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Participatory evaluation and demonstration of improved bread wheat (Triticum aestivum L.) varieties in South Gondar Zone, Amhara Region, Ethiopia

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ABSTRACT

Wheat is one of the most significant food security crops in Ethiopia, widely grown by smallholder farmers. Although there is enormous potential to expand Ethiopia's wheat production and productivity, it is still limited due to many challenges. Among others, the prevalence of biotic (yellow rust, stem rust, septoria, fusarium) and abiotic (acidity, heat, drought) stresses, low adoption of new technologies, weak extension system, high cost and limited availability of inputs, and poor infrastructure and marketing systems are some of the challenges. Therefore, this research activity was conducted with the objectives of demonstrating bread wheat varieties to farmers, providing them with the opportunity to evaluate the varieties with their management practices, and raising the knowledge and skills of farmers on wheat production packages. Quantitative and qualitative research approaches were used to compare the improved varieties with those of the local variety with the local practice. Cost-benefit analysis and descriptive statistics were employed for quantitative data analysis. Farmers' variety preference was assessed using the pairwise ranking method. Thus, based on the overall selection and evaluation criteria, farmers selected Tay, Danda'a, and Kekeba 1st, 2nd, and 3rd, respectively. Tay has 98.5% and Danda'a 82.7% yield advantage over the local check (Kekeba variety). Furthermore, the economic analysis result showed that an average marginal return of 130,822, 119,084, and 66,808 Birr per hectare was gained from Tay, Danda'a, and Kekeba varieties, respectively. Based on farmers' selection criteria (disease resistance, plant height, and good spike length) and the actual yield data, Tay was selected for large-scale production in the intervention areas and other similar agroecologies.

1. INTRODUCTION

Bread wheat (Triticum aestivum L.) is one of the most important staple food crops for billions of people in the world. It is the most important food security crop at the global level (FAO, 2017). Global wheat production crossed 800 million metric tons in 2022, which makes it the second-most cultivated grain after corn (Visual Capitalist, 2024). Bread wheat was introduced to Ethiopia in the early 1940s, and since the 1970s, it has been the dominant wheat type, covering currently more than 90% of the total wheat production area in Ethiopia (Yirga et al., 2013; Hodson et al., 2020).

After South Africa, Ethiopia is the second largest wheat producer in sub-Saharan Africa (FAO, 2015b). It is produced largely in the southeast, central, and northwest parts of the country. A small amount is produced in the rest of the south and north regions (Minot et al., 2015). Ethiopia is among the environmentally gifted countries for crop production; wheat grows in almost all parts of the country. Its production area ranges from lowlands of pastoral and agro-pastoral like Afar, Gambela, and Somalia to the highlands of the northern, central, and south-eastern parts of Ethiopia (Asrat & Anteneh, 2020). Wheat is cultivated on a total area of 2.1 million (1.7 million ha rain-fed and 0.4 million ha irrigated) hectares annually with a total production of 6.7 million tons of grain at an average productivity of 3.0 and 4.0 t ha-1 under rain-fed and irrigated conditions, respectively, during 2021/22 (CSA, 2022).

Wheat is also one of the most significant cereal crops in Amhara National Regional State, where it's produced for both food and income. The overall area of wheat cultivation in the region was 427,719.81 hectares, accounting for 10% of the total cereal area. Wheat yielded on average 2.53 t ha^{-1} in 2017/2018 production season in the region (Anteneh & Asrat, 2020). The Amhara region's major wheat-producing zones are North Shewa, East Gojjam, and South Wollo, each of which produces more than one hundred thousand tons. Other notable wheat-producing zones in the region include West Gojjam, South Gondar, and North Gondar (Melena, 2021). Bread wheat is an important primary food crop in Ethiopia, particularly in urban areas. It is an indispensable food in the diets of several Ethiopians, providing about 15% of the caloric intake for the country's over 90 million population (Minot et al., 2015). It is milled into flour for traditional bread, bakeries, pastries, and couscous, mixed with other cereals to make injera, and also used as *kolo* (roasted whole grain) or *nifro* (boiled grain). Wheat also serves as an important source of income for smallholder farmers (Hodson et al., 2020). In addition to the grain, the straw is used as animal feed, fuel, a source of income, and for roof thatching (Nigus et al., 2022).

Wheat production has been increasing steadily in the past decades; however, the demand for the crop exceeded domestic supply and forced the country to cover about 30% of the deficit through commercial imports and food aid (FAOSTAT 2018; Senbeta & Walelign 2023). The actual yield under smallholder farmers' conditions is low due to various production constraints (Nigus et al., 2022). Wheat production and productivity are affected by complex and interactive effects of biotic and abiotic factors and socio-economic challenges, notably in the smallholder farming systems.

Wheat diseases, such as stem rust and stripe or yellow rust and leaf rust, and insect pests such as the Russian wheat aphid are among the critical biotic factors affecting wheat production in Ethiopia. Other major factors that contributed to low wheat yields in Ethiopia are a lack of access to improved varieties, backward agronomic practices, use of marginal agricultural land, and terminal drought stress, among others (Belay and Araya, 2015; Hei et al., 2017; Semahagne et al., 2021). Moreover, wheat production is also affected by soil acidity, declining soil fertility, heat, monocropping, pre-harvest sprouting, and climate change. Furthermore, growing populations, increased rural-urban migration, low public and private investments, weak extension systems, inappropriate agricultural policies, and low adoption of new technologies remain major challenges (Negassa et al. 2013, Shiferaw et al. 2013).

Bread wheat accounts for 6.6% (102) of the total released and registered crop varieties in Ethiopia. However, fewer varieties are under production (Gebru et al., 2021; Tadesse et al., 2022). A large number of smallholder farmers (about 30%) are still using local varieties (Shiferaw et al., 2014). Farmers mostly demanded seeds of older, improved crop varieties due to slow varietal adoption, mainly with limited varietal promotion activities (Abate et al. 2018). Consequently, farmers in the region as well as in the study areas are using low-yielding and disease- and pest-prone local varieties and traditional practices. Given this, the promotion of newly released wheat varieties with their production package is indispensable to enhance farmers' production and productivity and thereby improve their income and livelihoods. Therefore, this study was designed to demonstrate and evaluate the performance of improved bread wheat varieties along with their production packages and to raise farmers' knowledge and skills in bread wheat production.

2. MATERIALS AND METHODS

Description of the Study Areas

Farta is located in the south Gonder Zone of the Amhara Region, Ethiopia. It is located between 11° 32′ to 12° 03′ latitude and 37° 31′ to 38° 43′ longitude (Figure 1). The woreda is bordered by Misrak Este in the south, Fogera in the west, Ebenat in the north, and Lay Gaint in the east (PEDD, 2007). It lies in an altitude range of 1920–4135 m.a.s.l. It receives an average annual rainfall of 900–1099 mm and a mean range temperature of 9–25 °C. The rainy season ranges from May to September (Nega & Melaku, 2009). In terms of topography, 45% of the total area is a gentle slope, flat lands account for 29%, and steep slopes for 26. In terms of land use pattern, an estimated 65% of the area is cultivated and planted with annual and perennial crops, while the area under grazing and browsing, forests and shrubs, settlements, and wastelands account for about 10, 0.6, 8, and 17%, respectively. About 50% of the soil is brown, 30% red, and 20% black.

Libokemekem, one of the woredas of the South Gondar Zone, is bordered by Ebenat in the north, Fogera in the south, Gondar Zuria in the west, and Farta in the east. It is located at 37°15'36" E to 38°06'36" E longitude and 11°54'36" N to 12°22'48" N latitude and has an altitude of 1975 meters above sea level (Endesew, 2019). Addis Zemen is its administrative center. It is situated 645 km from Addis Ababa and 82 km from the regional capital, Bahir Dar, and has 29 rural and 6 urban *kebeles* (the lowest administrative unit in Ethiopia, equivalent to a commune). About 95% falls under the midland agroecology, 4.1% highland, and 0.9% lowland. The maximum average temperature is 27.9 °C and the minimum is 11.1 °C. The cropping systems are mainly dependent on meher rains, with 75% production contribution, and with supplementary irrigation, 25% of major crops. The *woreda* is characterized by rain-fed subsistence farming of crops (maize, millet, "*teff*," and sorghum), animal husbandry, and irrigated paddy rice cultivation, and these remain the principal agricultural activities despite poor soil fertility and highly variable rainfall in most areas (Yalew et al., 2012).

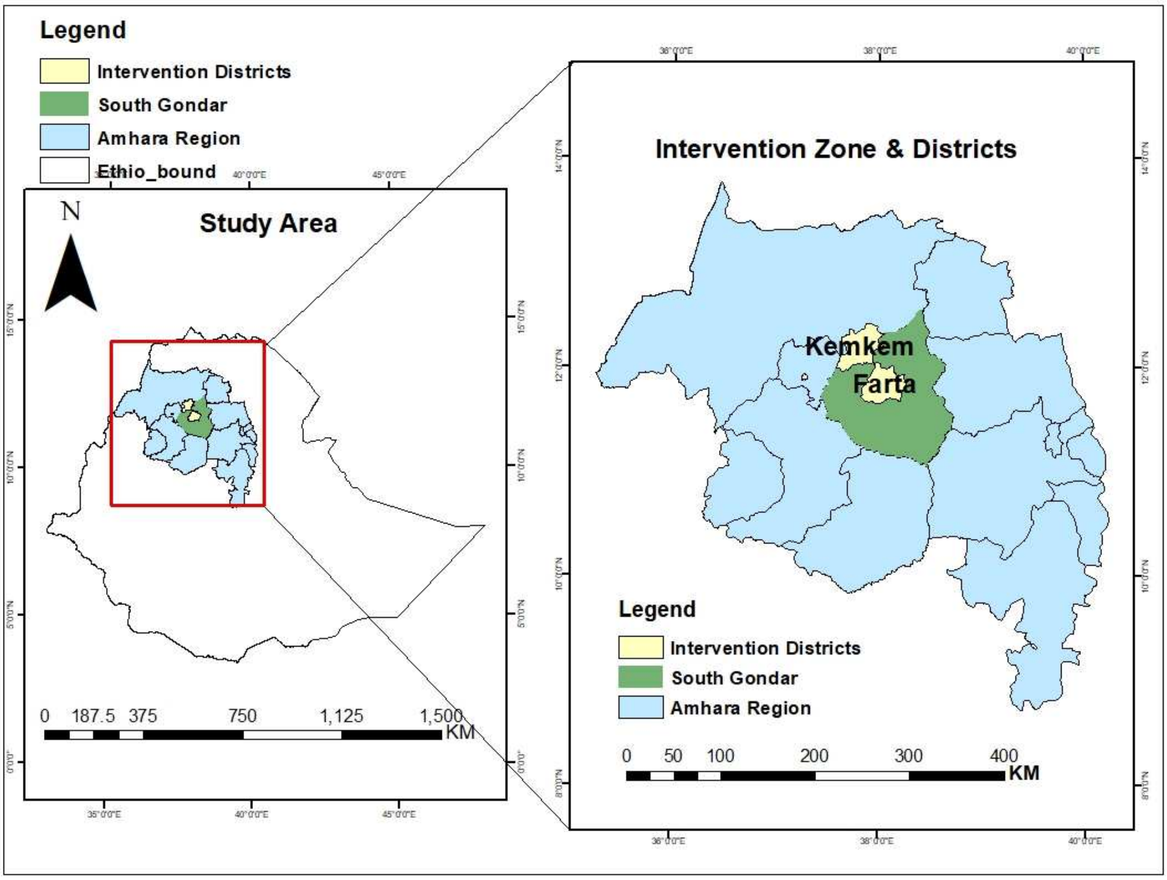

Figure 1: Map of Libokemkem and Farta *Woredas*

2.1. Site Selection

The trial was conducted in Farta and Libokemkem *woredas* of the South Gondar zone, Amhara region, in 2020. Like many other parts of the region, wheat production and productivity in these *woredas* are very low. Hence, to promote the technology packages (varieties, agronomic practices such as use of row planting, fertilizer application, weeding, and crop protection practices) and work in partnership with the NFG/FLRP (Norwegian Forestry Group/Forest Landscape Restoration Program), the Amhara Agricultural Research Institute (ARARI) purposefully selected the two *woredas*. NFG/FLRP, which is the partner of the institute, deals mainly with the restoration of degraded landscapes and the protection of exclosures. Farmers' demand for bread wheat technology packages was communicated to the institute through the program. Consequently, ARARI, via Adet Agricultural Research Centre, executed the research activity to address farmers' technology needs and help farmers get additional income and food until they start to benefit from the fruits of natural resource conservation endeavors.

2.2. The Roles and Responsibilities of Different Stakeholders

Before conducting the demonstration and evaluation, researchers discussed and agreed with extension workers and representative farmers about the purpose of the participatory on-farm technology evaluation and demonstration (improved bread wheat technology packages), division (sharing) of responsibilities in the execution of the research activity (testing), the date on which the PTE would be implemented, and the modalities of implementation. Given this, a memorandum of agreement was signed by Adet Research Centre and the *Woreda* and *Kebele* Agricultural Offices. It was signed to persuade each stakeholder to play its role (s) toward the successful accomplishment of the PTE with knowledge, diligence, and responsiveness. PTE is an approach that was developed to integrate a wide range of knowledge and values in the evaluation and policy-making of new technologies that involve complex and uncertain decision contexts (Tavella, 2016). Thus to execute the PTE the roles and responsibilities of different stakeholders enshrined in the memorandum of agreement are indicated as follows.

2.3. Adet Agricultural Research Centre (AARC)

The major responsibilities of Adet Agricultural Research Centre (AARC) in this participatory technology evaluation and demonstration activity were to establish FREGs together with *Woreda* and *Kebele* Agricultural Offices; select trial sites and host farmers together with Agricultural Offices; organize and provide training; deliver inputs (bread wheat seeds and fertilizer); assist in planting and conduct M & E and field days.

2.3.1. Farmers

Farmers' main responsibilities in this study were to provide labor and land (at no cost), plant and weed the demonstration and evaluation undertaking; apply urea top dressing; guard the demonstration and evaluation research activity against livestock damage; make diversion canals when there are heavy rains; Moreover, they have to participate in the planning of successive activities (agronomic and crop protection); contribute in the evaluation and selection of the bread wheat varieties; and take part in the field visits and field days.

2.4. Offices of agriculture (*Woreda* and *Kebele* level)

The main responsibilities of the *Woreda* and *Kebele* Offices of Agriculture in this research undertaking were the facilitation of the formation of FREGs with AARC; assisting in the selection of trial sites and host farmers; mobilizing farmers for couples training; assisting researchers in planting; mobilizing farmers for technology evaluation; organizing field visits and field days with AARC and ensuring the participation of farmers and extension workers; and conducting joint M&E with researchers and experts from NFG/FLRP.

2.5. NFG/FLRP

NFG/FLRP had the responsibility to participate in the selection of farmers, arrangement of field days, storing inputs in warehouses that are to be distributed to participant farmers, and grain samples after harvesting in the warehouses. Moreover, they had the duty to provide transport services (motorbikes) to DAs whenever necessary and make periodic inspections of the PTE.

2.6. Farmers Selection and FREG Establishment

Farmer's Research and Extension Group (FREG) approach was employed to demonstrate and evaluate improved bread wheat varieties (technology packages). FREG is one of the research approaches in which a group of farmers, extension workers, and a multidisciplinary research team jointly participate in agricultural technology generation, verification, and improvement so as to meet farmers' needs and improve farmers' production and management practices (Geneti et al., 2017). Thus, two FREGs were established, having 50 male and 10 female members. Among the FREG members, 12 interested host farmers were selected in both *woredas*. The host farmers were used as replications and selected based on their willingness to allocate land, and labor and carry out the land preparation, planting, weeding, urea top dressing, guarding, harvesting, and so on with perseverance. They were also selected for their motivation to learn from their practical engagement throughout the implementation of the PTE. FREGs were established based on the underlying criteria (Abebe, 2008; Matsumoto et al., 2009). Manageable group size which ranges from 20-30;

- Farmers that are eager to learn and adopt technology;
- Farmers who are capable of diagnosing, analyzing, and coming up with possible solutions for problems through self-initiative;
- Capable of collecting necessary information from outside for solving the problem; Capable of trying out, evaluating, and improving new technology, or cocreation;
- Enthusiastic to planning, monitoring, and evaluating group activity and helping and advice, other farmers;
- Farmers who are close neighbors and know each other;
- Gender representation;

- Farmers having strong bonds between/among themselves;
- Farmers have shared vision and goals, i.e. the need to adopt and produce the technology at a wider scale, boost their production and productivity, and improve their income and livelihoods;
- Willingness to be bound by the agreed bylaws;
- Willingness to be led by democratically elected leadership

2.7. Provision of Training

After the selection of the testing site, signing of the memorandum of agreement, formation of FREG, and host farmers' selection, training was given to FREG members, *kebele* administrators, and extension workers in the towns of Addis Zemen and Farta. It was given to 29 farmers (11 female) and 11 experts (3 female) in Addis Zemen, while it was provided to 30 farmers (12 female) and 12 experts (5 female) in Farta. A multidisciplinary team of researchers comprising breeders, pathologists, agronomists, and agricultural research extensionists gave the training. The training focused on wheat planting, agronomic practices, integrated disease and pest management, post-harvest management, pre-scaling up, up-scaling, participatory research, and seed dissemination mechanisms.

Couples training was given to FREG members to provide equal opportunity to women. It was adopted as a training approach where both husbands and wives receive training together for collective household decisions and actions (Lemma et al., 2017). Couples training helps women exchange information more effectively both inside the household and with neighbors; it is imperative that couples training be implemented to promote information absorption, collective household decisions, training application, and family labor mobilization. On the other hand, for ease of communication among members; carrying out M&E and technology evaluation; participation in field visits and field days.

Planting and Agronomic Practices

Two improved bread wheat varieties (*Tay and Danda'a*) and one local variety (*Kekeba*) were used (Table 1). Planting material (seed) and fertilizers were prepared in advance from the Adet Agricultural Research Center.

Table 1: Characteristics of bread wheat varieties used for the evaluation

Variety Name	Year of release	Research Center	Altitude	Rainfall	Productivity	
					Research	Farmers
Tay (ET-12D4/HAR 04(1)	2005	Adet	1900-2800	>700	25-61	3
Danda'a (ETBW6130)	2010	Kulumsa	2100-2700	700-1000	50-60	40-50
Kekeba (ETBW6861)	2010	Kulumsa	>2200	800-1100	55-65	40-55

Source: Ministry of Agriculture and Natural Resources, crop variety register, 2005 and 2016.

Single plot observation (farmers' as a replication) was used, and the size of the participatory technology evaluation and demonstration plot was 10 m by 10 m (100 m2) for each variety. The spacing between rows was 20 cm, and the seed rate was 150 kg ha^{-1}; planting was done in rows by drilling. Fertilizers were applied at the rates of 121 kg ha^{-1} NPS and 200 kg ha^{-1} Urea. All NPS and half Urea were applied at planting, while the remaining half Urea was applied at the tillering stage. Two improved bread wheat varieties, namely *Tay and Danda'a*, and a local check (*Kekeba*) were used in the selected testing sites of Libokemkem and Farta *woredas.*

2.8. Participation through Farmers Research and Extension Group/FREG

A participatory agricultural research approach through FREG was adopted for the implementation of the PTE. Thus, the approach was employed to enhance farmers' knowledge of bread wheat production bottlenecks, newly released bread wheat varieties and the recommended production practices, problem identification, joint planning and execution, and monitoring and evaluation of the research activity. Moreover, for the ease of communication and knowledge transfer, farmers who were organized in FREG were allowed to make bylaws and elect their chairperson and secretary. This was done after the training of the local community and extension workers on the objectives of participatory technology demonstration and evaluation and other related pressing issues. The chairpersons and the secretaries are responsible for fixing and notifying members in advance about group work, regular meeting dates, times, and places, which are manifested in the bylaws. They are also responsible for summoning FREG members for field visits and field day attendance. The committees arrange the group meeting at a time when it is convenient for FREG members. All group members, other supporting agencies, and facilitators are expected to attend group discussions and respect whatever the group decides (Matsumoto et al., 2009).

2.9. Joint Monitoring and Evaluation (M and E) T

The team of researchers from Adet Agricultural Research Centres and the Amhara Agricultural Research Institute and agricultural extension workers from the *Woreda* and *Kebele A*gricultural Development Offices, along with the main beneficiaries (farmers), jointly monitored and evaluated the trial twice. During the M & E, the team confirmed the implementation of agronomic practices such as weeding, urea topdressing, and crop protection practices against the incidence of diseases and pests. Having a look at the trial and assessing the constraints encountered, the team was able to suggest corrective measures considering the roles and responsibilities of each actor in the undertaking.

2.10. Technology Evaluation

Members of FREGs, with the help of researchers and extension workers, evaluated technologies. A participatory technology evaluation approach was adopted and implemented at the maturity stage of the crop, whereby farmers were able to set their evaluation and selection criteria based on their own experiences. The evaluation and selection criteria were ranked in order of their importance by using the pair-wise ranking method. The technologies were evaluated considering each criterion by direct scoring methods (1= the best), and scores given to each variety in relation to each criterion were finally added together and then ranked in ascending order in each *kebele* (the lowest sum gives the best score). The sum of the preference value (score x weight) of each variety across all criteria was used to determine the final acceptability rank among the varieties in each of the locations**.**

2.11. Data Collection and Analysis

Data on agronomic traits such as plant height spike length (panicle length), tillering capacity, and days to physiological maturity were recorded from ten plants randomly selected at harvest from each plot. Plant height, which affects lodging resistance, total biomass yield, as well as mechanical harvesting, is defined as a vertical distance measured by the researcher (s) in cm from the base of the stem of the main tiller to the tip of the panicle at maturity (Tasew et al., 2024). Spike (panicle) length (cm), which is one of the yield determinant traits of cereals, is measured from the distance between the node where the initial panicle emerges and the tip of the main panicle when it reaches maturity (Fenta, 2018). Krishnan et al. (2011) defined tillers as branches that develop from the leaf axils at each unelongated node of the main shoot or other tillers during vegetative growth, growing independently using their own adventitious roots. Days to physiological maturity are the occurrence of maximum seed dry weight and represent the end of dry weight accumulation and seed filling period (Malarkodi & Srimathi, 2007). Assefa & Chanyalew (2018) defined total dry biomass yield as the whole plant part, which includes leaves, stems, and seeds harvested above the ground from the whole plot at maturity.

Days to maturity (the date by which 90% of the plot is ready for harvest) and grain yield (gm/plot) were collected using quadrants (1m x 1m) from each plot following the x fashion [It is the taking of biomass samples in a criss-cross (cross of two diagonal lines) fashion using 1m x 1m quadrants]. The grain moisture content was adjusted to 12.5%using the formula AMC= GY * (100-AM) *100/(100-12.5). Where AMC= Adjusted Moisture Content, GY= Grain Yield, AM= Actual Moisture Yield. Adjusted moisture content requires the correctness of what yield is produced per hectare of land. Yield-related quantitative data as well as perception-related qualitative (social) data were collected. Yield data were collected after harvesting and threshing of the crop, and social data (farmers' and experts' opinions/perceptions) were gathered during M & E, technology evaluation, and field days. After ranking and weighting the identified parameters pairwise, a weighted ranking matrix table was made. Farmers in each group were asked to compare and contrast varieties with each other and then to give values based on the identified parameters. The scores given by farmers to each variety based on each criterion were summed, and then the obtained rank was multiplied by the respective weight for each variety. Finally, the products were aggregated for each variety for final selection (the least sum was ranked 1st) (Russell, 1997). To this end, a correlation was made to compare the actual grain yield, total biomass yield, and days to maturity ranks with the farmers' preference rank of each treatment and expressed in percentage points (Ferdous et al., 2016). In addition, spearman's correlation analysis was used to analyze how the farmers' preference rank coincided with the actual rank of grain yield. Spearman's rank correlation coefficient is defined as:

$$r_s = 1 - \frac{6\sum d^2}{n(n^2 - 1)}$$

where N denotes the number of individuals or phenomena ranked (number of varieties in this case); d denotes the difference in the ranks assigned to the same individual or phenomenon (actual yield rank minus farmers preference rank).

On the other hand, gender-disaggregated data were taken on couples training, organized field visits, and field days so as to rectify the flaws and propose the development of a strategy for the upcoming pre-scaling-up endeavors. In addition to this, issues that were raised and discussed during the field days about the roles of the stakeholders in the upcoming technology pre-scaling up were recorded.

3. RESULTS AND DISCUSSIONS

Farmers' Preference Ranking

Bread wheat varieties along with their production practices were evaluated and selected by FREG members assisted by the researchers from Adet Agricultural Research Centre and extension workers from the *kebeles*. A participatory approach was used to evaluate and select improved bread wheat varieties at their maturity stage. Based on their long years of accumulated experience, farmers were allowed to come up with their own evaluation and selection criteria (disease resistance, spike length, seed size, plant height, and uniform maturity) and rank them in order of their relevance using the pair-wise ranking method. Hence, based on each criterion, the varieties were selected by direct scoring methods (1 = the best, 4 = the poorest), and the scores given to each variety were added together and then ranked in ascending order (the lowest sum gives the best score). The sum of the preference value (score x weight) of each of the varieties in all criteria was used to determine the final acceptability rank of the varieties in each location. Hence, farmers in Libokemkem *woreda* ranked disease resistance and uniformity in maturity as 1st and 2nd, seed size, spike length, and long plant height as 3rd, 4th, and 5th, respectively (Table 2).

Table 2: Pair-wise ranking of evaluation and selection criteria at Libokemkem *woreda*

Selection criteria	Disease Resistance	Spike length	Seed size	Plant height	Uniform maturity	Total score	Rank
Disease Resistance (DR)		DR	DR	DR	DR	4	1

Spike length (SL)	SS	SL	UM	1	4
Seed size (SS)		SS	UM	2	3
Plant height (PH)			UM	0	5
Uniform maturity (UM)				3	2

In Farta *woreda,* farmers were given the freedom to develop their own evaluation and selection criteria; based on their many years of cumulative experience, they selected disease resistance, spike length, uniformity in maturity, plant height, and threshability as the best selection criteria. Then they ranked these criteria using the pair-wise ranking method in order of their relevance. Thus, the varieties were chosen using direct scoring techniques (1 being the best, 4 being the poorest) depending on each criterion. The scores assigned to each variety were then totaled up and ranked in ascending order (the lowest sum yields the best score). The final acceptability rank of the varieties in each site was calculated as the total of the preference values (score x weight) of each variety in all categories. Concerning selection criteria, farmers chose uniform maturity as the third selection criterion next to spike length. They gave precedence to disease resistance above the other two criteria because of frequent disease occurrences on farmers' wheat farms (Table 3).

Table 3: Pair-wise ranking of farmer's selection criteria in Farta *woreda.*

Selection criteria	Disease Resistance	Spike length	Uniform maturity	Plant height	Thresh Ability	Total score	Rank
Disease Res. (DR)		DR	DR	DR	DR	4	1
Spike length (SL)			SL	SL	SL	3	2
Uniform maturity (UM)				UM	UM	2	3
Plant height (PH)					TH	0	5
Thresh ability (TH)						1	4

The pair-wise ranking and final preference values analysis result revealed that farmers have confirmed that varieties Tay and *Danda'a* were good for their disease resistance, spike length, and long plant height compared to the local variety showing their potential for high grain and biomass yield but they lack uniformity of maturity when seen with local variety (Table 4 and 5). This result complies with the study reports of Dunjana et al. (2015) and Sisay et al. (2024). Likewise, the study finding conforms with Esatu et al. (2020), who reported that the Tay variety is also known for its tolerance to yellow, stem, and leaf rust.

In Libokemkem *woreda*, the pair-wise ranking, and the final preference values analysis result showed that *Kekeba* bread wheat variety was highly preferred for its uniform maturity, and seed size when compared to Tay, while Tay was preferred for its disease resistance, plant height, and good spike length compared to both *Danda'a* and *Kekeba* bread wheat varieties (Table 4). Put differently, farmers have confirmed that variety Tay was very good for its disease resistance, spike length, and long plant height, showing its potential for high grain and biomass yield, but it lacks uniform maturity, which may contribute to differences in seed size. The disease resistance merit of the variety is in harmony with the report of Sisay (2024), which reveals that the Tay bread wheat variety is very good in its disease resistance compared to *Danda'a* and *Kekeba*. Moreover, according to a similar report, it has a more or less similar spike length (very good) to that of *Danda'a;* however, it outsmarts *Kekeba* in its spike length. The three varieties were given the same amount of fertilizer or grown in the same environment; however, Tay outshined the other two varieties in height due to its genetic potential. This corroborates the report of Dunjana et al. (2015), such that plant height is an important growth-related parameter influenced more by genetics and least influenced by environmental factors such as nutrients and others.

Kekeba (the local check) has been selected by farmers for its uniform maturity and seed size over the other two varieties. Its earliness might have been attributed to its seed size. This is confirmed by Gadisa (2019), who reported the announcement of the relationship between seed size and early growth since the early of this century. Uniform maturity was farmers' second selection criterion next to disease resistance. *Kekeba* was selected for its uniform maturity over Tay and *Danda'a*. This is in agreement with Abboyee et al. (2020) and Melese et al. (2020), who reported that bread wheat varieties had a significant difference in days to 90% physiological maturity due to genetic differences. In the overall evaluation criteria, Tay and *Danda'a* were selected 1st and 2nd, respectively, over the local variety (check) by farmers (Table 4). This complies with Sisay et al. (2024), who reported that in biomass and grain yield, Tay ranks 1st, *Danda'a* 2nd, and *Kekeba* 3rd.

On the other hand, *Danda'a* variety has been found to have the merits of disease resistance similar to that of Tay, but a longer spike compared to Tay. While the *Kekeba* variety was good in uniformity of maturity compared to both Tay and *Danda'a*, it is susceptible to diseases, as indicated in Table 5. This corroborates the report of Esatu et al. (2020), which affirms that the variety is moderately resistant to stem rust but is susceptible to yellow rust. As a result, this variety has shown poor performance and is becoming out of production in most potential wheat-producing areas of the country (Khan et al., 2020; Solomon, 2022). In terms of threshability, the local check and *Tay* have better threshability than *Danda'a.* Considering the overall evaluation criteria (total score), Tay, Danda'a, and Kekeba were selected 1st, 2nd, and 3rd, respectively, by farmers in Farta *woreda* (Table 4).

Table 4: Summary of scores given to the variety x weights and their ranks in Libokemkem *woreda*

Woreda	**Selection criteria**		**Varieties**		
			Kekeba	***Danda'a***	***Tay***
Libokemkem	Disease Resistance	Score	28(1)	33(1)	25(1)
		Score * Weight	28	33	25
	Spike length	Scores	40(4)	30(4)	16(4)
		Score * Weight	160	120	64
	Seed size	Scores	20(3)	26(3)	30(3)
		Score * Weight	60	78	90
	Plant height	Scores	36(5)	28(5)	22(5)
		Score * Weight	180	140	110
	Uniform maturity	Scores	16(2)	30(2)	40(2)
		Score * Weight	32	60	80
	Sum of score		460	431	369
	Rank		3	2	1
Farta	Disease resistance	Scores	22(1)	15(1)	15(1)
		Score * Weight	22	15	15
	Spike length	Scores	25(3)	11(3)	16(3)
		Score * Weight	75	33	48
	Threshability	Scores	15(5)	22(5)	15(5)
		Score * Weight	75	110	75
	Plant height	Scores	26(4)	10(4)	16(4)
		Score * Weight	104	40	64
	Uniform maturity	Scores	10(2)	26(2)	16(2)
		Score * Weight	20	52	32
	Sum of score		296	250	234
	Rank		3	2	1

Note: A variety that scores the least is the best. Numbers in parenthesis are ranks

3.1. Yield and Yield-related Parameters and Farmers' Preferences

The result of agronomic traits and yield components, i.e., plant height, tillering capacity, spike length, biomass, and grain yield, were summarized in Table 5. The two improved varieties, Tay and *Danda'a*, were relatively better in biomass yield than the local check-in in both locations. Hence, the higher (8.9 t ha-1) yield of biomass was recorded from *Tay*, followed by *Danda'a* with an average yield of 7.82 t $ha^{-1.}$

Plant height is an important parameter that positively contributes to grain and biomass yields. The variation in plant height between the treatments (the varieties) generally ranged from 98.2 to 120.24 cm. The highest plant height (120.24 cm) was recorded from the *Tay* improved variety, while the lowest plant height (98.2 cm) was recorded from the local check (*Kekeba* variety) (Table 5). The mean value of genotypes in spike length ranged from 7.1 to 12.3 cm, and the average number of tillers ranged from 3.2 to 6.11. The result revealed that the Tay variety was relatively found to be better in spike length and tillering capacity, while the lowest average tiller number was recorded from the *Kekeba* variety.

The yield advantage was calculated by deducting the yields of the demonstrated improved bread wheat varieties from the yield of the local check, dividing the value by the yield of the local check, and multiplying it by 100 (3.8 - 2.36/2.36*100; 3.41 - 2.36/2.36*100).

Table 5: Mean values of yield and yield-related attributes in Libokemkem & Farta *woredas*

Woreda	Variety	DM (days)	PH (cm)	TC (#)	SL (cm)	BY (t ha^{-1})	AGY (t ha^{-1})	Yield Advantage (%)
L/kemkem	*Tay*	101	117.90	4.5	10.3	8.67	3.8	61
	Danda'a	95	105.62	3.43	8.9	7.02	3.41	44.5
	Kekeba	90	98.20	3.2	7.1	6.75	2.36	-
Farta	*Tay*	105	120.24	5.11	12.3	8.90	3.98	156.7
	Danda'a	98	108.74	4.77	9.30	7.82	3.75	141.9
	Kekeba	92	100.30	4.5	7.50	6.81	1.55	-

DM= Days to maturity; PH= Plant height; TC= Tillering capacity; SL= Spike length; BY= Biomass yield; AGY= Average grain yield

As indicated in Figure 2, Tay on average gave the highest grain yield of 3.8 t ha^{-1} in Libokemkem and 3.98 t ha^{-1} in Farta *woreda* while *Danda'a* gave an average yield of 34.1 t ha^{-1} and 3.75 t ha^{-1} in Libokemkem and Farta *woredas* respectively. It is the second-highest yielder next to Tay in both *Woredas*. *Kekeba* (local check) gave the lowest yield of 2.36 t ha^{-1} in Libokemkem and 1.55 t ha^{-1} in Farta *woreda*. According to the combined analysis result of the yield performances of bread wheat varieties, a mean yield of 3.89, 3.58, and 1.96 t ha^{-1} was obtained from Tay, *Danda'a,* and *Kekeba* bread wheat technology packages, respectively. From the result, it can be inferred that Tay and *Danda'a* have surpassed the local variety (*Kekeba*) in terms of yield and have given average yield increments of 1.93 and 1.62 t $ha^{-1,}$ respectively, in the same production season. Accordingly, the *Tay* bread wheat variety has 98.5%, while *Danda'a* has an 82.7% yield advantage over the local check.

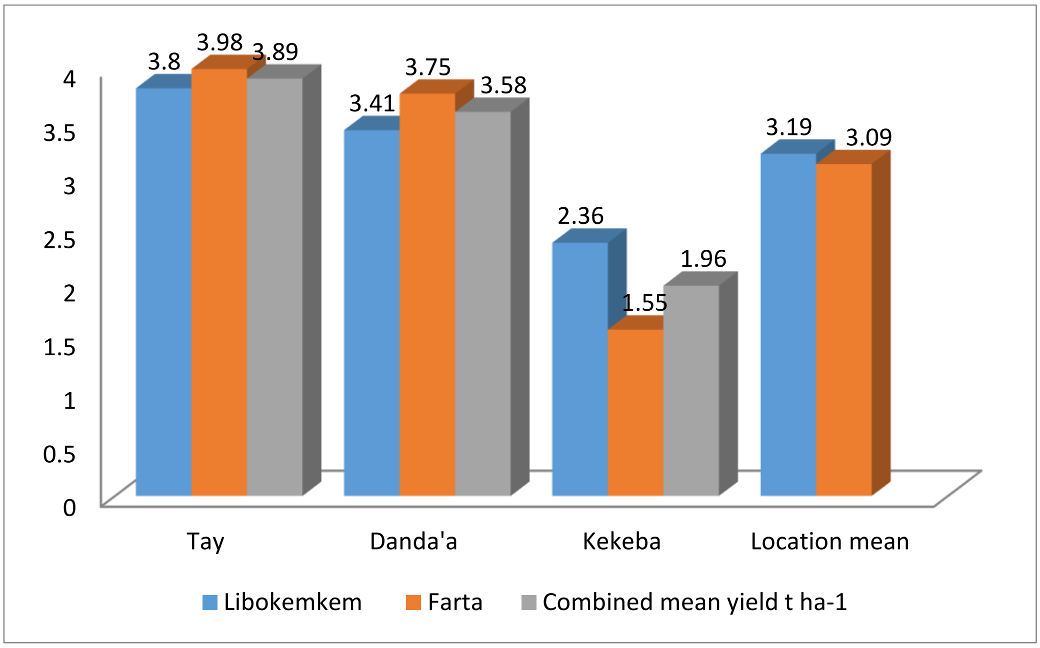

Figure 2: Grain yield t ha^{-1} in Libokemkem and Farta *woredas* and location mean

3.2. Farmers' preference versus actual yield comparison

Farmers' preferences and the actual yield obtained have coincided in the *woreda* after harvesting and threshing. The first evaluation of the performances of the three bread wheat varieties was done at their maturity stage before harvesting and threshing, just on the field conditions. The second evaluation was done next to harvesting and threshing after the grains of the three wheat varieties were displayed. Seeing the total dry biomass yield, grain yield, and seed size of each of the varieties carefully, farmers have selected Tay 1st, *Danda'a* 2nd, and *Kekeba* 3rd.

Spearman's Rank Correlation Coefficient

Spearman's rank correlation coefficient; "rs" can be used to see the degree of coincidence between farmers' preference ranks with the actual grain yield rank of each treatment and then expressed in percentages (Ferdous et al. 2016) as shown below in Table 6.

Table 6: Farmers' preference value and actual yield comparison of varieties

No	Varieties	Libokemkem			Farta		
		Preference values	Actual yield	D 2	Preference values	Actual yield	D 2
1	*Tay*	1	1	$(1-1)^2$	1	1	$(1-1)^2$
2	*Danda'a*	2	2	$(2-2)^2$	2	2	$(2-2)^2$
3	*Kekeba*	3	3	$(3-3)^2$	3	3	$(3-3)^2$
Spearman"s rank correlation coefficient for both locations, Rs =1(100%)							

$\sum D2 = (1-1)^2 + (2-2)^2 + (3-3)^2 = 0$; $Rs = 1 - \frac{6\sum D^2}{N(N2-1)} = 1 - \frac{6 \times 0}{3(32-1)} = 1 - 0 = 1$

The correlation coefficient, "rs" result, i.e., 100%, showed the degree of coincidence (matchness) between farmers' preference rank and the actual yield obtained in both locations. Thus, the Tay variety, which is preferred by farmers as their first choice, should be scaled up further; if Tay seed is unavailable, *Danda'a* can be scaled up widely in the *woredas* as an option since it surpassed the local check-in productivity.

3.3. Economic Analysis

The economic analysis result shows that an average return of 130,822 Birr, 119,084 Birr, and 66,808 Birr per hectare can be gained from Tay, *Danda'a,* and *Kekeba* varieties, respectively, in one production season in the study areas. The benefit-cost ratio for *Tay* was 7.1%, for *Danda'a* it was

6.5%, and for *Kekeba* it was 3.7%. As indicated in Table 7, the benefits of the Tay variety were very high compared to the other two varieties.

Table 7: Economic analysis of bread wheat varieties

Cost-benefit indicators	**Variety**		
	Tay	***Danda'a***	***Kekeba***
Seed cost	3600	3600	3600
Fertilizer cost	6000	6000	6000
labor cost	8000	8000	8000
Cost of transport, sacks	778	716	392
Total variable costs (TVC)	18378	18316	17992
Yield qt/ha (Y)	38.9	35.8	19.6
Revenue from yield	116700	107400	58800
Straw yield qt/ha	65	60	52
Revenue Straw yield	32500	30000	26000
Total Revenue	149200	137400	84800
Gross Margin (GM) = TR-TVC	130822	119084	66808
Benefit-cost ratio	7.1	6.5	3.7

Notes: Labor costs include operational costs for land preparation, planting, weeding, harvesting, and threshing.

Grain/straw yield selling price = 30/5 ETB kg^{-1}

The average price of NPS and UREA fertilizer in = 32 and 28 ETB kg^{-1}

Seed purchasing price = 36 ETB kg^{-1}

Average cost of Labor =200 ETB person day^{-1}

ETB (Ethiopian Birr) 1 USD=56 ETB

3.4. Farmers and Extension Workers' Feedback and Gender

Adet Agricultural Research Centre, the *Woreda* Offices of Agriculture, and the NFG/FLRP organized field days collaboratively on 25th October 2020, and 30th October 2020 in Libokemkem and Farta woredas respectively. The participants were farmers and agricultural experts from the intervention *kebeles* and *woredas* and researchers from AARC. A total of 73 (10 female) farmers and 15 experts and researchers (5 females) in Libokemkem and Farta *woredas* attended the field days. At the scene of the field day, farmers in Farta and Libokemkem *woredas* appreciated the performances of the bread wheat technology packages and asked the government to provide them with seeds of the varieties. Farmers have expressed their determination to scale up these technology packages by themselves, as they have already gained practical knowledge and experience. Put simply, all farmers who participated in the field day disclosed their interest in planting *Tay* variety in the next cropping season.

Similarly, participant farmers have also pointed out that triticale, which has been cultivated in Farta for years, is not palatable and nutritious for human consumption, and its straw is not as edible and palatable as other straws for livestock feeding. Triticale is not comparable to the introduced wheat varieties; they got the yield they predicted when the crop was at its booting stage. The high straw yield from the two improved varieties, which is linked to the high dry biomass yield, is also a good source of feed for livestock in the two *woreda*s where feed is scarce. Besides, the high straw yield could be used as a construction material as well as a source of income in the research intervention *woredas.*

A resident host farmer in Wowa *Kebele* of Farta confirmed, "*Tay variety is very attractive at its vegetative stage and has not been infected by a disease. Besides, it is a high-yielding variety."* Similarly, a non-FREG member also pointed out: *"The Tay variety is good in its productivity and uniformity of seeds compared to Danda'a. This is a very important trait in wheat production. I have the determination and courage to sow it in the* *coming rainy season."* On the other hand, development agents of the two *woredas* were also very pleased looking at the happiness of farmers about the evaluation and demonstration activity; they were highly satisfied by the outshining performances of the wheat varieties, and hence they boldly asked how they could be made available to all residents of the *kebele***.**

At the end of the field days, farmers have confirmed their interest in the varieties so long as they are given certified seeds and/or Quality Declared Seed (QDS). Quality declared seed (QDS) is an alternative system for seed quality assurance, developed for countries with limited resources. It is less demanding and less expensive than full seed certification systems yet promotes a satisfactory level of seed quality (Anastasia, 2022). During the field day, representatives from ARARI, AARC, NFG/FLRP, and agriculture offices of the *woredas* and the *kebeles* have promised to put their utmost effort into the next bread wheat pre and up-scaling endeavors.

The participation of women was low (22.4%/192 farmers, of which 43 were females) in the two *woredas*, where FREGs were established and couples training and field days were held. Bringing drastic change within a short period is unthinkable where patriarchy and cultural norms are prevalent. Couples training where women farmers had the chance to be trained with their male counterparts has enabled them to have an understanding of bread wheat production, to be inspired, and contribute their part in the execution of the demonstration and evaluation (testing), comparison of varieties based on agronomic traits, participation in preference (pairwise) ranking, evaluation and selection of varieties based on their merits, and learning and gaining experiences from other FREG members through involvement in the field visits and field days.

Figure 3: Bread wheat varieties evaluation at Wowa & Kanat Kebeles, Farta Woreda

4. CONCLUSION AND RECOMMENDATION

This participatory technology demonstration and evaluation research activity was conducted in Libokemkem and Farta *woredas* of the South Gondar Zone of the Amhara region, Ethiopia, with the objectives to demonstrate and evaluate the performance of improved bread wheat varieties along with their agronomic and management practices and to raise farmers' knowledge and skills on bread wheat production. The PTE was conducted by establishing FREG with 30 members (5 females) in each of the *woredas* as shown before. Among the bread wheat varieties demonstrated and evaluated in Libokemkem and Farta *woredas*, Tay has given a mean grain yield of 3.89 t ha^{-1} and *Danda'a* 3.58 t ha^{-1} over the local check. These results are exactly in agreement with farmers' preference ranking. Given this, Tay and *Danda'a* bread wheat varieties gave a yield advantage of 98.5% and 82.7% over the local check *(Kekeba)*. Likewise, the economic return of the technology packages was evaluated and found to be rewarding. Therefore, based on farmers' selection criteria and the actual yield data and economic feasibility, Tay and *Danda'a* varieties were selected for further scaling up or large-scale production in the study *woredas* and other similar agro-ecologies.

Farmers' participation in FREG and PTE from its inception to its conclusion has acquainted them with and raised their knowledge and skills on bread wheat technology packages and has enabled them to assess the merits of the bread wheat varieties along with their management practices and select varieties of their choice. Participating key stakeholders in the whole process of PTE is very vital to speed up the diffusion of farmers' preferred varieties, or bread wheat technology packages in the farming communities, as each of the stakeholders has its own roles to overcome. Signing a memorandum of agreement with stakeholders on the roles and duties of each actor is central to the successful implementation of PTE and for the intended wider production of the selected bread wheat varieties in the South Gonder Zone and the Amhara region at large.

Of the total participants of FREG, couples training, field visits, and field days, 22.4% of them were women. However, it is below what has been planned by ARARI (30%) over the past 15 years and the target set by the Amhara Bureau of Agriculture (GTP II: 50% and 100% of the total extension service beneficiaries to be married women and female-headed households, respectively). Hence, for wider adoption and dissemination of the bread wheat technology packages in the *woredas* and the region at large, and for increasing the roles, participation, and benefits of women in agriculture, the following general recommendations are suggested.

- Before the promotion and dissemination of bread wheat varieties on a wider scale through pre-scaling ups and up-scaling, seeds of the selected varieties have to be produced (multiplied) by the respective seed producers.
- Biophysical researchers should consider farmers' bread wheat varieties evaluation criteria when they strive to develop new varieties in the future so that they will be adopted easily by farmers.
- As Tay and *Danda'a* gave a better yield and economic advantage, the two varieties have to be scaled up at a wider scale in the two *woredas* and in other similar agroecologies.
- To make women farmers active participants and beneficiaries of participatory research and extension, such as improved bread wheat technology packages, through pre-scaling up and scaling up, their participation has to be improved through community awareness creation and providing more opportunities.

Women's participation has to be bolstered in participatory agricultural research and development endeavors, as they are often plant breeders in small-scale farmer production systems, responsible for domesticating species and selecting varieties that have the best qualities for cooking, baking, and taste. They are more concerned than their male counterparts about quality, which is one of the factors for the adoption of varieties. They are more concerned because they are responsible for cooking and feeding household members.

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