**Review on Postharvest Loss of Tomato in Ethiopia: its Extent, Cause and Copping Measures**

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**Abstract**

**Tomato production can serve as a source of income for most rural and periurban producers in most developing countries of the world. However, postharvest losses make it unprofitable and not achieving nutrition security. Hence analysis and documenting of available research works helps to minimize the postharvest loss of tomato and achieving the balanced nutrition of the society. This review focuses on the status, cause and prevention measures of postharvest loss of tomato. Postharvest losses in tomatoes can be as high as 42% globally and it varies in different countries due to the level of application postharvest management technologies. The causes of postharvest losses can be internal and external factors. The internal factors can be respiration, transpiration, ethylene production, and physiological disorders, while external factors are temperature, relative humidity, air velocity, and atmospheric composition and sanitation. Postharvest loss of tomatoes can be minimized by appropriate variety selection and nutrient application, washing and disinfecting of produce (acetic acid, bitter leaf extract, neem leaf extract), application of elicitors (salicylic acid, chitosan), 3-5% CaCl2, application edible coating (aloe vera gel, cactus mucilage, gum Arabic, beeswax), heat treatment, storing of the produce in locally constructed cold storage structures and appropriate handling of produce in the value chains.**

**Key words**: *cold storage structures, edible coating, elicitor, physiological deterioration, tomato*

## Introduction

Tomato (*Solanum lycopersicum*) is one of the most popular vegetables worldwide and is grown for its edible fruit (Beckles, 2012). Ethiopia has a huge potential for the production of vegetables including tomatoes. Tomato can be produced in different agro-ecologies in the country where the climate, soil and water conditions are favorable (Lemma, 2002). Even though the production of tomato in Ethiopia is mainly from open and small land holdings, the total production was estimated to be 0.42 million mT in 2020/21 (FAOSTAT, 2021).

The majority of the fruits produced are for home consumption and domestic market. The small-scale farmers are interested in fresh market tomato production more than any other vegetables for its multiple harvests, which result in high profit per unit area (Wonduwossen, 2014). The export of tomato dated back in 1993 with the export of 721Mt and revenue of 79,000 USD (World Bank, 2004). In 2016/17 fiscal year, the country earned 7,629,037.00 USD from the export of 24,769.49 ton of tomato. The major market destinations were Djibouti, Somalia, UAE and Saudi Arabia (ERCA, 2017).

Tomato is a climacteric fruit and its ripening is actually stimulated by ethylene (Razali *et al*., 2013; Pesaresi *et al*., 2014) and due to this, it has a very short life span, usually up to 2 weeks (Gharezi *et al*., 2012). Ripening follows climacteric pattern involving a wide range of physical, chemical, biochemical and physiological changes, which start in the plant and follow after detachment from it (Serrano *et al*., 2008). Through this period, the biochemistry, physiology, and structure of the organ are developmentally altered to influence appearance, texture, flavor, and aroma (Giovannoni, 2004) due to decrease in the chlorophyll and starch content and increase in the softening enzyme polygalacturonase and antioxidant lycopene, making the fruit attractive for consumption (Jones, 2008).

Tomato fruits deteriorate rapidly after harvest (Fentahun Asrat *et al*., 2019) and in some cases after transport and marketing (García *et al*., 2014). Ripening, which leads to deterioration and loss of tomato fruits, is a highly coordinated developmental process that coincides with seed maturation. It is controlled by the expression of thousands of genes which regulate fruit softening as well as accumulation of pigments, sugars, acids, and volatile compounds that increase attraction to animals (Klee and Giovannoni, 2011).

Postharvest losses can take place at all stages of the supply chain such as harvesting, handling, storing, processing, packaging, transporting and marketing, resulting in deterioration of fruit quality and nutritional value (Mrema and Rolle, 2002; Kader, 2005; McKenzie *et al*., 2017). Losses occur due to immaturity, over-ripening, mechanical damage, and decay and these losses can be attributed to poor harvesting method, rough handling, improper packaging and poor transport conditions (FAO, 2018).

Postharvest loss can be controlled by different preharvest and postharvest treatments. First cultivate selected cultivar with appropriate plant nutrition, and disease and insect pest control measures. Then apply best postharvest treatments in harvesting, transporting, storage and marketing to minimize the PHL of produce. Treatments like salicylic acid application (Asghari and Aghdam, 2010; Srivastava & Dwivedi, 2000, Aleminew Tagele *et al*., 2022), calcium preharvest application (Usten *et al*. 2006, Aleminew Tagele *et al*., 2022), Chitosan pre-or postharvest application (Bautista-Banos *et al*., 2006; Aleminew Tagele *et al*., 2022), edible coatings application (Dhall, 2013a; Cha and Chinnan, 2004) can be used to maintain the postharvest quality of tomato fruits. Similarly, tomato fruit shelf life extension can be obtained by disinfecting tomatoes fruits and use of cold storages after harvest (Arah *et al*., 2016; Aleminew Tagele *et al*., 2022).

As a nut shell, post-harvest losses represent a waste of the resources (land, labour, energy, water, fertilizer, etc.) that went into producing the crop (FAO, 2018). A huge postharvest loss of fruit and vegetables including tomato is one of the major bottlenecks of agricultural sector industry development (Getachew *et al*., 2018). But updated compiled information on PHL of tomato for future research and policy decision is not available. Hence this paper is aimed to review and document the status, cause and copping measures of tomato postharvest loss.

## Extent of Tomato Postharvest Loss

Postharvest losses of tomatoes reported by several scholars and different values are estimated as high as, 25-42% (Rehman *et al*., 2007), 42 % (Arah *et al*., 2015) globally. Loss of 13.89% due to transport in Ilorin (Idah *et al*, 2007), 20% at harvest and 28% in transport in Kano state (Olayemi *et al*., 2010), Nigeria, 40.3-55.9% in commercial tomato supply chains in Australia (McKenzie *et al*., 2017) were reported.

The postharvest loss of tomato in Ethiopia is also considerably large. Postharvest tomato losses of 25.9% in the supply chain of Mecha, North Achefer, Fogera and Bahir Dar (Eskinder E. *et al*., 2022), 24.17% in Fogera (Fentahun Asrat *et al*., 2018) were estimated. Similarly PH tomato losses of 45.32% in Dire Dawa (Mohammed Kasso and Afework Bekele, 2018) and 3.7%, 2.8%, 3% and 6.7% at producer, collector, wholesaler and retailer level, respectively, at Bora and Dugda (Bezabih Emana *et al*., 2017) were reported.

## Causes for Postharvest Loss of Tomato Fruits

Postharvest loss of tomato can be resulted from preharvest and postharvest factors along the supply chain (FAO, 2018). According to Aidoo *et al*. (2014), Postharvest losses resulted largely from rot and bruises (mechanical damage) which were mainly caused by on-farm activities (Figure 1). They also reported that rot resulted from over-use of spraying chemicals (herbicides and insecticides), excess watering and contact of fruits with the soil. Bruises, however, resulted from poor staking and poor handling during harvesting and sorting.

Similarly Fentahun *et al*. (2019) revealed that almost half of tomato produced is damaged and puts out of normal use with highest loss at producer level due to different causes which are complex and interrelated across tomato market chain. Marketing situation, insect pest and disease, lack of awareness, low economic status of producers, late harvesting, mechanical damage during harvesting and transportation, poor quality of produce and price fall were some of the reasons identified as major cause of post-harvest loss of tomato.

The causes of PHL of tomato are very complex and varied. As a result several researchers have reported different critical factors that impacted heavily on PHL of tomato like lack of ready market for produce (Aidoo *et al*., 2014), longer distances and unreliable transportation means to the market (Aidoo *et al*., 2014; Fentahun Asrat *et al*., 2019) and poor storage conditions and damages (Fentahun Asrat *et al*., 2019).

Figure 1. Causes of postharvest loss of tomato fruits

Source : Aidoo *et al*., 2014

## *Preharvest causes affecting tomato fruit loss*

Fruits of different cultivars differ in size, colour, texture, and flavour as well as storage potential. Significant variation in quality properties among the tomato varieties was reported by Yebirzaf and Kassaye (2018).

The tomato plant has a high demand of nutrients. Nitrogen, phosphorus and potassium are the major macronutrients used at tomato plant cultivation. Excess or deficiency of nitrogen, phosphorus and potassium is known to impact negatively on fruit quality (Beckles, 2012). High nitrogen supply can impair some important quality traits of fruits, such as total soluble solids, glucose, fructose, and pH (Parisi et al., 2006). Potassium is the most efficient cation for tomato plants and it plays a key role in the improvement of several postharvest quality traits in tomato fruits and in almost all vegetables (Cakmak, 2005). Calcium application in tomato production has been found to have a positive effect on the prevention of some diseases (Passam et al., 2007).

Tomato is not a drought resistant crop and therefore yields decrease considerably after short periods of water deficiency during production (Arah et al., 2015). Studies revealed that deficit irrigation with increased salinity reduced fruit water accumulation and fresh fruit yield but increased fruit total soluble solids levels (Senevirathna and Daundasekera, 2010) and Abdel-Razzak et al. (2016) reported increased fruit quality traits at 50% ETc water stress treatment. This is due to the fact that tomato fruit comprises about 95% water by volume and with increasing EC, water is removed from the phloem and the concentration of the solute that is supplied to the fruit increases. This ultimately stimulates higher dry matter and sugar concentration per fruit (Beckles, 2012). Such high dry matter accumulation improved the shelf life of tomato fruits.

The maturity stage of tomato fruit at harvest is an important determinant of many quality traits as well as postharvest shelf life. It can be harvested at different stages during maturity, like mature green, half ripen, or red ripen stage. Each stage at harvest has its own postharvest attribute that the fruit will exhibit (Arah *et al*., 2015). According to Ramaswamy (2015), maturity plays an important role in the defense of the plant organs against microbial attack.

The defense, which is very strong in young tissues, continues to persist until the organ matures, after which the resistance begins to drop as the tissues are weakened as the mature fruit goes through the stages of ripening and senescence. Several studies ascertain the effects of maturity on postharvest quality and shelf life of tomato fruits. Getachew *et al*. (2018) also reported a significant effect of maturity stage on sugar content, titrable acidity and firmness of tomato fruits. The shelf life of all tomato cultivars was also the longest when harvested at green mature stage (Moneruzzaman *et al*., 2009).

## *Postharvest causes affecting tomato fruit loss*

***Temperature:*** Temperature is the most important environmental factor to consider in the postharvest life of tomatoes because of its effects on the rates of biological processes (Mostofi and Toivonen, 2006). Chemical, microbial, biochemical, or physiological activity in a stored product is significantly influenced by the storage conditions, especially temperature. A ten-degree change in temperature can result in a two- to three-fold change in these activities (Ramaswamy, 2015).

High storage temperature can result in increased respiration and ethylene production as well as accelerate ripening and weight loss (Mutari and Debbie, 2011). De Castro *et al*. (2005) reported that a storage temperature of 10-15°C and 85-95% relative humidity could extend the postharvest life of fruits. At these temperatures chilling injury and ripening rate are minimal. Khairi *et al*. (2015) also found increased lycopene and color value of tomato with storage temperatures above 10 °C. However, the report by Znidarcic *et al* (2010) indicated that tomato cv. Belle could be stored using temperatures below the recommended storage temperature of 10 0C and observed delays the climacteric peak, and consequently the ripening.

***Relative humidity:***The rate of water loss from fruits and vegetables depends on the vapor pressure deficit between the commodity and the surrounding ambient air, which is influenced by temperature and relative humidity (RH). At a given temperature and rate of air movement, the rate of water loss from the commodity depends on the RH (Kader, 1985). At very high relative humidity, harvested fruits maintain their nutritional quality, appearance, weight, and flavour, whilst reducing the rate at which wilting, softening, and juiciness occur. Tomato fruits are very high in water content and susceptible to shrinkage after harvest. Fruit shrivel may become evident with any small percentage of moisture loss (Arah *et al*., 2015).

The optimal values of RH for mature green tomatoes are within the range of 85-95% but 90 95% for firmer ripe fruits (Suslow and Cantwell, 2009). Yahia and Brecht (2012) also reported that the optimum relative humidity (RH) during storage and transport is 90-95%, whereas the optimum RH for ripening is 75-80% and higher RH will promote infection by fungi and the development of decay. Very high relative humidity conditions may lead to mold growth on produce surfaces while lower relative humidity can result in desiccation (Ramaswamy, 2015). The findings of Chilson *et al*. (2011) revealed that tomatoes stored at RH lower than 88% were softer, with stems that appeared to be less fresh, more shriveled, and had higher weight loss and lower acidity, SSC, and AA content than those stored at higher RH levels.

***Atmospheric composition:*** Reduction of O2 and elevation of CO2, whether intentional (modified or controlled atmosphere storage) or unintentional can either delay or accelerate the deterioration of fresh horticultural crops by promoting microrespiration in produce. The magnitude of these effects depends on the commodity, cultivar, physiological age, O2 and CO2 levels, temperature, and duration of holding (Kader, 1985; Ramaswamy, 2015). Artes *et al*. (2006) reported that the optimal atmosphere needed to inhibit senescence in mature green and ripe fruit of tomatoes is 3-5% (v/v) of oxygen but for carbon dioxide it is 1-3% (v/v) and 1-5% (v/v) in mature green and ripe fruit, respectively. The finding of Adanech *et al*. (2017) depicts that tomato fruits treated with 5% CO2 maintained their high quality with regards to vitamin C, skin color (a\*), lycopene content, weight loss, physiological parameters (ethylene production rate, respiration rate, and volatile compounds), flesh firmness, cell wall thickness, and pectin content at both maturity stages compared with 3% CO2 treatment and the control.

## Postharvest Deterioration of Tomato Fruit

Tomato fruits undergo different metabolic changes throughout its life cycle. Among the postharvest metabolic changes, respiratory activity and transpirational loss of water are the two basic processes that determine the storage-life and quality of fruits (Lawes and Prasad, 1999). Deterioration of fruit can result from physiological breakdown due to natural ripening processes, water loss, temperature injury, physical damage, or invasion by microorganisms (Babatola *et al*., 2008). Both qualitative and quantitative losses occur in fruits between harvest and consumption. Rapid ripening of tomato fruits due to its climacteric nature leads to postharvest losses (Paul *et al*., 2011).

### *Postharvest physiological deterioration*

Both internal and external factors cause deterioration of tomato fruits. Internal factors include respiration, ethylene production and action, compositional changes, mechanical injuries, water stress, physiological disorders, and pathological breakdown. The rate of biological deterioration depends on several external factors, including temperature, relative humidity, air velocity, and atmospheric composition and sanitation procedures (Kader, 2005; Saeed and Khan, 2010; Serrano *et al*., 2008). Although the review considers only the major processes leading to deterioration *viz-viz* respiration, transpiration process, ethylene production, physiological and microbiological disorders.

***Respiration of tomato fruits after harvest:*** Respiration is the process by which stored organic materials (carbohydrates, proteins and fats) are broken down into simple end products with a release of energy. Oxygen is used in this process, and carbon dioxide is produced (Kader, 1985). The respiration rate of a product determines its transit and post-harvest life. The respiration rate is affected by a wide range of environmental factors, including light, radiation, water stress, growth regulators and pathogen attack.

The most important post-harvest factors are temperature, atmospheric composition and physical stress (Pinheiro, *et al*., 2013). According to Yahia and Brecht (2012), biologically fruits are classified as climacteric or non climacteric based on their respiratory behavior and ethylene production rates during ripening. Climacteric fruits are those whose ripening is accompanied by a distinct increase in respiratory rate (climacteric rise) which is generally associated with elevated ethylene production just before the increase in respiration. Non-climacteric fruits are those that do not exhibit increases in ethylene and respiration, but rather undergo a gradual decline in respiration during ripening. Tomato fruit show a climacteric pattern of respiration, and therefore ripening can be initiated before or after harvest.

***Ethylene synthesis in harvested tomato fruits:*** Ethylene, also known as the ‟death” or ‟ripening hormone” plays a regulatory role in many processes of plant growth, development and eventually death. Fruits, vegetables and flowers contain receptors which serve as bonding sites to absorb free atmospheric ethylene molecules (Dhall, 2013b). Generally, ethylene production rates increase with maturity at harvest and with physical injuries, disease incidence, increased temperatures up to 30°C, and water stress. On the other hand, C2H4 production rates by fresh horticultural crops are reduced by storage at low temperature, by reduced O2 levels (less than 8%), and elevated CO2 levels (more than 2%) around the commodity (Barry and Giovannoni, 2007; Kader, 1985).

Ethylene production is initiated in mature-green tomatoes in the locular gel coincident with the disintegration of that tissue, the cell walls of which are completely degraded (Yahia and Brecht, 2012). Tomato maturation process is affected by ethylene and this is accompanied by texture alterations, more specifically firmness loss, owing to structural changes in the principal cell wall components (cellulose, hemicellulose and pectin). Finally, the accumulation of sugars, such as glucose and fructose, and organic acids in vacuoles, and the production of complex volatile compounds is responsible for fruit aroma and flavor (Pinheiro *et al*., 2013). Rate of ethylene production in fruit during the course of ripening is controlled by the ability of the tissue to synthesize 1-aminocyclopropane-1-carboxilic acid (ACC) and to convert it in to ethylene. The two key enzymatic controls are at the expression and activity levels of ACC-synthase (ACS) and ACC-oxidase (ACO) (Paul *et al.,* 2011).

***Transpiration in harvested tomato fruits:*** Water loss is a main cause of deterioration because it results not only in direct quantitative losses (loss of salable weight), but also in losses in appearance (wilting and shriveling), textural quality (softening, flaccidity, limpness, loss of crispness and juiciness), and nutritional quality (Kader, 1985). Fruit water balance is determined by entry of sap through xylem and phloem, and losses due to backflow from fruits to other organs, and to transpiration.

The transpiration, evaporation of water from the plant tissues, plays a significant role in fruit water balance (Leonardi *et al*., 2000). It depends on the vapor pressure deficit between the product and its surrounding atmosphere and on product characteristics such as the surface-volume ratio, structure and composition of the product (Tano *et al*., 2005). In addition, it is the main driving force for the xylem stream in which calcium seems to move relatively freely while this ion is also well known to be substantially immobile in the phloem (White and Broadley 2003).

***Physiological disorders in harvested tomato fruits:*** A number of disorders affect the quality of fresh-market tomatoes. These disorders result from a combination of environmental, production and handling procedures, or are genetic in origin. Anther scarring, blistering, blotchy ripening, blossom-end rot, cracking, green shoulder, misshapen fruit, russeting, sheet pitting, sunscald are the major physiological disorders of tomato fruits (Saltveit, 2005).

Chilling injury is also a postharvest physiological disorder caused by improper storage temperatures that results in several symptoms, including sunken areas on the fruit (blemishes), disease susceptibility, color development inhibition and ripening (Pinheiro *et al*., 2013). Very low O2 <1%) and high CO2 (>20%) atmospheres can cause physiological breakdown of most fresh tomato fruit, and C2H4 can also induce physiological disorders. The interactions among O2, CO2, and C2H4 concentrations, temperature, and duration of storage influence the incidence and severity of physiological disorders related to atmospheric composition (Kader, 1985).

***Microbiological disorders in harvested tomato fruits:*** During postharvest a reduction in fruit quality also occurs because of diseases and possible microbial spoilage. Micro-organisms readily attack fresh produce and spread rapidly, owing to the lack of natural defense mechanisms in the tissues of fresh produce, and the abundance of nutrients and moisture that supports their growth.

Fruit skin is a protective barrier against disease, but when damaged, either by the presence of cuts or abrasions, provides a potential microorganism’s entry and consequent fruit deterioration (Pinheiro *et al*., 2013). Stresses such as mechanical injuries, chilling, and sunscald lower their resistance to pathogens (Kader, 1985).The most common decay problems in tomatoes are black mould or alternaria rot, grey mould, bacterial soft rot, sour rot, hairy or rhizopus rot, early blight rot, ring rot and bacterial speck (Yahia and Brecht, 2012).

### Mechanical deterioration

Increased use of mechanical equipment for the harvesting, packing, and transporting fruits and vegetables has led to mechanical injury becoming a more significant problem. The stage of fruit ripeness at harvest is one of major factors influencing the susceptibility of commodity to mechanical injury; riper tomatoes were more susceptible to mechanical damage (Lee *et al*., 2007).

Various types of physical damage (surface injuries, impact bruising, vibration bruising, and so on) are major contributors to deterioration. Browning of damaged tissues results from membrane disruption, which exposes phenolic compounds to the polyphenol oxidase enzyme. Mechanical injuries not only are unsightly but also accelerate water loss, provide sites for fungal infection, and stimulate CO2 and C2H4 production by the commodity (Kader, 1985).

##  Prevention of Postharvest Loss of Tomato Fruits

## *Preharvest treatments to minimize tomato loss*

***Application of elicitors to prevent loss:*** Elicitors (Chitosan and salicylic acid) are molecules which, at low concentrations, induce plant defense systems by promoting the synthesis of biologically active metabolites. The plant response induced by the application of an elicitor can affect tolerance to other non-related abiotic or biotic stresses (cross-tolerance) (Hernandez *et al*., 2015).

The application of agro-chemical substances is considered as one of the most innovative methods to extend the commercial storage life of vegetables and fruits (Zeraatgar *et al*., 2018). Salicylic acid (SA) or ortho-hydroxyl benzoic acid is an endogenous plant growth regulator of phenolic nature and classified as a growth promoter (Champa *et al*., 2015; Khan *et al*., 2003). It has been found to play a key role in the regulation of plant growth, development and enhance plant vigour under biotic and abiotic stresses (Hayat *et al*. 2010). SA positively affect on reducing fruit respiration, ethylene biosynthesis (Srivastava and Dwivedi 2000; Kumar *et al*., 2018), stomata closure, ion uptake, transpiration (Khan *et al*., 2003), weight loss, decay and softening rate (Babalar *et al*. 2007; Shafiee *et al*. 2010) during storage. Aleminew *et al*. (2022) also reported preharvest spray of SA extended the shelf life tomato fruits by slowing TSS, lycopene and pH increment rate in the storage.

Application of SA is useful in inhibiting tissue softening in fruits by reducing cell wall hydrolases activities and maintaining cell membrane consistency (Supapvanich, 2015). According to Rao *et al*. (2011), treating the fruits with of SA lowers the activity of these enzymes which might have been associated with a high integrity of the cell membrane and contributed to high levels of crispness and firmness in the fruits during storage. It decreases ethylene biosynthesis by decreasing both ACS and ACO gene expression and also enzyme activity (Aghdam *et al*., 2016).

The firmness and shelf life of tomato fruits with preharvest spray of 450 mg/L SA was higher than the control (Javanmardi and Akbari, 2016). On the study conducted by Aleminew et al (2022) on tomato the maximum firmness recorded on SA sprayed with 0.045%. Aghdam *et al.* (2014) attributed longer storability and higher chilling resistance of detached tomato fruits treated with SA to increased endogenous proline content. SA could be a promising tool to improve tomato yield, fruit quality attributes and health beneficial compounds (including phenolic compounds, vitamin C and flavonoids having antioxidant activity) because of its diverse regulatory roles in plant metabolism (Tommonaro *et al.*, 2012). Preharvest treatment of tomato fruits with salicylic acid at 2g/l SA increased fruit carotenoids, reducing, non-reducing and total sugars, SSC, acidity and ascorbic acid contents at harvest, while, decreased fruit pH and electrolyte leakage (Almunqedhi *et al*., 2017). Similarly, Baninaiem *et al*. (2016) reported tomato fruits treated with 4mM SA in preharvest and postharvest periods increased fruit TSS, TA, ascorbic acid contents and firmness; while, decreased chilling injury, decay and electrolyte leakage. Generally almost all authors reported that application of SA increased the shelf life of tomato fruits.

Chitosan is a natural carbohydrate polymer modified from chitin, which is derived from crustaceous shells such as crabs and shrimps (Abd El-Gawad and Bondok, 2015). Chitosan is a biopolymer with tremendous variation in its structure and properties. Chitosan stimulates various plant responses, through the formation of physical and chemical barriers against invading pathogens and abiotic stress resistance, enhancement of plant growth and yield, and shelf life of flowers and fruits, and activation of secondary metabolite production (Sukwattanasinitt *et al*., 2001; Pichyangkura and Chadchawan, 2015).

When applied to plant tissues, chitosan triggers similar responses to that of wounding in which, pectic fragments from oligogalacturonides in the cell wall induce the accumulation of ROS and pathogenesis-related proteins to protect plant tissues against pathogen infection (Ferrari *et al*., 2013; Pichyangkura and Chadchawan, 2015). Moreover, the plant defense system induced by chitosan was triggered via the nitric oxide (NO) pathway (Raho *et al*., 2011). Its pre-or postharvest application has been considered as an alternative to the use of synthetic fungicides in order to prevent postharvest decay and extend storage life as well as retain the overall quality of different fresh fruit and vegetable commodities (Bautista-Banos *et al*., 2006). El Ghaouth *et al*. (2004) also indicated that fruits and vegetables may be able to develop enhanced resistance to pathogens infection by pre-or postharvest treatments of chitosan.

Chitosan has excellent selective permeability to the respiratory gases, acting as a barrier to the passage of oxygen (Elsabee and Abdou, 2013). This control of gas exchange between the fruit and environment reduces the respiration and the action of ACC oxidase and synthase enzymes, which besides being key enzymes of ethylene biosynthesis, are greatly influenced by the presence of oxygen (Noh, 2005).

Several studies indicated preharvest application of chitosan improves the shelf life and maintain the physicochemical properties of tomatoes and other fruits. Chitosan at 6.0 g/l increased the shelf life of tomato fruits. In addition, it significantly increased fruit carotenoids, reducing, non-reducing and total sugars, SSC, acidity and ascorbic acid contents at harvest, while, decreased fruit pH and electrolyte leakage (Almunqedhi *et al*., 2017). Aleminew et al., (2022) also reported preharvest spray of 0.1% chitosan increased significantly the shelf life tomato fruits stored in ambient storage conditions.

***Application of calcium chloride to minimize tomato loss:*** Calcium, as a constituent of the cell wall, plays an important role in forming cross-bridges, which influence cell wall strength and regarded as the last barrier before cell separation (Fry, 2004). It is a key plant nutrient required for several key physiological processes related to ripening-related changes, including those in cell wall structure, membrane integrity and functionality, activity of particular enzymes, or signal transduction and reducing softening and senescence of fruits (Lara, 2013; Barker and Pilbeam, 2015; Kadir, 2004). It is considered the most important mineral element determining fruit quality (El- Badawy, 2012).

Because calcium uptake from the soil and its movement to aerial plant organs is limited, direct spray applications onto the plant canopy are preferable, as they often allow effective increase of calcium content in the fruit (Ferguson and Boyd, 2002). Both preharvest and postharvest applications of calcium on fruits and vegetables have reported to play an important role in maintaining their quality (Daundasekera *et al*., 2015). Pre-harvest calcium applications increase calcium content of the cell wall of plants (Serrano *et al*., 2004). In general, the direct application of calcium to the fruit is the most effective method for increasing fruit calcium content, which could be accomplished by preharvest sprays (Trentham *et al*., 2008).

Application of calcium contributes to the maintenance of postharvest quality and shelf life of fruits. Preharvest application of calcium may delay senescence in fruits with no detrimental effect on consumer acceptance. Calcium application in tomato production found to have a positive effect on the prevention of some diseases like bacterial and viral diseases (Usten *et al*., 2006), whilst slowing the reduction in fruit firmness during ripening (Passam *et al*., 2007). Kirmani *et al*. (2013) reported a minimum decline in firmness and weight and better retention of sensory quality attributes in storage of tomato with spray of 0.5% CaCl2. Application of 3% CaCl2 at 7 days after full bloom resulted in fruits to exhibit longer shelf life and higher firmness (Daundasekera *et al*., 2015). While Alemniew et al. (2022) reported maximum fruit firmness and delaying of physio-chemical changes during storage achieved with the application of 5% CaCl2.

Pre-harvest spray applications of calcium chloride increased the calcium content in the peel of fruits that had been treated with calcium (Madani *et al*., 2014). Calcium binds with pectin contents in vegetables and fruits by forming the salt bridge and these pectic substances provide sites for the binding of calcium (Hocking *et al*., 2016). Due to this reason calcium pectate is formed thus helpful in reducing the degradation of cell wall and ultimately reduces the production of ethylene resulting in maintaining low TSS by slowing down the ripening process. Reduction in weight loss is observed in all those fruits which are treated with calcium as compared to control fruits. Significantly higher fruit firmness was observed in fruits of plants treated with higher concentration of CaCl2 (Abbasi *et al*., 2013; Aleminew et al., 2022).

## Postharvest treatments to minimize tomato loss

### *Chemical treatments to control micro-organisms*

***Chlorination of tomato fruits:*** Washing tomato with chlorinated water is used to prevent and control microbial proliferation during the storage period (Bartz *et al*., 2013; Genanew Tessema, 2013). Chlorine-based solutions are commonly used as a disinfectant due to its very strong oxidizing properties and cost effectiveness, but chlorine have been associated with the formation of carcinogenic compounds. In addition, Chlorine-based compounds have a limited effectiveness in the reduction of microbial load on fresh produce (Sandarani *et al*., 2018). Washing whole produce by dipping or submerging in chlorinated water is routinely used and has a sanitizing effect, even if reduction in pathogenic and other micro-organisms is minimal and cannot reach total elimination (Pinheiro *et al*., 2013). Inhibitory activity of chlorine solution depends on the amount of free available chlorine (as hypochlorous acid –HOCl) in the water that comes in contact with microbial cells (Beuchat, 1998).

***Acetic acid as preservative for tomato fruits:*** An increase in the shelf life and improvement of tomato fruit quality is really desirable and the initial step required for ensuring successful marketing is to harvest the crop at the optimum stage of maturity. The major concern of the food service sector is the availability of reliable and effective methods of sanitizing fresh fruits and vegetables. One of the most widely employed sanitization method of tomato is the addition of vinegar (acetic acid). It is commonly used by food manufactures as antimicrobial preservative or acidulates in a variety of food products and safe to environment (El-Katatny *et al*., 2012). Acetic acid is plant bioregulator belonging to the auxin group (Gharezi et al., 2012).

Dipping or fumigating tomato fruits with acetic acid can also be used inexpensively to preserve fruits for long periods without any side effect (Alawlaqi and Asmaa, 2014; Gharezi *et al*., 2012). Being effective in preventing postharvest fruit decay caused by *P. digitatum* and *P. italicum,* itis a proven antimicrobial agent and a natural and safe food ingredient (Radi *et al*., 2010). Sholberg *et al*. (2000) also reported its effectiveness in preventing germination of conidia of brown rot, grey mould and blue mould and subsequent decay of stone fruit, strawberries and apples. The mechanism of acetic acid effect on inhibiting microorganisms is apparently due to its effect on the cell membrane through the interfering with transport of metabolites and maintenance of membrane potential (Sholberg, 2009).

The report also indicated a lower TSS and decay and an increase in shelf life, firmness and titrable acidity and ascorbic acidity with the treatment of tomato fruits with 5% acetic acid compared to the untreated ones (Gharezi et al**,**. 2012). Alawlaqi and Asmaa (2014) reported that tomato fruits in 4% acetic acid solution significantly reduced the growth and severity of *A.* *alternata* and *B. cinerea.* Shehata (2006) reported that all the tested Fruits treated with acetic acid concentrations of 5, 10, 15, 20 and 25%, applied for 1 h at 13°C significantly reduced the percentage of infected areas over the control.

***Bitter leaf extract to control tomato fruit loss:*** *Vernonia amygdalina (*bitter leaf) belongs to the family Compositae; the family is the largest family of the flowering plants comprising 950 genera and about 23,000 species (Yaradua *et al*., 2015). Leaves of bitter leaf plants possess some anti-microbial properties against a wide range of pathogenic bacteria and fungi (Bompeix and Cholodowski-Faivre, 2000). It was found to contain secondary compounds which include tannins, saponins, cardiac glycosides and alkaloids (Anibijuwon et. al., 2012) and this make it to have useful antimicrobial properties (Yaradua *et al*., 2015).

They also reported bitter leaf extract at 25% concentration showed remarkable antifungal activity (Kumlachew *et al*., 2014). Yaradua *et al*. (2015) also observed antimicrobial activity against *Staphylococcus aureus, Escherichia coli, Pseudomonas aeroginosae, Streptococcus species, Klebsialla pneumonia and Salmonella typhi*. Extracts of *bitter leaf* have inhibitory potential on rot causing fungi of tomato in storage and suggest its ability to prolong its shelf life (Ogo-Oluwa and Kator, 2016; John *et al*., 2016). Kumlachew *et al*. (2014) also observed an improvement of shelf life in mango with bitter leaf extract. The authors also reported an improved firmness at 25%, lower pH at 50% and lowering the TSS at 50% concentration of bitter leaf in mango fruits.

Aqueous extract is environmentally friendly, non-toxic, readily available and affordable (Ogo-Oluwa and Kator, 2016). In addition, Oladimeji *et al*. (2013) reported no significant difference in taste between the treated and untreated tomato suggesting that one can consume tomato fruits extracts without any fear.

***Neem leaf extract to control tomato fruit loss:*** Control of PHL in crops especially those caused by fungi has presented different problems which include hazardous effect of fungicides to man and the environment, development of resistance by fungi to synthetic fungicides, unaffordable cost of the chemicals to local farmers and in the recent times, the increasing demand by consumers for produce with no chemical residues (Tripathi and Dubey, 2004; Habiba, 2012). The concept of using plant leaf extracts as coatings to extend the shelf life of fresh produce and protect them from harmful environmental effects has been emphasized based on the need for high-quality fruits and storage technologies (Tharanathan, 2003). Neem leaf possesses some anti-microbial properties against a wide range of pathogenic bacteria and fungi (Bompeix and Cholodowski-Faivre, 2000).

Some studies showed the effect of neem leaf extract coating on the postharvest characteristics of of tomato. The use of neem extracts reduced the development of fungi during the storage period compared with the control. The report of Hosea *et al*. (2017) observed an increase in shelf life of tomato treated with neem and this is attributed to its suppression on the activity of certain fungi that cause spoilage. Because of no significant difference in taste between the neem treated and untreated tomato, one could treat tomato for consumption with the extracts without any fear of consumer rejection (Oladimeji *et al*., 2013).

### *Physical treatments to control tomato loss*

***Heat treatment of harvested tomato fruits:*** In recent times, there is a higher demand for heat treatments in postharvest technology instead of chemicals. Mode of action of heat treatment is to wash off the spores from the surface of the commodity. In addition, due to heat energy there is a considerable reduction of microorganisms such as bacteria and fungi (Schirra *et al*., 2000). There are different types of heat treatments including hot water dip, saturated water vapor heat, hot dry air and hot water rinse with brushing (Fallik, 2004). It can be better alternative to fungicide application, because it is chemical free, and maintains fruit quality. Moreover, it is relative easy to use, the fruits and water temperatures monitoring is reliable, and comparatively presents lower commercial system cost (Pinheiro *et al*., 2013).

Heat treatments have shown beneficial effects for insect control, prevention of fungal development, delayed ripening through inactivation of enzymes and prevention of postharvest storage disorders including chilling injury (Lurie and Pedreschi, 2014). Many commodities will develop chilling injury if the temperature is too low or if the cold conditions are maintained for too long. Heat treatments have been found to delay or prevent the development of chilling injury and ripening processes. Ripening can be delayed by heat inactivation of degradative enzymes and the time of the heat treatment can depend upon several factors and it can be vary from hours to days (Fallik, 2004).

Boonkorn (2016) reported extended storage life of tomato fruits by soaking in hot water at 40°C for 10 minutes before storage at 13°C and this resulted in increased peroxidase, and catalase activities possibly due to the defense response of fruits against the effect of high temperature. Hot water treatments at 50 0C for 20 minutes (Safiyaa *et al*., 2016) and 40 and 50°C for 20 minutes (Tigist Tadesse and Wosene Abtew, 2016) were better in extending the shelf life, to delay the peel color change and to reduce the weight loss of tomato (Roma VF and Cochoro) fruits.

***Edible coating to prolong shelf life of tomato fruits:*** The high production of tomato fruits during the harvest time and its associated postharvest loss due to inefficient calls for appropriate systems of preservation and processing (Ameyapoh *et al*., 2008). Postharvest treatments with conventional synthetic waxes and/or chemical fungicides have been used for many years to control postharvest decay and extend fruit shelf life. However, the health and environmental issues and the proliferation of resistant pathogenic strains, consumers are demanding for new preservation methods (Sapper and Chiralt, 2008). Thus, in recent years, edible coverings and biodegradables have generated interest of the food industry because of them being nature friendly materials with a lower environmental impact (Camatari *et al*., 2018).

Surface coating can survive fruits from migration of moisture, microbial growth, chemical changes due to light exposure, degradation of nutrients and act as source of bioactive materials such as antioxidant compounds, antimicrobial agents, color and flavor compounds. The use of edible coatings is one of the strategies to improve physical strength, reduce particle clustering and improve visual and tactile features of fruits (Cisneros- Zevallos *et al*. 1997). Edible coatings are traditionally used to improve the properties of food products appearance, their maintenance, enhance shelf life and slowing decaying by delaying ripening and moisture loss (Jahanbin *et al*., 2016).

Edible coatings can be made from various types of materials. The commonly used are polysaccharides (cellulose, starches and derivatives, vegetable or microbial gums, etc.), proteins (gelatin, zein, gluten, etc.) and lipids (waxes and lipid derivatives) alone or in combination (Jahanbin *et al*., 2016). Polysaccharide films have relatively low permeability to gases, but little resistance to water vapor transfer. Such coatings have been used to retard moisture loss of some foods during short term storage. Chitosan is the second most abundant polysaccharide available in nature and can be obtained from the deacetylation reaction of chitin (Aider, 2010).

***Aloe vera gel:*** Recently, plant based products have now found usage in fresh fruits and vegetables as bio-preservatives. *Aloe* *vera* gel is one of the promising bio-preservatives which have a great potential to become a common use for most fresh fruits and vegetables (Kator *et al*., 2018). Itcontains two major liquid sources, yellow latex (exudates) and clear gel (mucilage). Application of *Aloe vera* gel in the food industry is increasing day by day as resource of drinks, beverages and ice creams (Eshun and He, 2004).

Using *Aloe vera* gel as a coating for improved postharvest shelf life and maintaining quality of mature green tomato fruits. The effect of the gel coating resulted in reducing the postharvest losses. Chandran and Mini (2018) reported a significantly increase in the shelf life evidenced by reduced percentage weight loss, respiration rate and higher membrane integrity with Aloe gel + INS 402 (2%, 2 min) and Aloe gel + INS 402 (2%, 5 min). Kator *et al*. (2018) also reported the lowest value for decay and increased firmness with 100% concentrations of *Aloe vera compared to the untreated ones.* Tomato fruit coated with *Aloe vera* gel and hot water reduced changing procedure of decay, soluble solids, and pH in coated samples, and generally slowed the rate of ripening and reduce weight loss, as well as can increases retention of the vitamin C, improve better appearance properties, increase the firmness and acidity (Jahanbin *et al*., 2016).

***Cactus mucilage:*** The mucilage of cladodes of cactus has a highly branched complex polymeric structure of carbohydrate nature (Medina-Torres *et al*., 2000) and characteristics of mucilage enables the production of edible coatings with a high nutraceutical value possible. Espino-Diaz *et al*. (2000) indicated that for its use as an edible film at pH between 4 and 8, it is necessary to add a plasticizer to improve mechanical properties of the films. Fruit coating with cactus mucilage makes the product shiny.

Coating of fruits with cactus mucilage improved the firmness and reduced weight loss, which could reduce economic losses due to spoilage produced from mechanical damage during handling and transportation in tomato (Bernardino-Nicanor *et al*., 2018). This positive effect of the mucilage in firmness is attributed to the restriction in metabolic activities associated with cell wall-degrading enzymes. Cactus mucilage coating also hindered the growth of microorganisms on mango fruits (Oluwaseun *et al*., 2014a) and total microbial counts on papaya fruits fruits (Oluwaseun *et al*., 2014b) compared to untreated.

***Gum Arabic:*** Films based on galactomannans can be used to reduce water vapor, oxygen, lipid, and flavor migration between components of multi-component food products, and between food and its surroundings (Hendrix *et al*., 2012). Guar gum is a dried, gummy exudates and a galactomannan-rich flour, water-soluble polysaccharide obtained from the stems or branches of Acacia species (Chacon *et al*., 2018).

Surface coating of tomato fruits using gum Arabic solution has influence on the physicochemical and shelf life of tomato. Ali *et al*. (2013) reported that tomato fruit coated with 10% gum Arabic showed a significant delay in the change of weight, firmness, titratable acidity, soluble solids concentration and color during storage at 20 0C as compared to uncoated control fruit. The application of a mixture of 10% gum Arabic and 1% chitosan reduced the color evolution, the respiration rate and the ethylene production of the coated fruits compared with the control in banana. Similar results of lower weight loss, higher firmness, lower TSS, higher titrable acidity slowed color development are reported by Ruelas-Chacon *et al*. (2017) and El-Anany *et al*. (2009).

Increased respiration results in quicker ripening of fruit, which leads to faster deterioration of quality. Gum arabic coating delays ripening by providing a semi-permeable film around the fruit resulting in decreased the respiration rates and ethylene production. This leads to the decrease in hydrolysis of starch as well as the use of metabolites (Ali *et al*., 2013). Decreased respiration rates also slow down the synthesis and use of metabolites resulting in lower TSS, lower loss of weight, higher TA (Yaman and Bayoindirli, 2002). Since organic acids, such as malic or citric acid, are primary substrates for respiration, a reduction in acidity is expected in highly respiring fruit (El-Anany *et al*., 2009).

***Beeswax:*** Waxing is the process of covering fruits and vegetables such as apples, garden eggs, watermelon, cucumbers and tomatoes with artificial and natural waxing material (Richard, 2014). Beeswax is a natural wax produced by honey bees are widely used as a coating material after purification (Prasad *et al.,* 2018). Different research reports revealed the influence of beeswax coating on fruits. Mandal *et al.* (2018) reported that wax coated tomato fruits delayed pigmentation with good fruit firmness with low weight loss and fruit decay.

### Storage environment

Optimum temperature and relative humidity during storage are crucial to the marketable quality of fruits and vegetables including tomato and have a major impact on their shelf life (Chilson *et al*., 2011; Kitinoja, 2013). Use of refrigerators requires uninterrupted electricity and high initial capital for procurement and installation. However, evaporative cooling, which is premised on cooling by evaporation is a cheaper option for resource poor farmers to achieve low temperature and high relative humidity storage hence reducing postharvest losses (Manyozo *et al*., 2018; Getinet *et al*., 2011). In addition, it requires less or no energy consumption, easy to install and operate and uses locally available materials for construction (Ambuko *et al*., 2017; Ndukwu and Manuwa, 2014).

Zero energy cool chambers (ZECC), utilizing the principle of evaporative cooling is reported to maintain relatively low temperature and high humidity compared to ambient conditions (Rayaguru *et al*., 2010). With the use of ZECC, Mekbib (2016) and Manyozo *et al*. (2018) reported significant temperature difference between ambient and inside the ZECC and it gave better maintenance of the physicochemical and shelf life of tomato fruits. Hence, Aleminew Tagele *et al.*, 2022; Manyozo *et al*., 2018; and Hirut Getinet *et al*., 2011 are also reported as a cheaper option for resource poor farmers, with no electricity access, to achieve low temperature and high relative humidity storage.

## Conclusion and Recommendations

Tomato production can serve as a source of income for most rural and periurban producers in most developing countries of the world. However, postharvest losses make its production unprofitable in these parts of the world particularly in Ethiopia. Postharvest losses in tomatoes can be as high as 42% globally and it varies in different countries due to the level of application postharvest management technologies. The causes of postharvest losses can be internal and external factors.

Tomato postharvest losses can take place at all stages of the supply chain and estimated to be 25-42%. The loss can be on harvesting, handling, storing, processing, packaging, transporting and marketing, resulting in deterioration of fruit quality and nutritional value. Losses occur due to immaturity, over-ripening, mechanical damage, and decay and these losses can be attributed to poor harvesting method, rough handling, improper packaging and poor transport conditions.

After harvesting different metabolic activities take place internally in tomato fruits. As a result mechanical damage and micro-organisms hasten the deterioration due to high moisture content in the tissue of tomato fruits. Hence giving enough emphasis on physiology of tomato fruits have a great impact on the understanding and managing of PHL of the produce.

Postharvest loss of tomato can be caused by internal as well as external deteriorating factors. The internal factors includes respiration, ethylene production and action, compositional changes, mechanical injuries, water stress, physiological disorders, and pathological breakdown, while external factors are temperature, relative humidity, air velocity, and atmospheric composition and sanitation.

Tomato fruit shelf life extension can be achieved by application of preharvest and postharvest treatments as well as integration of them. Among different mechanisms, sanitation, disinfecting and other chemical treatments can be used to manage devastating effect of pathogens. Although disinfecting of tomatoes after harvest, is a best and economical option to minimize the loss, it is not a common practice for most tomatoes handlers in developing countries. Similarly use of pesticide is not advisable, due to the public concerns about the harmful effects of synthetic fungicides on human health and environment. Hence, the search for new alternatives is important like application of elicitors and edible coating and use of non-electric supported cheap evaporative cooling structures constructed with locally available materials.

Preharvest application of salicylic acid, chitosan, CaCl2 hinder the postharvest loss of fruits. SA application induces the expression of pathogenesis related genes and also conferred resistance against various pathogens. It delays the ripening of fruits, probably through inhibition of ethylene biosynthesis or action, and maintains postharvest quality. Chitosan pre-or postharvest application can be used to prevent postharvest decay and extend storage life of tomato fruit. Preharvest application of calcium enhances firmness and increase the shelf life of tomato. Similarly, edible coatings can be a best alternative to maintain the postharvest quality of tomato fruits. It enhances the natural waxy cuticle on the surface of a produce, protecting it against spoilage microorganisms and physical damage. It also reduces respiration and transpiration rates.

The use of cold storage and application of pesticides, it is costly and needs infrastructure and postharvest facilities. Furthermore, there is no reliable information on the use of disinfectants, elicitors, edible coating and locally constructed cooling storage structures (ZECC, Charcoal evaporative cooling) for tomato fruits among Ethiopian farmers. Despite the rich knowledge of postharvest losses in tomato production and marketing in the world, there is huge knowledge gap in postharvest handling and management in Ethiopia. Hence, estimating of postharvest loss with certified methodologies as well as testing of alternative pre-storage disinfections, application of available elicitors and edible coatings, storage conditions can bring reduction in postharvest loss. As a nut shell, fine tuning of effective technologies and searching for other new options should be designed in an integrated manner.

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