Journal of Postharvest Technology
2022, **10**(3): 78-93
www.jpht.in

REVIEW ARTICLE

Postharvest deterioration of tomato and it's management strategies: a review

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Received: 08.05.2022   Accepted: 01.07.2022

ABSTRACT

Tomato (*Lycopersicon esculentum* Mill.) is an important vegetable crop cultivated and consumed worldwide. Due to inadequate postharvest handling in the field, transit and storage, pathogenic mycoflora leads to processes of rot with consequent loss of products up to 30-40% in developing countries. Several studies regarding the postharvest decay of tomato and prevention of loss of quality have been studied; various methods such as physical, chemical, biological and botanical have been carried out. This review aims to explore several postharvest fungal diseases and physiological disorders of tomato along with their management strategies.

Keywords: Tomato, postharvest diseases, management, physical, chemical, botanical

Citation: Rai, R.K. and Singh, P. 2022. Postharvest deterioration of tomato and it's management strategies: a review. *Journal of Postharvest Technology,* **10**(3): 78-93.

INTRODUCTION

Tomato is an annual plant, which belongs to family- Solanaceae, Order- Solanales. It reaches up to a height of 1.3 meter (3-10 ft) and has weak stem. The leaves are 10-25 cm long and pinnate with 5-9 leaflets. Tomato plants are mainly cultivated for it's edible fruits (Ijato et al., 2011). It is native of South American Andes. It was introduced to Europe by Spanish people in the Sixteenth Century. Later it was brought from Europe to South and East Asia, Africa and Middle East (Bergougnoux, 2014).

Tomato is one of the most important vegetable, which is used on large scale in the whole world (Gould, 2013). It is also important from the economic point of view due to its high yielding capacity and short time period crop (Berova and Zlatev, 2000). It is very beneficial for our health having vitamins, minerals, carbohydrates, dietary fibers and essential amino acids along with Iron, Phosphorus, vitamins A and C in sufficient amounts (Frusciante et al., 2007). Fresh tomato fruits are consumed as salads while after cooking it is used as sauces, soup, meal or fish dishes. In United States, 35% of fresh tomatoes are processed into sauces, 18% processed into tomato paste, 17% used as canned tomatoes, 15% into juices, and 15% used as catsup (Lucier et al., 2000).

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ISSN: 2348-4330

PRODUCTION

According to report of FAOSTAT (2019) China, India and USA are the major tomato producing countries (Table 1). Ministry of Agriculture and Farmers Welfare, Government of India (June 2020) reported that, the major tomato producing states in the country are Andhra Pradesh, Madhya Pradesh, Karnataka, Gujarat, Odisha, Chhattisgarh, Maharashtra, West Bengal, Bihar, Haryana, Uttar Pradesh, Telangana and Tamil Nadu. The total tomato production of the country in year 2018-19 is 19,00,7240 Tonnes, in year- 2019-20 is 20,57,2510 Tonnes (Table 2).

Table 1. Major tomato producing Countries of world

Countries	**Total tomato production (in ,000 Tonnes)**	
	Year 2017-18	Year 2018-19
China	59599.34	61631.58
India	20708.00	19377.00
USA	11141.86	12612.39
Turkey	12750.00	12150.00
Egypt	6729.00	6624.73
Iran	6234.71	6577.10
Italy	6015.86	5798.10
Spain	5163.46	4768.59

(Source- Food and Agriculture Organization of the United Nation, 2019)

Table 2. Major tomato producing states of India

STATES	**Total tomato production (in ,000 Tonnes)**	
	Year 2018-19	Year 2019-2020
Andhra Pradesh	2503.49	2667.43
Madhya Pradesh	2516.08	2655.29
Karnataka	2030.04	2163.00
Gujarat	1367.57	1378.78
Odisha	1304.18	1306.00
West Bengal	1268.57	1271.35
Maharashtra	860.75	1040.00
Bihar	964.48	964.20

(Source- State Department of Horticulture and Agriculture, 2020)

POSTHARVESTLOSSES

After harvesting of fruits and vegetables, their proper management is very important to minimize losses, due to lack of which a large part of total production is spoiled before reaching the consumers. Tomato fruits suffers considerable postharvest loss due to fungal pathogens, physiological spoiling and physiological damages (El Ghauth et al., 1992). In horticulture, loss of tomato produce is a huge problem in postharvest chain, which is caused by several factors starting from growing period through handling at retail level. These losses are not only the wastage of food but also wastage of human effort, livelihoods, farm input, investment and scanty resources like water (Addo et al., 2015). The postharvest loss in tomato is due to inappropriate harvesting periods, lack of appropriate harvesting containers, excessive field heats, lack of on-farm storage facilities, inappropriate packaging materials, poor field sanitation, inappropriate mode of transport, lack of processing equipment and factories and also lack of reliable market (Arah et al., 2015).

Postharvest losses of tomatoes are about in range of 30-40% worldwide (Agrios, 2005, Kader, 1992), but it is higher in developing countries due to improper handling and dearth of methods to inhibit decay (Prigojin et al*.,* 2005). Total postharvest losses of tomato in Peshawar valley of Pakistan were estimated 20 %. These losses mainly occurred in field during picking, handling and transportation to the markets (Khan and Jan, 2007). Gajanana et al. (2006) indicated that total postharvest losses in tomato is 19% in Karnataka, which comprised 9.43% at field, 4 - 5% at market and about 5% at retail level. According to Sharma and Singh (2011), total postharvest loss in tomato is 15.16 % in Uttarakhand, due to inadequate storage and lack of proper handling in fields, transport and markets.

To overcome the problem of postharvest deterioration, several synthetic fungicides were used as most common and impressive method to control postharvest diseases (Jordan, 1973). However, uses of synthetic fungicides lead to imminent problems, such as increasing number of fungicides-resistant strains of postharvest pathogen and many synthetic fungicides are under review due to related health risk (Spotts and Cervantes, 1986). Thus, to solve this problem there is a need of an alternative plant- based preservative which is safe, biodegradable and eco-friendly.

POSTHARVEST DETERIORATION OF TOMATO

Olayemi et al. (2010) reported, postharvest deterioration in tomato is mainly caused by microbial infection, inappropriate storage facilities, insect pests, physiological breakdown and environmental conditions like heat and drought. Moreover, improper sanitation, bad packaging practices as well as mechanical damage during harvesting, handling and transportation may increase spoilage of tomato.

Fungal diseases

In nature, tomato have low pH, higher moisture content and nutrient composition which being susceptible for the attack of pathogenic fungi (Table 3), causing rots and producing mycotoxins which have many hazardous impacts on human life as well as on environment (Etebu et al., 2013).

Table 3. postharvest fungal pathogens of tomato fruit.

Diseases	Pathogens	Symptoms	References
Anthracnose	*Colletotrichum coccodes,* *C. dematium,* *C. gloeosporioides*	First small, circular, slightly sunken spots appear on the surface of ripening fruits. The spots quickly enlarge and develop into a water-soaked lesion under the fruit skin. As these spots expand, they develop dark centre spots.	Sanoubar and Barbanti (2017) Gleason and Edmunds (2005)
Buck eye fruit rot	*Phytophthora nicotianae* *Phytophthora capsici* *Phytophthora drechsleri*	Initially greyish-brown, water - soaked lesions seen on fruits. Which form brown concentric rings that resemble a buck eye. In young fruit brown discoloration can extend into fruit centres, while mature fruit quickly rot by secondary organism.	Sanoubar and Barbanti (2017) Gleason and Edmunds (2005)
GrayMold	*Botrytis cinerea*	Initially, a watery area with a light brown central region developed on fruit which changed into a soft, watery mass within a few days. After that fruit Skin is broken and greyish mycelium and spore clusters developed.	Wu Z et al. (2016) Gleason and Edmunds (2005)
Rhizopus rot	*Rhizopus stolonifer*	water-soaked liquid lesion seen on fruit surface may be covered with thin, cotton-like fungal structures. Infection transmitted adjacent fruit through mechanical wounds or natural openings and diseased fruit.	Petrasch et al. (2019) Bautista-Baños et al. (2008)
Phoma Rot	*Phoma destructive*	black colour spots with Small, black, pimple-like eruptions seen on fruits. Spots are the pycnidia or fruiting bodies of the fungus.	Hasija and Batra (1979)

Physiological disorder

These problems are not caused by infectious microorganisms but they are caused by different environmental stress on the plants (Table 4).

Tomato crops are mostly susceptible to fungi, bacteria, viruses (biotic factors) and temperature, sun light, malnutrition etc. (abiotic factors) (Fletcher, 1993). These diseases are contagious and when environmental conditions are favourable, then they often spread very rapidly. Fungi are most common cause of plant diseases that can produce a lot of damage. (Kumar and Babu, 2018).

Table 4. Physiological postharvest disorder of tomato fruit

Diseases	Symptoms	References
Blossom end rot	Initially a sunken, brownish black spot about half to one inch in diameter is seen on the blossom end of the fruit. This spot may gradually increase in size. Blossom end rot causes only local injury but secondary organisms frequently attack the wound and cause complete rot of the fruit.	Ho and White (2005), Gleason and Edmunds (2005), Taylor and Locascio (2004)
Fruit cracking	Cracking in tomato fruits is related to its rapid growth and due to wide fluctuations in the availability of water to the plant. Fruits that have reached the ripening stage during dry weather may show cracking if the dry period is followed by heavy rains and high temperatures.	Khadivi-Khub (2015), Gleason and Edmunds (2005)
Catfaced fruit	It is most common in large tomato fruits. Cold weather at the time of blossom set kills and distort certain cells which finally develop irregular bulges and bands of leathery scar tissue at the blossom end.	Drost (2020), Gleason and Edmunds (2005)
Sunscald	It occurs when green tomato fruits direct exposed to sun light. Initially whitish, shiny area developed that appears blistered. The killed cell gradually collapsed and forming a slightly sunken area. The killed tissue is frequently attacked by secondary organism and fruit decays.	Gleason and Edmunds (2005), Rabinowitch et al. (1974)
Blotchy ripening	Blotchy ripening is indicated by the absence of red pigment at localized area of ripening fruits. These areas show grey green or yellow patches otherwise normal red colour. cultural problems, nutritional and climatic may contribute to blotchy ripening.	Gleason and Edmunds (2005),

POSTHARVEST MANAGEMENT

Due to inadequate management, postharvest losses of fruits and vegetables have been estimated about 30%–50% or more in developing countries (Salunkhe and Desai, 1984). Central Institute of postharvest Engineering and Technology (CIPHET) in Ludhiana (2015) reported postharvest loss was maximum (4.58–15.88%) in fruits and vegetables among other crops. Therefore, there is need of an effective strategy for postharvest management to reduce losses. In the following section, various methods of postharvest disease management of tomatoes have been discussed.

Physical control

Physical treatment of perishable fruits and vegetables has obtained great interest in recent years to control many postharvest diseases because of minimum environmental effects and total absence of remnants (Usall et al., 2016).

Irradiation- After UV-C and red-light treatment for up to 21 days, there was improvement of the nutritional qualities without any significant changes in the physical properties of postharvest tomatoes during storage (Liu et al., 2009). Direct application of UV on fruits and vegetables reduced microbial population in these products and increase the shelf life (Ribeiro and Alvarenga, 2012). LIU et al., 2012, reported that mature-green tomato fruits were exposed to UV-C irradiation at 4 and 8 kJ m^{-2} and then stored under the dark at 14℃ and 95% relative humidity for 35 days, enhanced the accumulation of total phenolics, flavonoids and promoted the antioxidant activities. Fruit firmness was better maintained in UV-C treated tomato fruit. UV-C irradiation delay cell wall disassembly in the pericarp and significantly inhibited production of Ethylene (Bu et al., 2013).

Low temperature treatment- Low temperature treatment is very important in controlling decay in many perishable fruits and vegetables. Low temperature may reduce the growth of the pathogens and reduce the ripening process. Low temperature treatment is important in reducing disease incidence, moisture loss and physiological deterioration. For this reason, low temperature treatment is useful for several fruits and vegetables to enhance their shelf-life (Barkai-Golan, 2001).

Hot water treatment- Hot water treatment is one of the most useful non-pesticide technologies for postharvest control of decay for several fruits and vegetables (Fallik, 2004).Tomato fruit was treated with hot water, at 50 ℃ for 20 min, it enhanced shelf-life and reduced the weight loss of tomato (Mama et al., 2016). Treatment with 40℃ for 20 min reduce the weight loss and chilling injury index but increased the firmness of fruit during storage (Tadesse and Abtew, 2016). The use of a combination of hot water treatment (42.5 ℃ for 30 min) and modified atmosphere packaging (low-density polyethylene film with 0.02 mm in thickness) reduced decay and weight loss and maintained firmness of postharvest tomatoes (Itoh, 2003).

Hot air treatment- Heating of tomato fruit in air at 34 °C for 24 hours just before storage at 10 °C for up to 30 days resulted in the least losses in antioxidant content, and fruit colour developed adequately (Soto-Zamora et al., 2005). Hot air treatment of tomato fruit at 38 °C and 95% RH for 24 hours and/or storage at low temperatures, caused negative effects on several of the antioxidant components, while exposure to 34 °C and 95% RH for 24 hours enhanced the tomato antioxidant system (Yahia et al., 2007). According to Wei et al. (2017) hot air treatment induces disease resistance by activating the phenylpropanoid pathway in tomato fruit.

Cold plasma treatment-A promising new postharvest treatment is cold plasma, which is a gas-derived mix of atoms, excited molecules and charged particles (Machala *et al*., 2013; Mai-Prochnow et al., 2014). Cold plasma has no known adverse effects on fresh produce or the environment. Cold plasma as a successful chemical-free method for management of postharvest diseases caused by fungal plant pathogens (Siddique et al., 2018).

Chemical control

Postharvest diseases are controlled by several synthetic fungicides and bactericides that inhibited the development of pathogens on the surface of the infected fruits. About 20 organic compounds have been evaluated for the postharvest diseases of perishable crops. First-generation postharvest fungicides (e.g.- Dichloran, Sodium o- phenylphenate, sec-butylamine) are preventing infection by wound (Rhizopus, Penicillium, etc) but less effective for potential and other deep-seated infections (Singh and Sharma, 2018).

To prevent fungal infection, some typical fungicides were used, like dichloran, fludioxonil, iprodione (Rovral) and fenhexamid. Which generally degrade into toxic compounds and puts hazardous impact on human health as well as on environment. (Palou et al., 2009; Sapers et al., 2005).

Some chemicals like Carbonate and Bicarbonate have ability to minimize the pathogenicity of many fungi, such as- Sodium bicarbonate have been used to control *Penicillium digitatum* (Smilanicket al.,1999), *Phytophthora erythroseptica* (Mills et al., 2004). Sodium bicarbonate, Sodium salicylate and Sodium metasulfite have antibotritis activity. These chemicals control Grey mold disease of tomato fruits (Alaoui et al., 2017). At mature green stage of tomato fruits, an application of borax and guazatine reduce the incidence of fungal diseases (Wang and Morris, 1992). Application of fungicidal wax including phenyl phenol on fresh market tomato was effective in reducing decay (Hall, 1990). Soft rot caused by *Pectobacterium carotovorum* was inhibited by chlorine (8% $CaCl_2$) (Gomes et al., 2005).

Accordingly, a safer, cheaper, and eco- friendly approach have been done in the form of edible coatings on the surface of fruits. Generally, natural biopolymers such as polysaccharides and natural ingredients were used for preparation of layers based on a hydrogen-bonding network. Usually, Chitosan has been used as an edible coating in several fruits due to its excellent antimicrobial and biocompatible properties (Grande et al., 2019; Jianglian and Shaoying, 2013).

In order to enhance the shelf life of tomato, several chitosan-essential oil-based strategies were developed to control fungal decay of tomatoes, a lot of them were applied during preharvest conditions, some of them were directly applied during the postharvest stage (Migliori et al., 2017; Ramos-García et al., 2012).

The recent studies reported, chitosan-based nano-emulsions used as an alternative for the conventional biofilms, having advantages like higher reaction rates and higher transfer area, higher solubility, optical transparency and enhanced bioavailability (Chaudhary et al., 2020). However, in case of the food applications, they can inhibit the non-essential reactions as well as limits deterioration during and after consumption (Anandharamakrishnan, 2014).

Biological control

Uses of synthetic fungicides are the most common and impressive methods for the control of postharvest diseases in past decades. Recent study shows that they cause several problems like – risk for human health and create several fungicides resistance pathogens. Now a days uses of several microbes as biological control agents is also prevalent. *Bacillus amyloliquefaciens* (strain 5PVB) was effective in reducing grey mold of fresh tomato in storage caused by *Botrytis cinerea*(Mari et al., 1996). Antifungal compounds of *Saccharomyces* were effective in reducing the growth of *Colletotrichum coccodes* spores and inhibited the decay in tomato fruits (Jones and Prusky, 2002). Zhao et al., (2008) observed that the activities of *Pichia guilliermondii* and yeast was sufficiently successful in reducing the fungal growth caused by *Botrytis cinerea*, *Alternaria solani* and *Rhizopus stolonifer* on tomato fruit. *Trichoderma harzianum* has been used as antifungal agent for postharvest diseases of tomato fruits (El-Katatny and Emam, 2021). *Bacillus subtilis* L1-21 was effective in prevention of grey mold and other postharvest diseases of tomato during storage time (Bu et al., 2021).

Botanical

In order to overcome the utilization of synthetic chemical fungicides, several novel strategies have been studied. Plant metabolites are a promising alternative because plants produce a wide range of secondary metabolites, which may be the part of their development or in response to stress. Recently, they have attracted world-wide attention due to their safe status, easily decomposable, environmentally friendly and non-phytotoxic nature (da Cruz et al., 2013). It has been studied that, plant extracts in various solvents and essential oils both having potent rich bioactive compounds, like phytoalexins. Most of them have anti-microbial activity for plant protection, such as alkaloids, flavonoids, isoflavonoids, tannins, glycosides, terpens, cumarins and several organic acids and they have been used as anti-microbial agent (Compean et al., 2014).

Essential oil

Essential oils have been reported to possess significant antiseptic, antibacterial, antiviral, antioxidant, anti-parasitic, antifungal, and insecticidal activities (Chouhan et al., 2017).Essential oil obtained from thyme, oregano and lemongrass completely inhibited the mycelial growth of *Botrytis cinerea*, which caused grey mold of tomato (Plotto et al., 2002, Vitoratos et al., 2013). The essential oil of *Cassia* and *Thyme* showed antifungal activity against *A. alernata*. *Cassia* oil inhibited the spore germination and germ tube elongation of pathogen in potato dextrose broth (Feng and Zheng, 2007). *Citronella* oil can remarkably inhibited *A. alternata* and has capable as a promising natural product for controlling black rot (Chen et al., 2014). The essential oil of *Cupressus sempervirens is a promising safe product for the biocontrol* of the postharvest disease *Botrytis cinerea* during storage and transport of tomato (Rguez et al., 2018). Oil of *Chenopodium ambrosioides* was effective against two aflatoxigenic strains of *Aspergillus flavus* at 100 μg/ml and also inhibited the mycelial growth of *Fusarium oxysporum, Aspergillus fumigatus, Botryodiplodia theobromae, Sclerotium rolfsii* and *Phythium debaryanum* (Kumar et al., 2007). Soylu et al. (2010) reported that essential oils obtained from rosemary and lavender showed various physiological changes in pathogen such as hyphae shriveled, conidia loss, protoplast leakage, and cytoplasmic coagulated on *B. cinerea* morphology. The extracted essential oil of oregano and lemon have also shown fungicidal effects on *B. cinerea* and decreases the disease severity of gray mold disease in tomatoes, cucumbers and strawberries (Vitoratos et al., 2013).

The edible coating based on alginate cross-linked with calcium chloride, and containing an oregano essential oil successfully contributed to increases the shelf life of tomato, over 14 days at room temperature (Pirozzi et al., 2020). Due to their edible nature, and their antifungal and preservative potential, essential oil of sweet orange peel and chitosan-based coatings can be used to extend the shelf life of tomatoes (Sheikh et al., 2021).

Plant extract

Plant extracts were used as an alternative to synthetic fungicides because of its more acceptance and less hazardous impact (Nazzaro et al., 2000). A study showed that, the aqueous extracts of Chamomile (*Anthemis nobilis* L.) and malva (*Malva sylvestris* L.) at 0.92 and 0.6 g/ml, respectively retarded the growth of four tested fungi *Aspergillus candidus, A. niger, Penicillium sp., and F. culmorum,* (Magro et al., 2006) on tomato fruits.

The crude ethanolic extract of *Thevetia peruviana* were found effective, against some test fungi (*A. niger* and *Penicillium* spp.) showing 50% of reduction in radial growth (Ravikumar Patil et al., 2007). It is reported that, *Vernonia amygdalina* used as an antifungal agent for the control of plant diseases. Thus, the recent study showed that *V. amygdalina* ethanol extracts have a good ability in controlling postharvest fungal pathogens *Rhizopus stolonifer* and *Fusarium moniliforme* (John et al., 2016). *Annona muricata* fruit extracts inhibited the mycelial growth of *Alternaria alternata*, which is the causative agent of black spots of tomato fruit (Rizwana et al., 2021). However, nanoemulsion formulations derived from *Vernonia amygdalina* leaf extract inhibited the mycelial growth of the *Botrytis cinereal,* which causes grey mold of tomato (Yusoff et al., 2021).

CONCLUSION

Horticultural techniques are thought to play a great role in our daily life. Inappropriate production, harvesting, packaging, handling and transportation all contribute to bad product quality, that's why postharvest treatment is required. In order to mitigate postharvest losses of tomatoes, there is a need for better handling, packing and transportations. The major postharvest losses in tomatoes reported by farmers, contractors and retailers during early maturity before and after harvesting mainly occurred due to wind velocity, poor packing, handling and transportation. Per year loss in tomatoes production is estimated to be 40%, which results in lesser supply and ultimately causes increase in the cost of the commodity. Thus, postharvest losses of perishable commodities cause a great effect on the agro-based economy. In this situation, several strategies are formed for the maintenance of good quality and production of fruit. From the findings of several researchers in the present review, it can be concluded that physiological, chemical, biological and botanical treatments relatively show good result and might be useful in particular circumstances for common postharvest treatment of tomatoes. Botanical and biological controls are alternative methods of chemical control of postharvest disease of tomato because use of synthetic fungicides is not allowed in organic farming and study of alternative methods to control postharvest decay has developed over several decades, along with the demand for safer storage methods.

Thus, keeping this in mind there is need of a bio-preservative which is safe, biodegradable and eco-friendly in nature, Essential oils and Chitosan is best biologically safe and edible preservative for fruits and vegetables because of its non-toxic, film-forming, antimicrobial and biodegradable properties. It also maintains the nutritive value of treated food material. The significance and future aspect of present work will be that plant derived bio-preservative used to prevent the postharvest losses in tomato as a sole or in integrated approach.

ACKNOWLEDGEMENT

The authors wish to thank the Head, Department of Botany, DDU Gorakhpur University, Gorakhpur, for providing the necessary library facilities.

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