of productivity with the application of pesticides was unable to function as a sustainable pest management system on which to predictably depend. Most of the negative impacts of pesticides on human health and the environment and the unintended consequences they brought. The agriculture sector has also been the victim of the consequences of pesticides. Pesticides disrupt the balance of pests and predators so that once harmless species grow sufficiently numerous to become pests. The use of wide spectrum pesticides disrupts natural mechanisms of pest management leading to the proliferation of more pests and diseases, including the emergence of secondary pests that would cause more trouble than the pests the chemicals were originally designed to control which in turn resulted in "pesticide treadmill".

Therefore, the challenges for plant protection professionals are to identify plant protection technologies that can reduce food losses while improving food quality and, at the same time, safeguarding our environment and healthy of the farmers. As the world population continues to increase while arable land and most other natural resources continue to decrease, and as our environment becomes further congested and stressed, the need for controlling plant diseases, insect pests and invasive parasitic effectively and safely will become one of the most basic necessities for feeding the hungry billions of our increasingly overpopulated world (Agrious, 2005).

The intensity of crop protection has increased considerably as exemplified by a 15–20-fold increase in the amount of pesticides used worldwide (Oerke 2005). Hence the importance of agricultural pesticides for developing countries is undeniable. However, the issue of human health and environmental risks has emerged as a key problem for these countries in a number of studies. Therefore, this article reviews the main issues related to pesticide use practices, potential benefit and hazard to the famers', environment and possible consideration as pathways for enhanced food production and safety in Ethiopia.

Pesticide Research in Ethiopia

Pesticides and agrochemicals in general have been considered as an important component of worldwide agriculture systems during the last century, allowing for a noticeable increase in crop yields and food production (Alexandratos and Bruinsma 2012). Research on pesticides was prominent, especially during the 1970s and early 1980s. The importance of crop protection research has long been recognized by the Ethiopian Agricultural Research and Extension System (A agents, and botanicals.Up until 2013 the number of pesticides being registered in Ethiopia consist 128, 73, 75 and 32 different insecticides, fungicide herbicide and other pesticides respectively (MOA, 2013).

Paths, alternative to the intensive use of crop protection chemicals, are open to trial and assessment. However the selection of future paths for enhanced food production shall be made through wise and science-based decision-making processes. Scientific research for developing food production and enhancing food safety, as well as environmental protection, is thus a necessary part of this process.

Importance of Pesticides and their Uses

Ethiopia is one of the African countries that use different kinds of pesticides for agricultural, industrial and health care purposes. Pesticides in agricultural sector were introduced in Ethiopia in the 19640s. Pesticides were first applied in Ethiopia in the mid-1940s, but expanded only when commercial farming expanded in the early 1960s. Recent economic development led to rapid growth in pesticides use (MOA, 2013; PRRP, 2014). Currently, pesticide use practices are changing as a result of the government plan to intensify and diversify agriculture by promoting high value export crops such as flowers and vegetables. (Sahle and Potting, 2013) have reported that more than 212 types of pesticides with different active ingredients are being used to cultivate roses in Ethiopia.

There are different types of pesticides being used in Ethiopia for agricultural uses. Smallholder farmers use different type's external inputs including pesticides to grow subsistence and commercial crops of different varieties. However, it has also been common for them to have been affected by pesticides and to have applied them without monitoring their crop fields for economic pests, taking action to control economic pests often after the crops had sustained significant damage and they had not received significant support while they were trying to manage regular pests. A number of studies and cases show the use and misuse of pesticides in Ethiopia. Recent studies made in West, North and South West Shewa Zones of Oromia Region by EIAR (2017) indicate farmers use chemicals (pesticides for the control of weeds, diseases and insects) depending on the type crops they grow and their purchasing power. Most farmers use 2-4-D to control broad leaf weeds and Green Star against grass weeds while a few of them use non selective pre-emergence herbicide like Roundup. To control rust on wheat, a few farmers spray chemicals like Tilt. Very few farmers spray Mancozeb to control chocolate spot disease on faba bean and late blight disease on potato. Some insecticides such as Deltametrine, Durasan, Malathion and Endosulfan are also used for the control of insect pests such as aphids, stalk borer, and African ball worm.

The use of chemical pesticides on many crops in general and vegetable crops and wheat in particular is a common practice in many parts of Ethiopia. An indication for greater demand for pesticides use has been described that more shops are selling pesticides, and farmers have easy access to them (Mengistie et al .2015). Similarly survey made by the Irrigation Development Authority Office of Ziway and Meki districts in the Central Rift Valley (CRV) during the 2013/14 crop seasons indicate about 53,044 l of insecticide and 50,957 kg of fungicide were applied by 13,889 smallholder vegetable farmers (Mengistie et al .2015). Damte and Tabor (2015) have reported that all vegetable growers in East Showa zone practice spraying of pesticides where fungicides and herbicides account for 90% and 7% of the respondents respectively.

The uses of pesticides are believed to bring various benefits mostly economic in particular for farmers. It is generally considered that pesticides improve or safeguard agricultural yields and the quality of agricultural products. They also minimize labor input. They can help limit soil erosion by reducing tillage cultivation, and they contribute to ensure reliable supplies of a wide choice of affordable agricultural produce. Plant protection products also play an important role in meeting plant health requirements and allowing international trade in agricultural products. Outside the agricultural sector, pesticides have a wide range of uses, preserving wood or fabric, and protecting public health. In general Cooper and Dobson (2007) have summarized that the use and benefit of pesticides include increased crop and livestock yields, improved food safety, human health, quality of life and longevity, and reduced drudgery, energy use and environmental degradation.

Most of the pesticides used in Ethiopia are imported by international manufacturing companies represented by local agents (registrants) (Amare, 2008, MOA, 2013, and Mengiste et al. 2014). However, there is also one factory that formulates pesticides within the country. Commercial farmers are the major users of pesticides in the country (Abate, 2006, EPA 2004). They are accounted for use of about 80%of the pesticides imported into the country. The remaining 20% of the total import is used for small scale farming, for household, health and industrial purposes. The use of pesticides in the individual smallholder farmers is very low, except for 2, 4 –D herbicide that is used to control weeds in the farmland. The amount of different pesticide imported to Ethiopia is indicated as in Table 2.

[redacted]0 -2012 (Metric Tons)

[redacted]	Others	Total
[redacted]	2.5	1,015.90
[redacted]	177.5	1,436.80
[redacted]	171	2,084.00
[redacted]	323.0	1,627.50
[redacted]	322.8	1,759.50
[redacted]	423.8 2,	2,27.7
[redacted]	801.6	3327.7
[redacted]	594.4	3031.7
[redacted]	212.7	2,442.4
[redacted]	12.6	3,718.3
[redacted]	25.4	4,211.4
[redacted]		1,741
[redacted]	520	3,611
[redacted]	9.7	100

There are also a number of pesticide use challenges in Ethiopia. For instance, pesticide sprayed particularly on vegetables crops are marketed and consumed by humans and livestock without consideration of the safety period specified for the product. Many studies have also demonstrated that almost all pesticide applicators in Ethiopia do not wear personal protective equipment. Pesticides and spraying equipments which can affect human health are stored in domiciles (Tadesse and Asferachew, 2008). Further more recent studies made in central rift valley areas of Ethiopia by Mengistie, et al. (2015) indicate various uses and misuse of pesticides. Mengistie et. al. (2015) also illustrated pesticide use in CRV is also done at the expense of the environment and human health. This has been indicated that pesticide application involves violation of the recommendations; unsafe storage facilities ignore risks and safety instructions and do not use protective devices in the process of applying pesticides. Damte and Tabor (2015) have reported about 72% of the respondents washed their sprayer after each application day and discharged the washings onto the soil. Moreover, the majority (62%) of the respondents threw empty pesticide containers around the field. Also, it was found that 71% of the respondents did not use personal protective equipment (PPE) while spraying pesticides, but a few used one or two types of PPE. More than half of the respondents sprayed pesticides on mature crops and sold the produce within three to five days.

Furthermore, pesticide-handling practices are steered by the combination of the system of provision, the farmers' lifestyle and the everyday context in which pesticides are being bought and used (Mengiste et al. 2015). The negative effect of pesticide use also observed on an indiscriminate uses of pesticides where it caused fatalities on honeybee colonies and incurred an economic loss amounting USD 819,291.37 (Desalegn, 2015).

Globally, the adverse effects of pesticides on environmental quality and human health have been known and well documented and have been considered as a major concern on the local, national, regional and global scales (Hough, 1998 and 2003). Pesticides as health hazardous for human health is happen when the degree of exposure exceeds safety levels. This exposure can be direct, such as the exposure of farm workers applying pesticides to various crops, or indirect, such as consumers using agricultural products containing chemical traces and bystanders near application areas (Hough, 2003; Skevas et al., 2013). The most common typical symptoms of acute (short-term) poisoning in humans are fatigue, headaches and body aches, skin irritation, eye irritation, irritation of the nose and throat, feelings of weakness, dizziness, nausea, vomiting, excessive sweating, impaired vision, tremors, panic attacks and cramps. Chronic (long-term) poisoning leads to severe health problems, such as cancer, damage to the reproductive system, the liver, the brain, and other parts of the body (WHO, 2003, 2009). The problem is exacerbated by poor access to pesticide information, unavailable or unaffordable protective equipment and unawareness of the toxicity of pesticides among people living in poor nations, (World Bank, 2000; Alavanja, 2009; Lekei et al., 2014).

Knowledge and Perception of Pesticide Uses

It is obvious that that pesticide knowledge and understanding of farmers on pesticide use is co-determining pesticide practices. Study made on Vegetable farmers in the CRV of Ethiopia indicates that about 92 % of the farmers knew the names of the pesticides they were using. The most commonly used pesticides were Mancozeb, Selecron, Ridomil, Malathion, Karate, Thionex and Profit. Table 2 indicates the farmers' knowledge and understanding about pesticide. Almost all farmers lacked extensive knowledge on the environmental and health effects from using pesticides. Although 76 % of the farmers indicated that pesticides cause damage to human health, the majority also indicated that pesticides do not cause damage to animal health (75 %) or water bodies (91 %) (Table 3).

Table 3. Farmers' knowledge and understanding about pesticide in CRV of Ethiopia

Item	Yes		N0	
	N	%	N	%
Knowledge of pesticides name?	203	92	17	8
Knowledge of pesticide effect on human health?	168	76	52	24
Knowledge of pesticide effect on livestock?	32	15	188	75
Knowledge of pesticide effect on environment (water bodies)?	20	9	200	91
Practice of reading labels?	63	29	157	71

Source: Mengiste et al. 2015)

As indicated above Mengiste et al. (2015) reported over 70 % of the farmers never read pesticide labels, because they were unable to read and understand the meaning of the label (56 %), because the labels were written in a foreign language (English, Swahili), the letter fonts too small or the language too technical (19 %). The study also found that only 8 % read and understood pesticide labels correctly. In another report by Damte and Tabor (2015) indicate that about 76% of the respondents read pesticide label before buying pesticides, while the rest 24% of the respondents did not read pesticide labels. Pesticide labels also contain self-explanatory pictures (for users with limited reading abilities) on safe use, safe handling and potential hazards. Table 4shows eight pictograms normally found on pesticide labels on the Ethiopian market. In this regard Mengiste et al (2015) have demonstrated that the majority of the farmers could not indicate the correct meaning of these pictograms, except for the pictogram ''wear gloves'', only 13 farmers understood all pictograms.

Table 4. Pictograms understanding level of Pesticide labels among CRV vegetable farmers in Ethiopia

Pictorial	Meaning	Understand meaning	
		Yes (%)	N (%)
	Keep in a safe place out of reach of children	17	83
	Protect your feet/wear boots	34	76
	Wear protective clothing/apron	28	72
	Wear gloves	72	28
	Harmful to farm animals	14	86
	Harmful to aquatic animals like fish	9	91
	Cover face/use a face shield	6	94
	Wash hand after use	7	9

Source: Mengiste et al. 2015)

Beyene et al., (2016) have also reported the uses of chemical pesticides are practiced regardless of their inherent hazard intensively in the fast changing agricultural sector of Ethiopia. The study identified a cross-sectional pesticide Knowledge, Attitude and Practice (KAP) among 601 farmers and farm workers (applicators and re-entry workers) in three farming systems [large-scale closed greenhouses (LSGH), large-scale open farms (LSOF), and small-scale irrigated farms (SSIF)]. The study identified 85% of workers did not attain any pesticide-related training but pesticide applicators in LSGH is higher (35%) and lowest in SSIF (4%). None of the female re-entry farm workers had received pesticide-related training, 81% were not aware of modern alternatives for chemical pesticides, 10% used a full set of personal protective equipment, and 62% did not usually bath or shower after work. Furthermore Gesesew et al. (2016) have also reported that the existence of high probability of pesticide exposure, the low safe use of pesticide and the low use of PPE. Personal protective equipment use was twice as high among pesticide applicators as among re-entry workers (13 versus 7%) while none of the small-scale farm workers used personal protection equipment. Damte and Tabor (2015) reported that about 71% of the respondents did not use personal protective equipment (PPE) while spraying pesticides, but a few used one or two types of PPE in East Shewa zone. More than half of the respondents sprayed pesticides on mature crops and sold the produce within three to five days.

Gesesew et al. (2016) also indicated stockpiling and burial of empty pesticide containers and discarding empty pesticide containers in farming fields were reported in both LSOF and by 75% of the farm workers in SSIF. Damte and Tabor (2015) have also reported that about 72% of the respondents of vegetable growers in East showa washed their sprayer after each application day and discharged the washings onto the soil. Moreover, the majority (62%) of the respondents threw empty pesticide containers around the field. Furthermore, Gesesew et al. (2016) have also demonstrated that knowledge of the farmers towards safe use of pesticides. A significant proportion 87.2%, of participants knew pesticides by name. Ingestion (88.9%) and inhalation (90.4%) were the major reported routes of pesticide exposure.

Congenital malformation (4.1%) and prenatal death (2%) were reported as possible outcomes of pregnancy following exposure to pesticides. More than half of participants (53.8%) had knowledge on negative effects of pesticide on animal health. More than half (55.2%) of the participants did not agree that most pesticides exposures happen in the workplaces, but through foods in the home or garden. Thirty-eight percent of the participants did not agree with the statement that reads, “it is very likely for pesticide residues to be present inside or on the surfaces of the foods we eat and water we drink”. The mean score of attitudes was found to be 3.9 (±0.4). Over half of participants (53.7%) had positive attitudes towards safe use of pesticides. These results point out a general lack of training and knowledge regarding the safe use of pesticides in all farming systems but especially among small-scale farmers. This in combination with the increase in chemical pesticide usage in the past decade likely results in occupational competence. Similarly, 27 of the 32 importers never asked for a pesticide trading license when selling their products to retailers.

Types of pesticides used by farmers and system of provision

Mengistie et al (2015) have identified that pesticides are readily available at wholesale stores (importers), the farmers' union and pesticides retailers. Pesticides are supplied in containers ranging from 0.25 to 5 l (sometimes even 200 l) or in packets ranging from 0.5 to 25 kg. One litre and 1 kg are the most common packages sold at retailers. Furthermore 41 different types of commercial pesticides with different chemical composition (organophosphates, organochlorines, pyrethroids and carbamates) were found in CRV of Ethiopia. Organophosphates and pyrethroids, with high levels of toxicity (in WHO class II, moderately hazardous), are applied at different growing stages Table 4 and 5). WHO (2009) classifies pesticides in five groups based on their hazard level, ranging from extremely hazardous (class Ia), highly hazardous (class Ib), moderately hazardous (class II), slightly hazardous (class III) to unlikely to present acute hazards (class U).

Mengistie et al (2015) have indicated in vegetable farming, insecticides (58 %) are the most widely used because of serious insect pests in vegetable production in CRV. This is followed by fungicides (42 %) usage, while herbicides are not used probably because hired laborers manually carry out weeding. This is contrary to cereal (maize and wheat) farmers, where herbicides are the predominant pesticides in use.

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Table 5. Pesticides used by vegetable farmers in the CRV of Ethiopia, 2013/14 crop seasons

Insecticides				
Trade Name	Active ingredient (AI)	Types of Crop	Types of pest or diseases	WHO's toxic class
Agro-Thoate40%EC	Dimethoate 40 %EC	Cabbage	Cabbage Aphids, African ball worm II	II
Selecron 720%EC	Profenofos ''Q'' 720 g/l	Onion	Thrips (broad spectrum) II	II
Karate 2.5% EC	Lambda-cyhalothrin	Tomato, cabbage	Thrips,sucking ,insects/wide range of insects	II
Polytrin315EC	Profenofos 300 g/l + Lambda-cyhalothrin 15 g/l	Onion	Insects (thrips)	II
Thionex 35EC	Endosulfan	Tomato, onion,	Ball worm,	II
Profit 720EC	Profenofos	Tomato, cabbage Onion	thrips, leaf hoppers	II
Ethiolathion 50EC	Malathion	Tomato, onion, cabbage	Any worms	II
Ethiozinon 60EC	Diazinon	Tomato, pepper	Boll worm, termite II	II
Polytrin_KA315EC	P Profenofos 300 g/l +	Onion	African bollworm,	II

	Lambda-cyhalothrin 15 g/l		thrips	
Ethiodemethrin 2.5EC	Deltamethrin 25 g/l	Onion	Thrips	II
Ethiothoate 40%EC	Dimethoate	Tomato	White flies, spider mites	II
Pyrinex 48%EC	Chloropyrifos-ethyl	Onion	Thrips	II I
Roger	Dimethoate 40 % EC	Onion	Thrips, Stalkborer	II
Radiant 120SC	Spinetoram	Tomato, onion Onion	Thrips, tuta absoluta	II
Coragen 200 SC	Chloratraniliprole	Tomato	African bollworm, tuta absoluta	III
Tracer 480SC	Spinosad	Tomato	Bollworm, tuta basoluta	IV
Helerat 50EC	Lambda-cyhalothrin	Onion	Thrips,boll worm	II
Dimeto40%EC	Dimethoate	Tomato, cabbage	Bollworms, Aphids	II
Lamdex 5% EC	Lambda-cyhalothrin	Onion, cabbage	Bollworm, Aphids	II
Decis 2.5%EC	Deltamethrin	Cabbage	Ballworm, aphid, fruit-borer	II
Ethiosulfan25%	Endosulfan	Tomato, onion	Bollworm	Ib

ULV				
Dursban 48%EC	Chloropyrifos-ethyl	Tomato, onion, cabbage	Stalk borer, termites, soil born insects	II
Fastac10EC	Alphacypermethrin	Tomato	Bollworm, thrips and whitefly	III
Hanclopa 48% EC	Chlorpyrifos	Pepper	Termites	

Table. 5. Continued…

Fungicide				
Trade Name	Active ingredient (AI)	Types of Crop	Types of pest or diseases	WHO's toxic class
Mancolaxyl 72WP	Mancozeb 64 % + metalaxyl 64 %wp	Tomato	Late blight, powdery mildew	II
Agrolaxyl M2-63.5 wp	Metalaxyl + Mancozeb	Tomato	Late blight, leaf spot	II
Victory 72WP	Metalaxyl +Mancozeb 64 %	Tomato	Late blight	II
Masco®_ 8-64	Mancozeb 64 %WP	Onion, cabbage	Downey mildew, Late blight	II
Ridomil 68WG	Metalaxyl-M 68 %WG	Onion, tomato	Purple blotch, Late blight and downy mildew	III
Unizeb	Unizeb Mancozeb 80 % wp	Onion Thrips II	Onion Thrips	II
Indom	Mancozeb 80 % wp	Tomato	Late blight, leaf spot	II
Fungozeb	Mancozeb 80 % wp	Tomato	Fungus	II
Indofil M-45 II	Mancozeb 80 % wp	Tomato	Fungus	II
Ethiozeb	Mancozeb 80 % wp	Tomato	Late blight	II
Cruzate R	Cymoxanil + Copper oxychloride	Cabbage, Onion	Purple blotch, downy mildew	III

			and late blight	
Bayleton 25 WP	Triadimegon 250 g/kg	Tomato	Powdery mildew, late blight	III
Matco 8-64	Metalaxyl 8 % +Mancozeb 64 %WP	Tomato, onion, cabbage	Late blight, Downy mildew	II
Kocide 101	Copper hydroxide	Tomato, onion, cabbage	Early and late blight	III
Revus 250SC	Mandipropamid	Tomato, onion	Late blight, Downy Mildew	III
Natura 250 EW,	Tebuconazole	Tomato, onion	Early blight, purple blotch	II
Nimrod 25 EC	Buprimate	Pepper, tomato	Powdery mildew	III

Pesticide Regulation

In Ethiopia guidelines have been developed for application and registration of plant protection product. (MOA, 2014). The objectives of this guideline are to (1), to develop a legal framework for the registration and post registration of pesticides (regulation, directives and guidelines) (2). To develop a proper pesticide registration system for Ethiopia and capacity building on dossier evaluation. (3). to develop a well-functioning post registration system (including monitoring, procurement guideline, inspection, storage of pesticides, capacity building and training). (4). to develop a formal consultation platform that will support PHRD with advice on (post)registration issues. (5). to execute an impact assessment of the new (post) registration system. Although there is legislation governing pesticide registration, clear guidelines on the importation, testing, and use of pesticides have not been enforced effectively. To date therefore it is not uncommon for pesticides whose use is restricted in industrialized countries to be widely used in Ethiopia. The country also has developed and established different decree. Some of the decree include Special decree for Pesticides Registration (Proc.20/1990), Environmental impact assessment proclamation ()roclamation Oo 2AAD2..2) and the Environmental Pollution Control proclamation (No 300/ 2002). However, there has been a slow national process of banning pesticides that had previously been banned internationally. For instance DDT, which is one of the banned pesticides in forty-nine countries worldwide and in many African countries, had been in use in Ethiopia until 2011 for the control of malaria-carrying mosquitoes by the Ministry of Health (MoH); and has been reported to have been illegally diverted to agricultural pest control in certain areas (Amera and Abate, 2008).

Ensuring the quality of the pesticides in the market and regulating the distribution and use of pesticides after registration is an important aspect of pesticide governance. In order to control the import of hazardous pesticides, prevent the contamination of the environment, and minimize the effects on human health, the government of Ethiopia has developed a pesticide policy. To support this policy, Ethiopia has also accepted and ratified different inter-national conventions and agreements including the Rotterdam, Stockholm, Basel, and Bamako conventions and the FAO code of conduct on pesticide distribution and use. The Ethiopian pesticide law covers the whole life cycle: from registration and procurement, via import/local manufacture and distribution to use by the growers. However, this state-based regulatory system has shown limitations because the implementation and enforcement proves not fully effective (FDRE/EPA, 2006). Despite the existences of police, guidelines and regulation many studies and experts have indicated that the existing laws do not function in an adequate way due to inefficient implementation and missing legal instruments. Mengistie (2016) have clearly iterated that the need to find ways to envisage better implementation of the law that is designed to govern pesticide use by farmers from registration to distribution and use and monitoring, including quality control. In addition the importance and the need to increase capacity of state actors in terms of human, financial and material both in the national and local level and participation of private actors are considered sustainable pesticide governance that will benefit Ethiopia.

Table 6. Pesticides being used in Ethiopia but not registered in European countries

Trade Name	Common name	Pesticide type
ACE 750 SP	Acephate I	Insecticide
Agro-Lambacin Super 315 EC	Profenfos 30% + Lambda-Cyhalothrin 1.5%	Insecticide
Ethiolathion 5% Dust	Malathion (Banned as plant protection product)	Insecticide
Ethiolathion 50% EC	Malathion Insecticide	Insecticide
Ethiosulfan 25% ULV	Endosulfan	Insecticide
Helmathion 50 Ec	Malathion 50% EC	Insecticide
Malathion 50% EC	Malathion	Insecticide
Malt 50% EC	Malathion 500 gm/lt	Insecticide
Marshal 20 UL	Carbosulfan	Insecticide
Marshal 25% EC	Carbosulfan	Insecticide
Marshal 25% ULV	Carbosulfan	Insecticide
Marshal/Suscon	Carbosulfan	Insecticide
Sumithion 96% ULV	Fenitrothion	Insecticide
Sumithion 95% ULV	Fenitrothion	Insecticide
Ametrazine 500 SC	Atrazine 250 gm/lt + Ametryn 250 gm/lt	Herbicide
Gesaprim 500 FW	Atrazine 500g/l	Herbicide
Queletox UL 600	Fenthion	Avicide
Mitac	Amitraz	Miticide
Mitigan 18.5EC	Dicofol	Miticide
Thiodan 25% ULV	Endosulfan3	Insecticide

A number of institutions are involved in pesticide management in Ethiopia. The Ministry of Agriculture and Natural Resources (MoAN), through the Plant Protection Directorate is the lead institute in pesticide management with responsibility for registration of pesticides, post-registration management as well as regulation and control. Under proclamation 674/2010, all pesticides have to be registered by a pesticide registration team before importation. The team approves registration of pesticides after receiving evaluation reports from the pesticide technical committee. The registration procedure also involves acceptance of applications and dossier evaluation for registration by the MoAN,

Technical efficacy tests are carried out by the Ethiopian Institute for Agriculture Research (EIAR) and universities who send their reports and recommendations directly to the MoAN for decisions. The EIAR is the lead research institute dealing with field efficacy tests. The Ministry of Environment and Forest (the then Environmental Protection Authority EPA) is the national umbrella organization with responsibilities regarding Environmental impact aspects of pesticides as well as development and implementation of national implementation plans towards the realization of international conventions and agreements that the country has signed and approved. The Ministry is also authorized to have an input in the issuance of investment licenses together with the Ministry of Trade and Industry.

The Ministry of Health (MoH) is the main importer and distributor of public health pesticides for vector control, including DDT before its total ban in Ethiopia in 2011.The Ministry of Trade and Industry (MoTI) issues licenses for importers, retailers and manufacturers of pesticides based on certificates of competence presented by the MoAN. The Ministry of Labour and Social Affairs (MoLSA) ensures that all employers create a safe work environment, keep records of incidences of injury to workers and make such records available to inspectors. The Federal Government Customs and Revenue Authority release imports of pesticides upon receiving certificates of clearance from the MoAN and adequate inspection by inspectors. The authority also keeps import records of pesticides.

Pesticide Stewardship Initiative in Ethiopia

According to Tadesse (2016) the first pesticide stewardship initiatives were started with appreciation of pesticide related problems in Ethiopia. The issues were brought to an agenda by MoA, DLCO-EA, USAID and USDA. The initiatives formed by creating a dialogue forum among actors on how to deal with the problem. The first planning workshop was conducted in 2008 to discuss pesticide problems in the Ethiopian agriculture sector and to identify the main actors in the pesticide delivery system (PDS) in Ethiopia. The primary objectives of pesticide stewardship programs have been to: (1). Optimize responsible pesticide use; (2).Reduce environmental and human health risks; (3). Improve quality of life and (4). Save lives and resources. The initiatives have identified the major actors involved in pesticides in Ethiopia and formulated Pesticide Delivery System (PDS). However, this initiative currently appears as it has not been shown much progress and has not realized the objective set in the program**.**

Summary and the way forward

The importance of agricultural pesticides for developing countries in general and Ethiopia in particular is undeniable. Pesticides also play a crucial role in public health, industry, livestock, and environmental protection and so on. Current initiatives by the Ethiopian government to bring about food self-sufficiency and increased security may maximize the diversity, by way of agricultural intensification and extensification. This is expected to result in increased demand for pest control management. Pressure by interest groups supporting pesticide sales will also increase and farmers may then be persuaded that pesticide use is the only way to reduce crop losses due to pests and diseases. In addition there is a concern and approach that pesticides may constitute an important component of IPM in high value crops in commercial agriculture. However, the issue of human health and environmental risks has emerged as a key problem for these countries in a number of studies. Despite their positive use aspects the products obviously pose very significant human health risks and environmental threats.

Therefore, research focus under such circumstances would be important to consider safe use of pesticides that are compatible with IPM program. It is also important to give due consideration in establishing pesticide stewardship network. Increased knowledge and skills help reduce pesticide problems and creating an alliance between and among the public sector and private sector can contribute to the national pesticide delivery system (PDS). The result of these multiple processes will then lead to and can enable the transfer of knowledge adaptable to the existing PDS and ultimately help protect human health and environmental safety. Important lessons learned from local and external sources need to be encouraged in an attempt to make the creation of a continent-wide pesticide stewardship network a reality.

Focus and promote an Integrated Crop Management (ICM) is commonly used to describe strategies that aim to optimize all available techniques in order to maintain pest populations at levels below those causing economic injury. In cases where economic and environmental concerns make pesticides use unsuitable for smallholder agriculture and therefore pest management in food crops should rely on an IPM approach. An IPM approach will maximize cultural practices, natural biological control, and use of host plant resistance. The concepts behind the subset called Integrated Pest Management (IPM) have evolved since their beginnings in the late 1950s. It is generally agreed that one of the primary objectives is reduced reliance on (especially toxic, broad-spectrum) chemical pesticide and some believe that IPM may (or should) result in reduction or removal of chemical pesticide use. There should be a need to inform farmers about integrated pest management to prevent severe health complications, which may occur as a result of unsafe and inappropriate use of pesticides.

Exercise rational pesticide use (RPU) is defined as a focused further subset of IPM, which attempts to mitigate the adverse effects of pesticide use by improvements in the selectivity of the products themselves and the precision of their application in both space and time. The benefits are maximized with a combination of all three, and the potential benefits include: reduction of costs (for both pesticides and labor), improved safety and reduced environmental impact (through more efficient use of sprays and the use of specific agents, including bio-pesticides.

Integrated Crop Management (ICM) is commonly used to describe strategies that aim to optimize all available techniques in order to maintain pest populations at levels below those causing economic injury. The concepts behind the subset called Integrated Pest Management (IPM) have evolved since their beginnings in the late 1950s. It is generally agreed that one of the primary objectives is reduced reliance on (especially toxic, broad-spectrum) chemical pesticide and some believe that IPM may (or should) result in reduction or removal of chemical pesticide use.

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The Role of Pesticides in Pest Management and Agricultural Production

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Abstract

#nsect, plant pathogen, and weed pests destroy more than 2.O of all potential food production each year. *his loss occurs despite the application of approximately million tons of pesticides per year plus the use of a wide array of non$chemical controls, such as crop rotation and "iological control. *he causes of pest out"reaks and losses of crops to pests are due to a wide array of changes in the agricultural ecosystem that encourages pest out"reaks. ,ome of the changes include the planting of introduced crops into new ecosystems. 0ative insects, plant pathogens, and weeds move into the agro$ecosystems simplified for crop production. *he use of pesticides also destroys "eneficial natural enemies and this allows known pests or new pests to occur in the agricultural ecosystem and damage crops. /any of the known pest control technologies provide significant economic "enefits when employed in a satisfactory manner. #ntegrated)est /anagement (#)/) is a key component of sustaina"le agriculture. *he advantage of #)/ for farmers in developing countries has "een clear for many years though its implementation is relatively limited.

Keywords: +griculture, #nsects,)est control,)esticides, Economic loss, =iological control.

Introduction

Reducing the current yield loss caused by pests is a major challenge to agricultural production. Global challenges facing agriculture include the rapidly increasing world human population, food and nutritional insecurity in many areas, and the need to improve agriculture efficiency (Rosegrant et al., 2014). Historically, increases in food production and management of pests have involved several strategies, including increasing the area of agricultural land, enhancing yield and competitive ability of crop plants through selection and breeding, use of organic and synthetic fertilizers, use of pesticides, improved soil and water management, and, more recently, the development of genetically modified crops (GMOs) (Godfray et al., 2010).

Globally, an average of 35 % of potential crop yield is lost to pre-harvest pests (Oerke 2005). In addition to the pre harvest losses, food chain losses are also relatively high (IWMI 2007). At the same time, agriculture has to meet at a global level a rising demand for food, feed, fiber, biofuel and other bio-based commodities. The provision of additional agricultural land is limited, as agricultural expansion would have to happen mostly at the expense of forests and the natural habitats of wildlife, wild relatives of crops and natural enemies of crop pests.

To make agriculture more productive and profitable in the face of rising costs and rising standards of human and environmental health, the best combination of available technologies has to be used. Much of the increases in yield per unit of area can be attributed to more efficient control of (biotic) stress rather than an increase in yield potential. The reduction of current yield losses caused by pests, pathogens and weeds are major challenges to agricultural production (Oerke and Dehne 2004). The intensity of crop protection has increased considerably as exemplified by a 15-20-fold increase in the amount of pesticides used worldwide (Oerke 2005).

Diverse ecosystems have been replaced in many regions by simple agro-ecosystems which are more vulnerable to pest attack. In order to safeguard the high level of food and feed productivity necessary to meet the increasing human demand, these crops require protection from pests (Popp 2011). Helping farmers lose less of their crops will be a key factor in promoting food security but even in the poorest countries whose rural farmers aspire to more than self-sufficiency. Food security is only the first step towards greater economic independence for farmers (FAO 2009). The beneficial outcome from use of pesticides provides evidence that pesticides will continue to be a vital tool in the diverse range of technologies that can maintain and improve living standards for the people of the world. Some alternative methods may be more costly than conventional chemical intensive agricultural practices, but often these comparisons fail to account for the high environmental and social costs of pesticide use. The externality problems associated with the human and environmental health effects of pesticides need to be addressed as well (National Research Council 2000).

The use of pesticides also destroys beneficiv0H,1HUvQ½r~v0H,1HUK1WWUHK:yI0D13BVKK:.IH to pest attack leading to increasing absolute losses and loss rates. An average of 35 % of potential crop yield is lost to pre-harvest pests worldwide (Oerke 2005).

In addition to the pre-harvest losses transport, preprocessing, storage, processing, packaging, marketing and plate waste losses along the whole food chain account for another 35 %. In addition to reduce crop losses due to pests, avoiding waste along the whole length of the food chain is also a key (Popp 2011). Crop protection has been developed for the prevention and control of crop losses due to pests in the field (pre-harvest losses) and during storage (post-harvest losses).

Evolutionary interactions between pests and farmers predate conventional pesticides by thousands of years. Various loss levels may be differentiated, e.g. direct and indirect losses or primary and secondary losses, indicating that pests not only endanger crop productivity and reduce the farmer's net income but may also affect the supply of food and feed as well as the economies of rural areas and even countries. An assessment of the full range of agricultural pests and of the composition and deployment of chemical pesticides to control pests in various environments would be an impossible task because of the large volume of data and the number of analyses required to generate a credible evaluation.

Estimates of pesticide-related productivity

The increased threat of higher crop losses to pests has to be counteracted by improved crop protection whatever method it will be (biologically, mechanically, chemically, IPM and training of farmers). The use of pesticides has increased dramatically since the early 1960s; in the same period also, the yield average of wheat, rice and maize, the major sources for human nutrition, has more than doubled. Without pesticides, food production would drop and food prices would soar. With lower production and higher prices, farmers would be less competitive in global markets for major commodities.

Where overall crop productivity is low, crop protection is largely limited to some weed control, and actual losses to pests may account for more than 50 % of the attainable production (Oerke 2005). In large parts of Asia and Latin America, great advances have been made in the education of farmers, whereas the situation is still poor in Sub-Saharan Africa and has worsened in the countries of the former Soviet Union because of the lack of resources (McDougall 2010).

Ensuring the safety and quality of foods and the increase in crop loss was accompanied by a growth in the rate of pesticides use. The annual global chemical-pesticide market is about 3 million tones associated with expenditures around USD 40 billion (Popp 2011).

A major factor in the "pesticide treadmill" involves two responses to pesticide resistance. The first is to increase the dose and frequency of use of the less effective pesticide; this typically results in higher levels of pest resistance and damage to natural enemies and the environment. The second response is to develop and commercialize a new pesticide. The treadmill concept assumes that this two-step process will continue until the pest meets a resistance-proof pesticide or until the supply of effective new pesticides is exhausted. The greater the impact of control measures on pest populations, the more extreme are their evolutionary responses. However, the moderate rates in yield increase in the major world crops during 1965-2000 did not offer a strong case for a high increase in pesticide use even taking into account the fair amount of change in the cropping systems of developing countries with an expansion of the fruits and vegetable sector (FAO 2000).

Costs and benefits of pesticide use

The economic analyses of pesticide benefits is hindered by the lack of pesticide use data and economic models for minor crops and non-agricultural pesticides. Cost-benefit analysis is increasingly used to assess resource management and environmental policies. The costs of pesticides and non-chemical pest-control methods alike are low relative to crop prices and total production costs. Pesticides account for about 7-8 % of total farm production costs in the EU. However, there is wide variation among Member States fluctuating between 11 % in France and Ireland and 4 % in Slovenia (Popp 2011). Pesticides account for 5-6 % of total farm input in monetary terms in the USA (USDA 2010).

Overall, farmers have sound economic reasons for using pesticides on crop land. The global chemical-pesticide market is about 3 million tones associated with expenditures around USD 40 billion in a year. In spite of the yearly investments of nearly USD 40 billion worldwide, pests cause an estimated 35 % actual loss (Oerke 2005). The value of this crop loss is estimated to be USD 2000 billion per year, yet there is still about USD 5 return per dollar invested in pesticide control (Pimentel 2009).

According to the national pesticide benefit studies in the United States, USD 9.2 billion are spent on pesticides and their application for crop use every year (Gianessi and Reigner 2005; Gianessi and Reigner 2006; Gianessi 2009). This pesticide use saves around USD 60 billion on crops that otherwise would be lost to pest destruction. It indicates a net return of USD 6.5 for every dollar that growers spent on pesticides and their application. However, the USD 60 billion saved does not take into account the external costs associated with the application of pesticides in crops.

The correct use of pesticides can deliver significant socio-economic and environmental benefits in the form of safe, healthy, affordable food; contribute to secure farm incomes and enable sustainable farm management by improving the efficiency with which we use natural resources such as soil, water and overall land use. Obviously, when pesticides are not used correctly, then the socio-economic and environmental benefits may not be realized and the economic damage resulting from widespread pesticide use should also be highlighted. The environmental and public health costs of pesticides necessitate the consideration of other trade-offs involving environmental quality and public health when assessing the net returns of pesticide usage.

Pimentel (2005) found that pesticides indirectly cost the U.S. USD 8.1 billion a year including losses from increased pest resistance; loss of natural pollinators (including bees and butterflies) and pest predators; crop, fish and bird losses; groundwater contamination; and harm to pets, livestock and public health. In a supplementary study, estimates that the total indirect costs of pesticide use was around USD 9.6 billion in 2005. Had the full environmental, public health and social costs been included the total cost could have risen to USD 9.6 billion figure (Pimentel 2005). It means that past assessments of environmental and social impact have been narrow and should they be broadened to USD 20 billion per year the previous estimate of USD 60 billion worth of production benefits to the U.S. from pesticide use would be dramatically lower (USD 40 billion) if net effects are considered. However, the net benefit still shows a high profitability of pesticides indicating a net return of USD 3 for every dollar spent on pesticides (Popp 2011).

Bio-pesticides and integrated pest management

Biological control is urgently needed, opening increasing possibilities for bio-pesticides. Bio-pesticides offer important social benefits, as compared with conventional pesticides. Yet in an agricultural industry that is still dominated by pesticides, biological control has found its place in the form of supplementary releases, particularly for the management of pests that are difficult to control with insecticides. Since pest problems in agriculture involve plants, plant-feeding organisms and their natural enemies, the regulation of biological control agents has usually been the responsibility of national plant quarantine services.

There has been a strong tendency to consider bio-pesticides as “chemical clones” rather than as biological control agents, and therefore the chemical pesticide model has been followed. On the other hand, regulation of bio-pesticides is needed because being “natural” does not mean it is safe.
However, the challenge of new and more stringent chemical pesticide regulations, combined with increasing demand for agriculture products with positive environmental and safety profiles, is boosting interest in bio-pesticides. It takes an average of 3 to 6 years and USD 15-20 million to develop and register a bio-pesticide compared with 10 years and USD 200 million for synthetic pesticides (REBECA 2007).

Bio-pesticides may be safer than conventional pesticides, the industry is composed mostly of small-to medium sized enterprises, and it is difficult for one company to fully and comprehensively fund research and development, field development and provide the marketing services required to make a successful bio-pesticide company. Another challenge is the lack of innovative bio-pesticide products coming to the marketplace and their registration (Farm Chemical Internationals 2010).

During the past two decades, IPM programs have reduced pest control costs and pesticide applications in fruit, vegetable and field crops. Reductions in pest control costs and pesticide use in IPM programs can be achieved by introducing or increasing populations of natural enemies, variety selection, cultural controls, applying alternative pesticides and improving timing of pest suppression treatments. For farmers, very often the main benefit of IPM is the avoidance of uneconomical pesticide use. However, a large part of the benefits are reduction of externalities and therefore occur to other groups. This poses considerable measurement and valuation problems. Although the IPM programs did reduce pesticide use, most of the programs still relied heavily on pesticides.

However, new scientific knowledge and modern technologies provide considerable opportunities, even for developing countries, to further reduce current yield losses and minimize the future effects of climate change on plant health. Finding continuously new cost-effective and environmentally sound solutions to improve control of pest and

Challenges of the global pesticide market

Globalization is affecting pest management on and off the farm. Reduction in trade barriers increases competitive pressures and provides extra incentives to farmers to reduce costs and increase crop yields. Liberalization of input markets, often labeled as successful market reform, can lead to inefficient pesticide use and high external costs (FAO 2009). Other forms of trade barriers create disincentives for adopting new technologies such as the reluctance of the EU to accept genetically modified organisms.

Around 30 % of pesticides marketed in developing countries with an estimated market value of USD 900 million annually do not meet internationally accepted quality standards. They are posing a serious threat to human health and the environment. Such pesticides often contribute to the accumulation of obsolete pesticide stocks in developing countries (FAO 2009). Possible causes of low quality of pesticides can include both poor production and formulation and the inadequate selection of chemicals. When the quality of labeling and packaging is also taken into account, the proportion of poor-quality pesticide products in developing countries is even higher. Falsely declared products continue to find their way to markets for years without quality control (FAO 2002).

The problem of poor-quality pesticides is particularly widespread in sub-Saharan Africa, where quality control is generally weak. The UN agencies urged governments and international and regional organizations to adopt the worldwide accepted FAO/WHO pesticide specifications to ensure the production and trade of good quality products. Countries should make these voluntary standards legally binding. The FAO/WHO standards are especially important for developing countries that lack the infrastructure for proper evaluation of pesticide products. Pesticide industries, including producers of generic pesticides, should submit their products for quality assessment to FAO/WHO (FAO/WHO 2010). Another negative economic consequence of a higher use of pesticides in developing countries is the loss of export opportunities for developing countries especially with horticultural crops as the developed countries are tightening maximum residue levels. In turn, agricultural lobbyists in industrialized nations may exploit this situation and use environmental standards as non-tariff trade barriers.

Sustainable, IPM based on biological control is urgently needed, opening increasing possibilities for bio-pesticides. Their beneficial features include that they are often very specific, they are “inherently less toxic than conventional pesticides” compatible with other control agents, leave little or no residue, are relatively inexpensive to develop and support the action of natural enemies in ecologically based IPM. The market share of bio-pesticides is growing faster than that of conventional chemicals. In recent times, large agricultural chemical companies have become very dynamic and are constantly on the lookout for technology that complements what they already have or that complements a segment of the market that they are focused on.

While bio-pesticides are typically seen as an alternative to synthetic chemicals, some experts see bio-pesticides as complementary to conventional pesticides already on the market. Increasing demand for chemical-free crops and more organic farming has led to augmented usage of bio-pesticides in North America and Western Europe (ICIS 2009). Key factors in this growth include a larger overall investment in bio-pesticide research and development, a more established application of IPM concept and an increased area under organic production. Products not requiring registration and products which already have been registered have priority in the research and development of these companies.

As a result of the various merger and acquisition that have taken place, the agrochemical sector is relatively highly consolidated. An increasing number of merger and acquisition transactions have been targeted at strengthening the respective product portfolios of the purchasing company through the acquisition of a particular agrochemical product or product range. While product acquisitions have always been a feature of the agrochemical industry, the overall level of this type of merger and acquisition activity has increased significantly in the last 10 years (McDougall 2010).

Conclusions

Cost–benefit analyses are important tools for informing policy decisions regarding use of chemical pesticides. The impacts of pesticides on the economy, environment, and public health are measured in monetary terms. However, there are many uncertainties in measuring the full array of benefits and costs of pesticide use. Making wise tradeoffs to achieve a fair balance between the risks that a community bears and the benefits that it receives is one of the most difficult challenges for policy makers.

Chemical pesticides will continue to play a role in pest management because environmental compatibility of products is increasing and competitive alternatives are not universally available. Pesticides provide economic benefits to producers and by extension to consumers. One of the major benefits of pesticides is protection of crop quality and yield. Pesticides can prevent large crop losses, thus raising agricultural output and farm income. The benefits of pesticide use are high-relative to risks. Non-target effects of exposure of humans and the environment to pesticide residues are a continuing concern. Side effects of pesticides can be reduced by improving application technologies. Innovations in pesticide-delivery systems in plants promise to reduce adverse environmental impacts even further but are not expected to eliminate them. The correct use of pesticides can deliver significant socio-economic and environmental benefits.

Many bio-control agents are not considered acceptable by farmers because they are evaluated for their immediate impact on pests. Evaluation of the effectiveness of bio-control agents should involve consideration of long-term impacts rather than only short-term yield, as is typically done for conventional practices. A concerted effort in research and policy should be made to increase the competitiveness of alternatives to chemical pesticides for diversifying the pest-management “toolbox”. But availability of alternative pest-management tools will be critical to meet the production standards and stiff competition is expected in these niche markets.

New scientific knowledge and modern technologies provide considerable opportunities, even for developing countries, to further reduce current yield losses and minimize the future effects of climate change on plant health. Finding continuously new cost-effective and environmentally sound solutions to improve control of pest and disease problems is critical to improving the health and livelihoods of the poor. The need for a more holistic and modernized IPM approach in low-income countries is now more important than ever before.

Total investment in pest management and the rate of new discoveries should be increased to address biological, biochemical and chemical research that can be applied to ecologically based pest management. Investments in research by the public sector should emphasize those areas of pest management that are not being undertaken by private industry. Transmission of knowledge in the past was the responsibility mostly of the public sector, but it has become more privatized. The public sector must act on its responsibility to provide quality education to ensure well-informed decision making in both the private and public sectors by emphasizing systems-based interdisciplinary research.

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Minutes of the Plenary Sessions of 24th Annual Conference of the Plant Protection Society of Ethiopia

Plant Pathology Papers

Chairperson: Eshetu Dersso (PhD)

Rapporteur: Habtewold Kifelew

Presenter: Berhanu bekele

Title: Maize lethal Necrosis Disease in Ethiopia: Status, Interventions and Prospect

Presenter: Demelash T

Title: Overview of Coffee Protection Research in Ethiopia

Presenter: Bekele Kassa

Title: Research advances in potato Bacterial wilt Research and its Relevance to defining the way

Forward for the potato sector in Ethiopia

Presenter: Feleke Sibhatu

Title: Exploratory investigation on cultural and morphological characterization and management

of ginger disease complex

Presenter: Bekele Hundie (PhD)

Title: Overview of Wheat Rust Epidemiology and Management in Ethiopia

Presenter: Gezahegn Getaneh

Title: Faba bean gall disease status, interventions and prospects in Ethiopia

Presenter: Adane Abraham (PhD)

Title: Newly Emerged Plant Virus Disease in Ethiopian agriculture: Status, Causes and Control

Discussions

Participants discussed the presented papers and commented on each of them. It was commented that we have been doing a lot on maize lethal necrosis disease and we have got three genotypes which vary in resistance reaction and we are going to use the genotype in the futue.

On coffee research, it was suggested that there is a shift in CBD resistance, there is also difference in virulence in CBD population and some genotypeswere found to have lost their resistance, so the breeding team should consider local CBD population for screening the genotypes. The coffee leaf rust disease has been localized disease and in our case not serious hawever coffee wilt disease is a serious one and we need more research on it. Spraying pesticides on coffee should be carefully done if at all, based on thresholds as was previously developed for Anthestia bug.

On the management of ginger bacterial wilt coming up with a number of disease complex can not lead us to the proper diagnosis.Thus focus needs to be on the major one. It was also mentioned that the paper on ginger bacterial wilt was presented at Adama and it was suggested there that there were procedureal errors and that the presenter come to Ambo Plant Protection Research Center for more technical support which he did not do.

In Ethiopia currently the major threat on ginger production is ginger bacterial wilt so we need focus on this disease. On Faba bean gall disease, it was indicated that a project has been developed and in near future we may come up with a permanent solution.It was also mensioned that “Bayleton wp 25 “fungicide is not registered in Ethiopian and not availabil on the market and should not be recommended.

It was also explainedthat on virus control through chemical spray on vector needs to be carefully handled since there is no clear direction on how and on spot spray on vector.On tomato virus there is high severity leading to abandonment of fields and spraying on vector is difficult since it is not coordinated with neighboring farms.

Use of terms such us infection for diseases and infestation for insect has to be consistent.consistency is also required on using MLN or MLND. The tomato virus was reported since 1980 and should not be presented as first reported in 2006.However it was mentioned that the written report on journal was in 2006 by the Mekassa research team.

It was also explained that MLN disease can not be regareded as a quarantine pest anymore but all imported seeds need to be checked. However the quarantine policy has to be formulated.

Entomology Papers

Chair: Dr. Tsedeke Abate
Rapporteur: Abiy Balcha

Presenter: Dr. Abraham Tadesse
Title: The larger grain borer, prostephanus truncates (Horn) Coleoptera: Bostrichidae): Status, interventions and the way forward.

Presenter: Dr. Belay Habtegebriel
Title: White mango Scale: A new threat to Mango production in Ethiopia.

Presenter: Hiwot Lemma
Title: Recent surges of Migratory Pests in Ethiopia: The case of Desert Locust

Discussions

Infestation by LGB from place to place was raised as a conceren and it was explained that invasion of the pest may be primarily through movement of contaminated commodities rather than to active migration of the insects, so improved between and within-country quarantine program combined with regular monitoring, may therefore , prevent further introductions or restrict spread of infestations.

It was emphasized that controlling locust in early stage before wide spread was a must and use IPM issue joint effort within different country. Clarification was also sought on the benefits of knowing the relationships between pests and climate from the satellite information.

Farmers are trained about different methods of controlling locusts including pesticides control.The training is effective in some areas but that cause damage to human and

animals health and also much effort was made on cultural practices in relation to climate as locust bredin down movement cloud in moist soil as rain starts so climate is important in controlling locust.
It is obvious climate play a major role in controlling pests satellite information is used to predict the occurrence as well as distribution of locust form country to country.

It was mentioned that white mango scale was studied by PhD students from Haramaya University so it is not a new threat in Ethiopia and that there are some local publications on it. There are also gaps in managing the white mango scale using host resistance and screening should be done to try and find any resistant varieties. The yield loss incurred by the pest should also be systematically studied although there is some estimation such as that of Mohammed et al., 2012 who suggested up to 30% yield loss.

Weed Science papers

Presenter: **Stephen Nyjoka (PhD) (especially invited by the society to share experiences of water hyacinth control in Uganda**

Title: Water hyacinth Control and Management in the case of Lake Victoria

The presentation covered introduction, Problem associated with Water hyacinth and control methods of the weed.

Presenter two: **Takele Negewo**

Title: Broomrapes (Orobanche and phelipanche spp.): Problem and Management in Ethiopia

Presenter: Abiyselase Mulat

Title: Invasive alien plant species in Ethiopia

Discussions

A concern was raised on the effectiveness of the predators/natural enemy of water hyacinth versus agroecology i.e. at what agro-ecology the predators are adaptable? It was explained that most of the study showed that hot and wet areas are suitable for water hyacinth weevils; the adaptability and survival of the weevils is also affected by extreme hot and cold.

Chemical control was practiced in some areas like in wonji sugar factory of Ethiopia and in the presentations it was mentioned that chemical control is not recommended.It was explained that although there are some experiencesin the case of Lake Victoria it was not recommended because, it is water body and the home for other organisms. Therefore, it is recommendedto use ecologically and economically safe management options like biological control using water hyacinth weevils. However, if we want to use herbicides, it is better to use by integrating with other control options rather than using single method. A concern was also raised on whether is it possible to eradicate water hyacinth by using bioagents? It was discussed that eradication is not possible but long-term damage results in the reduction of the production of flowers, leaves and daughter plants and a stunting of plant growth. Under the correct environmental conditions, the combination with the other control methods of water hyacinth may bring the weed under complete control. Otherwise with this alone, we can't eradicate.

On the paper aboutorobanchae, the presentation covered introduction, biological and ecological features of broomrapes, problems associated with broomrapes, management options, conclusion and future prospects. On this presentation, there was no pertinent question asked rather comments on the depth of review particularly on some of the achievement made by ICARDA and the effectiveness of the existing management options.

On the paper regarding invasive alien plant species in Ethiopia it was mentioned that some of the species listed as invasive alien plant species were not invasive and are old plantes. Questions were also raised on whether there is any policy to control such alien plant species? Concerns were also raised on why prosopis juliflora spread quickly from regions to regions. Explanation was given from the presenter that there is a policy and convention between countries and health certificate is also a must. With regard to). !uliflora , many scholars reported that the species has been increasing in density as well as area coverage from year to year even from month to month. Reason for this is better survival and growth rate under drought stress arid areas. Dissemination mechanisms of seeds by domestic and wild animals and the ability to germinate immediately after dispersal give). !uliflora great opportunity to grow faster and makes it a more adapted species to drought condition.

Minutes of Plenary Debate on the Way Forward of the PPSE discussed during the 24th Annual Conference of the Plant Protection Society of Ethiopia

Venue: Afran Qallo Hall (Haramaya University)

Present were:

1. Dr Frew Mekbib……..Facilitator
2. Dr Mashilla Dejene….Rapporteur
3. Members of Plant Protection Society of Ethiopia (PPSE)
4. Invited Guests Outside HU and Partners
5. Sponsors of the Society (Both for HU and PPSE)
6. Invited HU College Deans and Department/School Heads
7. Interested postgraduate students

Selected Panel Discussion Resource and Professional Persons

1. Prof. Chemeda Fininsa
2. Dr. Ferdu Azerefegne
3. Mr. Woldehawariat Asefa
4. Dr. Tsedeke Abate
5. Dr. Bekele Kassa
6. Dr. Abraham Tadesse

Agenda 1. Debate on the take-home message from the 24th Annual Conference of PPSE

Agenda 2. And Other Businesses (AOB)

Agenda 1. Take-home message from the 24th Annual Conference of PPSE

Dr Frew Mekbib, the Facilitator of the debate, commented on the objective of the discussion and invited all the resource panelists to come to the forum for discussion. He also remarked that since time was a pressing factor, speakers were requested to make their speech brief and to the point so that others could get opportunity to forward their opinion in line with the agendum. Then, the first chance was given to Prof. Chemeda Fininsa, President of Haramaya University, to forward the take-home message to the audience.

1. **<u>Professor Chemeda Fininsa's take-home message:</u>**

First and foremost, Prof. Chemeda Fininsa (from Haramaya University, Plant Pathologist, PhD) emphasized the significance of emerging and re-emerging pests that constrain crop production and protection these days, mentioning plant viruses for substantiating his opinion. He also stressed on the dire need for allocation of resources for plant protection. Similarly, he urged all researchers to write grant winning projects jointly with universities, research centers and other institutions involved in crop production and protection and, thereby, attracting local and international partners. The trend of starting to work on a certain important problem and ending without finish is not justifiable and is not acceptable, he added. Finally, he strongly suggested the need for strengthening and building capacity for teaching, research and outreach activities.

2. **<u>Dr Ferdu Azerefegne's take-home message:</u>**

When started his speech, Dr Ferdu Azerefegne (from Hawassa University, Entomologist, PhD), told the audience that commonly plant pathogens and insect pests come and we should act accordingly before entering and devastating our crops. He added that minor pests change and become major pests. Continuing his discussion, he stated that there are missing areas or issues that are given less attention. For instance, biological control area is not fully exploited in this country, i.e. researches are not done that much and available technologies are not extended to the desired level. Similarly, he pointed out research work on water hyacinth can motivate people to work intensively in such area. He added that the way students are trained should be improved and be practical oriented; and research on plant protection education should be comparable to the world area or standard.

3. **<u>Mr Woldehawariat Assefa's take-home message:</u>**

Mr Woldehawariat Assefa (from Ministry of Agriculture, Seed Science & Technology, MSc) indicated that policies have been drafted for most of the emerging pests and has been forwarded to the National Plant Quarantine Regulation for approval and endorsement. Similarly, he disclosed that a strategy has been developed for human capital development per region, especially for those regions where the number of available human experts is low, i.e. restructuring regionally at directorate level. Also, he disclosed that training experts is in process simultaneously. Concerning capacity-building, he pointed out that the Ministry has secured budget annually, i.e. on yearly basis. He mentioned that there is a plan to establish Plant Health Clinics at all woredas and zones in the country. He told the audience that regulation has been drafted on matters related to pesticide registration and disclosed that a concept note has been developed for disposal of obsolete pesticides at national level. He appreciated gathering and discussing together on burning issues; but bringing policy briefs to policy makers so that policy makers could give due attention to the issue on board. Finally, he urged researchers to seriously consider aflatoxin problems and pesticide residues that are risks to human beings and animals.

4. **<u>Dr Tsedeke Abate's take-home message:</u>**

At outset of his discussion, Dr Tsedeke Abate (distinguished and senior entomologist, PhD) stated that issues revolve around enabling the young generation and stressed that the nation has to be ready for the challenges of the 21st century and we need to consider quality-oriented aspect of education and research. He firmly stated that your (educators and researchers) power is your knowledge and vice versa. He indicated that researchers and educators are competing globally and make sure that incumbent academic institutions are competent front line organizations. He advised the researchers to make sure that the mix of conventional and modern state-of-the-art technologies are in place. He added that educators and researchers should not hesitate to embark on challenging issues; and hinted at focusing on educating rather than training, giving a local proverb **"ማንነውያስተማረሽ?" ተብላተማሪዋስትጠየቅየሰጠችውመልስ "እገሌ" ካለችበኋላ "ግንእሱእውቀትአላስጨበጠኝም" አለችይባላል፡፡** He advised the participants to go beyond training and prepare the young generation to be competent in all walks of life, considering home-borne solutions and a foreigner should not tell you what to do. He emphasized the importance of learning from experiences of others; but you should not do things over again and simply chip in. E.g. water hyacinth management. He told the audience to identify something that is considered to to contribute to the community. He discouraged boasting with little knowledge, but work hard and make sacrifices since one can not eat his potential. The young ones are teenagers and mentoring the young generation is required fo this country.

Dr Tsedeke Abate suggested to the Ministry of Agriculture to enforce phytosanitary aspects and grants for research projects. He suggested for universities to look for grants for training and for staff incentives or motivation, creating a rewarding system, which is very important for research activities. Even in the classrooms, appreciation is a mechanism of rewarding and encouraging students to be industrious. Above all, he suggested to have legacy and humble approach to the young ones.

5. **Dr Bekele Kassa's take-home message:**

Dr Bekele Kassa (from Holleta Agricultural Research Center, a pathologist, PhD) commented on the need for strengthening plant protection. He also shared the opinion of Dr Tsedeke Abate in connection with capacitating the young generation. Similarly, he capitalized on strengthening of human capacity and laboratory capacity, like Biotechnology Laboratory. He reiterated the need for consideration of research on emerging pests and mentioned the existence of newly emerged pests, like faba bean gall, maize lethal necrosis (MLN), leaf miners such as tomato leaf miner (*uta a"soluta), red spider mite, and larger grain borer. Finally, he opined for College of Plant Protection in Ethiopia.

6. **Dr Abraham Tadesse take-home message:**

Dr. Abraham Tadesse capitalized on the need to do researches and solve problems. To do this and to achieve the objectives, he advised researchers to use the available resources effectively and efficiently. Further, he said the country has some senior professionals and moderate resources and piecemeal approach is not commendable, i.e. fragmented work is not a good approach, citing good multidisciplinary team researches going on tomato viruses, maize viruses, etc. at national level. He emphasized the need for identification and knowing the major crop pests and working together, mentioning the existence of a virology group when Dr Habtu Assefa was the President of PPSE. Strengthening the quarantine aspect was a point of emphasis and consideration in his view, indicating seed health testing as a spring board. He suggested that the Ministry of Agriculture has to use its available resources and facilities towards supporting plant protection. Finally, he stated that if researchers, educators and all concerned offices and individuals join hands, successes could be achieved in a span of five years.

At the end of the debate and the way forward, Dr Frew Mekbib, the Facilitator, hinted at the publication of the Proceedings of the 24th Annual Conference of PPSE by Haramaya University. He appreciated Dr Belay Habtegabriel, the President of PPSE, for his dedication and said deserve love and applauding and both received the requested applauding from the audience. In response, Dr Belay Habtegabriel thanked Dr Frew Mekbib for the nice job done in his facilitation. Similarly, he thanked Haramaya University and all its community members and the Organizing Committee Members lead by Dr Awol Seid. Finally, Dr Frew Mekbib invited Prof. Nigussie Dechassa to make closing remarks and officially close the 24th Annual Conference of PPSE.

Closing Remarks

The 24th Annual Conference and Silver Jubilee of the Plant Protection Society of Ethiopia (PPSE)

Dear distinguished scientists,

Ladies and gentlemen,

We have now reached the climax of this stimulating conference.

It is gratifying to realize that this conference has brought together so many distinguished agricultural scientists from across Ethiopia and other parts of Africa and provided a great platform to learn and share experiences. In particular, it makes our University very proud of witnessing that most of the distinguished agricultural scientists that have joined us in this noble Conference are the ones that cut their professional teeth at this very institution, Haramaya University. We are happy that once again you have come back home and shared us your remarkable experience and wisdom. We have witnessed that your desire and passion as well as the commitment to make this Conference a reality have been unparalleled. Thank you!

This Conference has proved not only a meeting arena for us (plant protectionists, agronomists, plant breeders, and others), to share existing and new knowledge in the field of research on crop protection, but it has also proved to be a great platform to learn and uncover our potential to closely work together and share plant protection issues of agricultural importance for the future of food and nutrition security of our country.

The dynamism of scientific knowledge calls for ever readiness to adapt to changes and keep abreast of improved ways of thinking and doing things. The world has become a village and is now very competitive. On the other hand, there is no agriculture in the world that is so much threatened by climate change as the African agriculture. Therefore, we have to battle it out for a decent place in increasing agricultural production in our continent on sustainable basis through research and development in the field of plant protection and other agricultural disciplines. Thus, we need to promote research excellence as well as research impact to bring about the required change in our agricultural development.

On the whole, the Conference has been an enriching and fulfilling experience. We have been enlightened on plant protection issues that are close to our hearts. We have learnt about new threats posed to our crops by emerging, re-emerging and existing plant pathogens, insect pests, and weeds, and pondered over how to tackle the problems. We have gauged the positive changes, pitfalls, gaps, and future prospects of plant protection research in our country and shared views on the way forward to tackle the pitfalls and bridge the gaps.

However, for us, conducting a Conference on plant protection should not be an end in itself. We need to do some soul-searching now to push out the frontiers of our research and knowledge generation and application on plant protection. We need to assess what we have achieved so far and what remains to be done for a robust response to emerging pests and diseases. Thus, we need to think of where we want to dock with our plant protection research and outreach activities in the future.

Therefore, we have to infuse new energy, motivation, and commitment into plant protection research and extension for result-oriented outcome. We need to do cutting edge and impactful research and come up with home-grown innovations and recommendations to tackle the problems of emerging pests and diseases threatening our very existence, thereby ensuring sustainable agricultural production. In this respect, our University will continue playing its roles in training, research, and outreach programmes. However, we need to work cohesively in partnerships with each other by exploiting our synergies. Our University has the desire, passion, and commitment to work with you, i.e. scientists present here as well as those who have been unable to make it to this arena due to other commitments.

We are grateful to all of the volunteers of the Plant Protection Society of Ethiopia (PPSE) as well as that of Haramaya University, which were involved in organizing this stimulating Conference. We are also thankful to the keynote speakers, panelists, facilitators, research paper authors, from Ethiopian Institute of Agricultural Research (EIAR), Addis Ababa University, Sasakawa Global 2000, Ministry of Agriculture and Rural Development, Desert Locust Control Organization for Eastern Africa, Bahir Dar Fisheries and Other Aquatic Life Research Center, Farming Systems Ecology, Wageningen University, Bahir Dar University, Debre Markos University, Adama Science and Technology University, Debrebirhan Agricultural Research Center, Haramaya University, Wollega University, and others.

Our University as a whole feels that the two-day long Conference has been a significant accomplishment, which provided action packed agenda, providing something for everyone, which included thought-provoking keynote speeches, challenging panel discussions, presentations, group discussions, informal networking outside the Conference room and not to mention the enjoyable networking lunch.

We are particularly grateful to our senior and seasoned scientists who came all the way from where they are. Thank you for professionally and physically gracing our Conference.

Your infectious engagement and focus on the theme "Emerging and Re-emerging Plant Pests of Ethiopia: Status, Interventions, and Future Prospects in a Changing Climate" has exceeded our expectations and we are gratified to observe the development of new interesting knowledge exchange fora, relationships, and networks being formed.

Those who funded our conference: FAO, EIAR, OARI, Ethio-Agr-Ceft, Oda Bultum University, etc: On behalf of Haramaya University, I would like to take this opportunity to thank you for your generous financial support to cover the cost of the Conference with significant donations as well as pledges of donation. This money will go towards covering the cost of arranging and delivering the Conference.

I would like to assure you that all that has transpired from this Conference will be captured in proceedings and will be distributed to you as well. We look forward to receiving your feedback on the event.

Once again, thank you for making this Conference a reality and a memorable occasion. Congratulations to the Plant Protection Society of Ethiopia on a job well-done in organizing and celebrating your Silver Jubilee! Congratulations to Haramaya University on hosting this splendid historical Conference!

May I take this opportunity to wish you a happy journey back home!

With this remark, I declare that this Conference is hereby officially closed!

Thank you all!!!

Prof. Nigussie Dechassa (PhD)

Vice-President for Academic Affairs

Haramaya University.

List of Awardees

On the occasion of the 24th annual conference and the 25th year silver jubilee, recognition was given to various organizations and individuals who have so far made immense contribution to PPSE and plant protection by providing awards (presents and certificates). Here is the list.

No.	Name	Contribution to the PPSE
1.	Haramaya University	Host of the 24th annual conference
2.	Dr. Mengistu Huluka	President, 1992 – 1996 (2X)
3.	Dr. Habtu Assefa	President, 1996 – 2000 (2X)
4.	Dr. Yaynu Hiskias	President, 2000 - 2002
5.	Dr. Kemal Ali	President, 2002 – 2004: Editor, 2008-2009 and 2014 -2015
6.	Dr. Abraham Tadesse	President, 2004 – 2008 (2X)
7.	Dr. Bayeh Mulat	President, 2008 – 2012: Editor 2010-2013
8.	Dr. Gashawbeza Ayalew	President, 2012 – 2014
9.	Mr. Ermias Shonga	President, 2015 -2016
10	Dr. Tsedek Abate	First Editor of PMJoE, 1997 - 1998
11	Dr. Tadesse G/Medhin	Editor: 1999 – 2004 (3X)
12	Dr. Seid Ahmed	Editor: 2004 – 2007 (2X)
13	Dr. Waktole Sori	Editor: 2016 - 2018
14	Dr. Belay Habtegebriel	President, 2016 - 2018
15	Dr. Awol Seid	Chairperson/focal person of the Main Steering Committee of the silver jublee and 24th annual conference of the PPSE led by HU.
16	Prof. Chemeda Fininsa	President of HU and Advisor of the Main Steering Committee
17	Dr. Habtamu Terefe	Secretary of the Main Steering Committee
18	Dr. Firew Mekbib,	Member of the Main Steering Committee
19	Dr. Kibebew Kibret	Member of the Main Steering Committee
20	Dr. Bulti Tesso	Member of the Main Steering Committee
21	Dr. Mashilla Dejene	Member of the Main Steering Committee
22	Dr. Mulatu Wakgari	Member of the Main Steering Committee
23	Dr. Abdi Mohammed (PhD)	chairperson of the Accommodation Sub-Committee 2018.
24	Dr. Jemal Yousuf (PhD)	Vice-President for Research Affairs of HU and member of the Accommodation Sub-committee
25	Mr. Ibsa Aliyi (MSc)	Member of the Accommodation Sub-committee

26	Mr. Admikew Haile (MBA)	Member of the Accommodation Sub-committee
27	Mr. Ayele Akuma (MSc)	Member of the Accommodation Sub-committee
28	Dr. Belayneh Legese (PhD)	Vice-President for Administrative and Student Affairs of HU and chairperson of the Transportation Sub-committee
29	Mr. Birhanu Worku	Member of the Transportation Sub-committee
30	Mr. Bulti Merga (MSc)	Member of the Transportation Sub-committee
31	Mr. Belayneh Engidawork (MSc)	Member of the Transportation Sub-committee
32	Prof. Kebede W/Tsadik (PhD)	Vice-President for Community Services and Enterprise Development of HU and Cahir person of Meal and Refreshment Sub-committee
33	Mr. Abiyou Dabasso	Membmer of Meal and Refreshment Sub-committee
34	Mr.Atlabachew Mekonnen (MSc)	Secretary of Meal and Refreshment Sub-committee
35	Mr. Mintesinot Birara (MSc)	Membmer of Meal and Refreshment Sub-committee
36	Dr. Wassu Mohammed (PhD)	Member of the Exhibition Sub-committee
37	Mr. Degefa Gebisa (MSc)	Member of the Exhibition Sub-committee
38	Miss. Birtukan Yimam	Member of the Exhibition Sub-committee
39	Mrs Haimanot Bizuneh	Member of the Exhibition Sub-committee
40	Mr. Ahmed Molla (MSc)	Member of the Exhibition Sub-committee
41	Dr. Abdulrazak Yusuf (PhD)	Secretary of Safety and Security Sub-committee
42	C/r. Sisay Hirphaa	Member of Safety and Security Sub-committee
43	I/r. Dawit Taye	Member of Safety and Security Sub-committee
44	Mr. Gizachew Molla	Member of Safety and Security Sub-committee
45	Mr. Dawit Terefe (MSc)	Member of Safety and Security Sub-committee
46	Prof. Nigussie Dechassa (PhD) Vice-President forAcademic Affairs	Vice-President forAcademic Affairs of HU and Chairperson of the
47	Mr. Alemshet Teshome	Member of Media and Communications Sub-committee
48	Mr. Tamirat Kassa (MSc)	Member of Media and Communications Sub-committee
49	Mr. Belete Shawl	Member of Media and Communications Sub-committee
50	Mr. Tewodros Setito	Member of Media and Communications Sub-committee

51	Mr. Fuad Ahmed	Member of Media and Communications Sub-committee
52	Mr. Ashenafi Kassaye (MSc)	Member of the Facilitators Sub-committee
53	Mr. Bekele Gelena (MSc)	Member of the Facilitators Sub-committee
54	Mrs. Hirut Yirga (MSc)	Member of the Facilitators Sub-committee
55	Miss. Simret Burga (MSc)	Member of the Facilitators Sub-committee
56	Mr. Melese Mengistu (MSc)	Member of the Facilitators Sub-committee
57	Mr. Tafese Tsegaye	Member of the Facilitators Sub-committee
58	Mr. Besufekad Tesfaye	Member of the General Services Sub-Committee
59	Mr.Nigussie W/Tsadkan	Member of the General Services Sub-Committee
60	Mr.Shimelis Feleke	Member of the General Services Sub-Committee
61	Mr. Amin Damisho	Member of the Transportation Sub-Committee
62	Mr. Birhanu Asfaw	Member of the Transportation Sub-Committee
63	Mrs. Lewegnesh Estifanos	Member of the Transportation Sub-Committee
64	Mr. Alebachew Kassa	Meal and Refreshment Sub-Committee
65	Mr. Abdulhamid Aliyi	Meal and Refreshment Sub-Committee
66	Mr. Tsegaye Asfaw	Media and Communication Sub-Committee
67	Mr. Tsegaye Argaw	Media and Communication Sub-Committee
68	Mr. Yinebeb Alemu	Member of the Financing and Purchasing Sub-Committee
69	Mr. Biruk Firde	Member of the Financing and Purchasing Sub-Committee
70	Mr. Abera Molla	Member of the Financing and Purchasing Sub-Committee
71	Mr. Yilak Tessema	Member of the Financing and Purchasing Sub-Committee
72	Dr.Belay Habtegebriel (PhD)	President of PPSE and chairperson of the PPSE Executive Committee
73	Dr Netsanet Bacha (PhD)	Member of the PPSE Executive committee (Treasurer)
74	Mr Kedir Shifa	Vice-President of PPSE and member of the PPSE Executive Committee
75	Dr. Waktole Sori (PhD)	Editor in chief of PMJoE and Member of the excutive committee
76	Dr. Wogayehu Worku (PhD)	Accountant of the PPSE and Member of the exectutive committee
77	Mrs. Shashetu Bedada	Auditor of the PPSE and Member of the executive committee
78	Mr Kassahun Sedesa	Secretary of the PPSE and Member of the executive

		committee
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Themes of the annual conferences of the Plant Protection Society of Ethiopia

No.	Conference date	Conference theme	Remarks
I	5-6 March, 1992		Joint conference of the Ethiopian Phytopathological committee and committee of Ethiopian entomologists
1st	14 – 15 April, 1993	Role of Plant Protection in the National Agricultural Development	
2nd	26 -27 April, 1993	Locust Pests of Ethiopia: Status, Control and Research	
3rd	18 – 19 May, 1995	Integrated Pest Management	
4th	23 – 24 May, 1996	Pesticides in Ethiopia: Status and Policy Issues.	
5th	22 -23 May, 1997	Crop Protection in Sustainable Agriculture in Ethiopia	
6th	3 – 5 June, 1998	Role of Biological Control in Crop Production	
7th	5 -6 August, 1999	Crop losses in Agriculture	
8th	10 – 11 August, 2000	Plant Protection in Ethiopia: Status and Prospects, Education Research and Extension	
9th	4 – 8 June, 2001	Pests and Vectors Management for Food Security and Public Health in Africa: Challenges for the 21st Century	Conducted jointly with the 14th African Association of Insect Scientists
10th	15 – 16 August, 2002		
11th	5 – 6 June, 2003	Pest Management in Fruit and Vegetable Crops in Ethiopia: Challenges in the 21st Century	
12th	26- 27 May, 2004	Prospects and Application of Integrated Pest Management (IPM) in Ethiopian Agriculture	
13th	11 – 12 August, 2005	Plant Protection and Food Security in Ethiopia	
14th	19-22 December, 2006	Two decades of Plant Protection Research in Ethiopia and Prospects for the New Millennium	Two decades of Plant Protection Research was published under the title " Increasing Crop Production through

			Improved Plant Protection" Edited by Abraham Tadesse
15th	1 – 2 November, 2007	Challenges of Plant Protection Research and Development in the New Millennium	Dedicated to the late Dr. Dagnachew Yirgu, Pioneer Ethiopian Plant Pathologist, Educator and a Model Citizen
16th	13 -14 August, 2009	Food Crisis and Climate Change from the Perspective of Plant Protection	
17th	25- 26 November, 2010	Invasive Alien Pests of Plants Threatening Ethiopian Agriculture	
18th	29 – 30 December, 2011	Biological Control Incorporated IPM for Pests Management in the Growing Protected Agriculture in Ethiopia	
19th	27 – 28 December, 2012	Biotechnology for Plant Protection in Ethiopia: Challenges and Opportunities	
20th	25 -26 December, 2013	Plant Quarantine: the State of Affairs in Ethiopia	
21st	25 -26 December, 2014	New Pests Challenging the Current Pest Management Support System and Need of Reinvigorating the System	
22nd	10 – 11 March, 2016	Post Harvest Pest Management Education, Research and Extension in Ethiopia: the Status and Prospects	
23rd	9 -10 March, 2017	Post Harvest Pest Management along the Supply chain of Horticultural crops: Prospects and Challenges in the changing climate	
24th	March 16 -17, 2018	Emerging and re-emerging plant pests of Ethiopia:status, interventions and future prospects in achanging climate	Marked the 25th year silver jubilee of the society and was held at and in collaboration with Haramaya University