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Maintaining quality and extending the Post-Harvest Life of Tomato (*Lycopersicon esculentum* Mill.)

B. Pandey[1], S.Shrestha[1] and B.P.Mishra[2]

[1]Agriculture and Forestry University, Chitwan, Nepal

[2] Nepal Polytechnic Institute (Purbanchal University), Chitwan, Nepal

Abstract

Tomato (*Lycopersicon esculentum* Mill.) is one of the most important vegetable crops grown and consumed extensively throughout the world. Owing to its wide consumption it has very high nutritive value. Tomato is a high water containing horticultural commodity and therefore is highly perishable in nature. It is prone to several losses during its harvesting, post harvest handling practices, transportation, storage and marketing. It is estimated that post harvest losses in tomatoes ranges from 25-42% globally. From various investigations it has been found that the quality of harvested tomatoes cannot be improved but only be maintained after harvest. Similarly, the post harvest storage life can be extended through proper post harvest handling practices and various treatments methods. It has also been discovered that the post harvest quality of tomatoes not only depends upon the post harvest handling operations like physical handling, pre cooling, cleaning and disinfecting, sorting and grading, packaging, transportation, storage temperature, storage humidity and combination of different gases but also on some pre harvest factors like cultivar type, fertilizer application, irrigation, pruning, maturity stage at harvest, methods and time of harvesting. Furthermore post harvest life can be enhanced through various post harvest treatment methods like heat treatment, refrigeration storage (cold storage), CA storage, MAP, $CaCl_2$ treatment, use of ethylene inhibitors (1-MCP) ,growth regulators (GA and 2,4-D), and tomato wax treatment.

1. Introduction

Tomato (*Lycopersicon esculentum* Mill.), of all the horticultural produce, is the second important horticultural crop next to potato in terms of global production by weight [1]. It has become an integral part of human diet. It is extensively used in daily foods. It has diversified uses. It can be consumed as fresh salads or cooked with other vegetables. Similarly its processed forms like sauce, juice, ketchup, tomato soup, etc. are very common. Canned and dried tomatoes are widely consumed all over the world. In 2012, world production of tomatoes was estimated to be 162 million tonnes on 4.8 million hectares of harvested land area globally, with China accounting for 50 million tonnes, followed by India with 17.5 million tonnes [2]. The global production of tomatoes is in increasing trend.

Owing to its wide consumption it has very high nutritive value. Tomato is rich in minerals, vitamins, essential amino acids, sugars and dietary fibres [3]. Tomato is considered to be a good source of vitamin C. In addition tomatoes contain vitamins A, B, E and K, minerals like magnesium, manganese, phosphorous, iron, potassium, etc. and other constituents like lycopene and water. A tomato fruit

contains about 94.5% water per 100 g of fresh weight, 16% protein per 100 g of dry weight, 71.27% carbohydrate, 21.82 % of total dietary fibre, 15145.45 IU of Vitamin A and 230.91 mg of ascorbic acid [4]. Tomato is a high water containing horticultural commodity and therefore is highly perishable in nature. It is prone to several losses during its harvesting, post harvest handling practices, transportation, storage and marketing. Because of inadequate ideas and techniques in harvest handling, packaging, transportation and storage, there occurs a substantial loss both in quality and quantity of fruits. It is estimated that post harvest losses in tomatoes ranges from 25-42% globally [5].

There are various factors affecting post harvest losses in tomato fruits. Being climacteric fruit, losses occur due to natural ripening that can happen even after harvest because of ethylene production. Improper handling during harvest, packaging, transportation and storage also lead to various quantitative and qualitative losses. Cultural practices like types of nutrient, irrigation, pruning, maturity stage of harvesting and harvesting time and methods influence both pre- and postharvest quality of tomato [6]. Many postharvest quality losses are as a result of many pre harvest factors [7]. Water loss from harvested fruit produce is predominantly caused by the amount of moisture (relative humidity) present in the ambient air [8]. The quality of damaged, rotten, defective, diseased and infected, poorly irrigated and fertilised tomatoes or tomatoes of poorer quality before harvesting can never be improved by any postharvest treatment methods [9]. Thus it can be summoned as the post harvest qualities of the fruit cannot be improved after harvest but can only be maintained. So in order to maintain high quality fruits after harvest focus must be given towards managing various pre harvest factors whilst using appropriate post harvest management techniques and treatment methods. This paper discusses about various pre and post harvest factors governing fruit quality after harvest and about various post harvest handling practices for maintaining the quality of fruits after harvest.

2. Factors affecting post harvest quality of tomato:

2.1 Pre harvest factors:

2.1.1 Cultivar Type: The fruit quality of tomato is dependent on cultivar type. The differences in sweetness, sourness, and overall flavour intensity among the fruits are due to the differences among genotypes of tomato fruits in terms of sugar and acid contents [10]. Firmness at harvest and softening pattern determines the post harvest quality of fruits. And these parameters are genotype dependent. Cultivars that can maintain firmness after table-ripe stage can be harvested at later stages. This helps to obtain the better flavour of fruits. Different cultivars differ in their characteristics and are famous for their own quality parameters. Some are more resistant to diseases and pests while others have higher sugar content, some have lower weight loss on storage and some have appropriate shape and size that are appealing to the consumers, some have higher storage life, etc. So for obtaining good quality tomatoes, care must be taken while selecting the cultivars. Improper selection of cultivars may lead to lower yield and the lower quality of fruits that subsequently leads to poor post harvest qualities. Various studies have been made

on the influence of tomato cultivar on postharvest quality traits stored under different conditions. It was found that the tomato cultivar Roma VF has higher sugar content with lower weight loss as compared to the cultivar Marglobe [11,12]. Thus, cultivar selection is one of the critical factor governing the postharvest quality and storage life of tomatoes.

2.1.2 Fertilizer Application: Appropriate dose of fertilizers is very essential for proper growth of plants and production of higher quality fruits. Various research efforts have been made regarding the influence of fertilizers on the quality of fruits produce. Adequate application of potassium fertilizer has been found to improve the fruit colour and reduce the incidence of yellow shoulder [13] whilst enhancing the TA of the fruit [14]. Excessive supply of nitrogen fertilizer has been found to reduce the fruit quality by decreasing the sugar content of the fruits [14]. It also interferes with some important fruit qualities like TSS [15], glucose, fructose and pH [16]. However lower supply of nitrogen has been found to improve fruit flavours [17]. Boron deficiency leads to reduction in firmness of the fruit [18].Similarly calcium has a major role in fruit qualities of tomato. Blossom end rot disease is caused due to its deficiency. In some studies calcium is found to be helpful in prevention of some diseases [14].It also helps in slowing down the rate of loss of firmness of fruit. The fertilizer requirements of tomatoes are high and rate of application depends upon the soil fertility status.

2.1.3 Irrigation: Since tomato is not a drought resistant crop, water deficiency during its critical growth stages results in poor yield and low quality fruits. In a study carried out by Mitchell et al., it was found that the shortage of water reduced the accumulation of water in fruits and the fresh fruit yield was also reduced whereas TSS content of fruit was increased [19]. They also revealed that early morning irrigation every three days resulted in higher yields than daily irrigation. So for obtaining good quality fruits post harvest, irrigation at critical growth stages is essential.

2.1.4 Pruning: Pruning is another important practice which determines the quality of fruits. Excessive number of flowers and fruits should be avoided in order to reduce the competition between them for nutrients. This leads to the diversion of nutrients or assimilates to fewer sinks and subsequently there is increase in fruit size [20] and in some cases, there is increase in sugars and TSS content [21]. However, the effects of pruning on TSS depends on a number of variables including the fruit-to-leaf ratio (or fruit load), before and after pruning, truss position, sink developmental stage, and genetic background [20]. Pruning helps in obtaining bigger sized fruits that are considered appealing to most consumers.

2.1.5 Maturity at harvest: Being a climacteric fruit, tomato can be harvested at any stages of maturity between immature green and fully ripe stage. Harvesting at different maturity stages has its own advantages and disadvantages during post harvest storage. Harvesting at proper maturity is a major determinant of the post harvest fruit quality (flavour, firmness, pH, shelf life, etc.).Tomato harvested at immature green stage will have poor ripening and poor post harvest quality. When harvested at mature green, it

will have sufficient time for ripening and as a result it has longer post harvest life. The shelf life of all tomato cultivars is longest when harvested at mature green stage [22]. Shelf life is not the only concerning attribute regarding post harvest quality of fruits. Fruit nutritional value, flavour and appearance also play a major role. Fruits harvested at immature green or mature green stage will not attain better flavour upon ripening and have lower nutritional value. On the other hand tomatoes harvested later than mature green stage will attain better flavour and will be less susceptible to water loss because of their better developed cuticular layer [23]. Nutritional value of fruit increases if harvested later than mature green stage. Harvesting at later stages also gives sufficient time for accumulation of sugar which increases the risk of mechanical injuries and shorten shelf life as well [24]. It was found that the tomatoes ripened in vine in mother plant will accumulate more sugars, acids and ascorbic acid, and will develop better flavour than mature-green tomatoes ripened off the plant [25]. Tomato harvested in over-ripe stage was shown to have lower ascorbic acid content and higher ascorbate oxidase activity [26]. Intensities of sweetness, saltiness and "fruity-floral" flavour were higher in tomatoes harvested at the table-ripe stage than at earlier stages [27]. Thus tomatoes should be harvested at various maturity stages depending upon the distance of marketing i.e. mature green stage for long distance and fully ripe stage for local marketing.

2.1.6 Methods of harvesting: Tomatoes can be harvested mechanically or through hands. These harvesting methods determine the extent of physical injuries which in turn affect the post harvest quality of fruits. During hand harvesting, fruits should be gently twisted at pedicel without tearing or pulling. For cluster harvesting of vine-ripe tomatoes, whole fruit cluster is cut off from the plants with the help of secateurs, clippers or sharp scissors. Physical damage during harvesting leads to increase in respiration, ethylene production and water loss and makes fruits susceptible to pathogen infestation.

2.1.7 Time of Harvesting: Harvesting time also affects the quality of harvested fruit. It has been found that fruits harvested before 10 AM in the morning yield better quality and lasts longer. Therefore, harvesting in morning within 10 AM is advantageous in controlling the damage due to high temperature.

2.2 Post harvest factors:

2.2.1 Handling: Physical handling of the harvested fruits plays a significant role in determining the post harvest quality. Improper harvesting and mishandling during various steps like packaging, sorting, grading, washing/cleaning, storage and transportation may cause several physical injuries like bruises, scars, scuffs, cuts, punctures, etc. to the fruit. These damages drastically reduce the post harvest quality of fruits. Due to the above mentioned damages, various undesirable physiological changes occur in the fruit such as accelerated transpiration, respiration, ethylene production, pathogen infestation and other unwanted chemical reactions which degrade its quality [28,29]. Further, in a study carried out in Nigeria, it was found that the TSS and TA of fruit with external physical injuries were lower than that of intact fruits on transportation from the area of production to the city market for sale [30]. The best

preventive measure for physical damage is to harvest the fruit in mature green stage when it still can withstand the physical injuries during harvesting, handling after harvest and transportation [31]. Care must be given during post harvest handling operations to maintain the quality of fruits.

2.2.2 Pre cooling: Field heat on fruits after harvest can cause undesirable increase in metabolic activities such as respiration, ethylene production, water loss, etc. This results in loss of quality and storage life of tomatoes. So the field heat should be removed as quickly as possible. To reduce the field heat pre cooling must be carried out. For pre cooling harvested tomatoes can be handled at about 13-20˚C [32,33]. Pre cooling helps in reducing respiration, ethylene production and rate of water loss. It also helps in minimizing the microbial activity and rapid decay of fruits thereby preserving the quality and extending the shelf life of harvested tomatoes [34,35]. In most advanced countries, pre cooling is done through forced air cooling, vacuum cooling, hydro cooling or through icing. But in developing countries, cooling of harvested tomato fruits is done by room cooling or by dipping the fruits in cold water (hydro cooling) or by keeping the harvested fruits under shade house. During hydro cooling disinfectants can be mixed with water such that both field heat and microbial infestation can be reduced.

2.2.3 Cleaning and disinfecting: Tomatoes after harvesting may be filled with dirt and cleaning of these dirty fruits is very essential. These dirty tomatoes reduce the quality and are not appealing to the consumers. Similarly, pathogen infested tomatoes have poor quality and short storage life as pathogen attacks the fruits and decay them faster. Also various food-borne illness and diseases are transmitted via infected fruits. So cleaning and disinfecting are important activities after harvesting of fruits. According to a report by Indian government, a number of pathogens like *Salmonella, Cryptosporidium, Cyclospora, E. coli, Clostridium* sp., Hepatitis A virus, etc. have been found to be transmitted to the consumers through infested fruits [36]. In most under developed and developing countries the practice of cleaning and disinfecting of harvested fruits is not common. However they are mandatory in most developed countries. Tomatoes should be cleaned with water after harvest. For disinfection various chemicals like sodium hypochlorite solution, thiabendazole solution and chlorinated water are common. Sterilizing the harvested tomatoes with sodium hypochlorite solution reduces the incidence of fungal infection [37]. Similarly the microbial load on fruits can be reduced by dipping them in thiabendazole solution [38]. Treating tomato fruits with chlorinated water is also helpful in reducing microbial load. Disinfection of tomatoes by dipping in the chemical treated water not only reduces the microbial load but also maintains the superior quality of tomatoes during storage [39].

2.2.4 Sorting and grading: Sorting and grading are two important processes that determine the post harvest quality and shelf life of tomato fruits. Removing of rotten, damaged, diseased or defective fruits from a batch of healthy ones is sorting. In these diseased, rotten and damaged tomatoes, there is greater production of ethylene which can have significant effects on adjacent healthy tomatoes interfering with quality and

storage life of those healthy ones [40]. Sorting prevents the spread of infectious pathogen from diseased to healthy ones. In grading, the tomatoes are categorised on the basis of shape, size, colour, maturity stage or degree of ripening. Grading in terms of colour is very advantageous for maintaining the post harvest quality and storage of fruits. Over ripe fruits can be eliminated from less matured ones which otherwise would produce ethylene that would hasten the ripening process in whole batch. Proper sorting and grading will give assurance of quality of harvested fruits.

2.2.5 Packaging: Packaging plays an important role in determining the post harvest quality of fruits. Tomatoes must be packed in such a way that they are protected properly. During packaging, care must be given while placing the fruits in the boxes or containers. Generally in most developing countries, it is found that farmers fill the boxes beyond its standard capacity. This over filling may result in increased compression pressure on lower fruits thus leading to different mechanical injuries like bruises, scars, touching marks and other internal injuries. The quality of packaging materials and boxes is also very important. Some packaging materials like nylon sacks do not allow enough aeration causing increased respiration while some have rough surfaces and sharp internal edges which can cause mechanical injuries to fruits. Similarly tall crates or boxes create more compression pressure on lower fruits. In order to minimize the damages inside the box and maintain quality of fruits, cushioning materials like newspapers, gunny bags, rice straw, or other locally available materials should be used. Perforation or ventilation on boxes helps to reduce the losses.

2.2.6 Transportation: Tomatoes after harvesting need to be transported to the market for consumers to gain access of the fruits. Tomatoes are subjected to post harvest losses even during transportation. In developed countries the transportation losses do not account much since handlers use sophisticated refrigerated vans or refrigerated containers and trailers and the roads are in good condition as well. But the condition of roads is very poor in most of the developing countries with several ditches, undulations and rough surfaces. People of developing countries cannot afford such sophisticated modes of transportation. They use low cost mode of transportation such as human labour, donkeys, public transport, rented trucks, tractors, pick up vans, busses, lorries, etc. [12,41]. Due to inaccessibility of sophisticated technologies and vehicles for transporting harvested tomatoes coupled with poor road condition, transportation of harvested tomatoes has become a great challenge in developing countries both for producers and distributers [42]. Also delay in transportation of the harvested fruits also causes losses [43]. Due to transportation delays losses of about 20% occur in tomatoes [44]. During transportation tomatoes must be made immobilized by proper packing, packaging and stacking. Transportation at night can be a better solution to reduce the losses caused by high temperature during transportation.

2.2.7 Storage temperature: Temperature and humidity are the most important factors that determine the post harvest quality (esp. shelf life) of all agricultural commodities. Tomatoes after harvesting are still living and respiring. Since heat stored in field-harvested fruit is the major source of high temperature in the harvested

fruit, time of harvesting of fruit should be carefully considered. Tomatoes after harvesting should be maintained at lower temperature. It has been found that one hour of delay between harvesting the crop and its cooling will lead to one day loss of shelf life [45,46]. Generally to maintain the quality of the fruit it should be stored at lower temperature of about 10–15˚C [47]. Higher temperature results in increased respiration and higher production of CO_2. This will lead to the increased production of ethylene and faster ripening of fruit thus lowering the shelf life of fruit. Increased respiration causes quality deterioration including loss of nutritional value, changes in flavour and texture and weight loss. Keeping the fruits at lower temperature after harvesting will help in lowering the respiration rate, decreasing the ethylene production and reducing the water loss. This helps in alleviating the shelf life of the fruit. Storing at too low temperature is also not good as it may result in chilling injury to the fruits. This chilling injury may result in premature softening, irregular colour development, and surface pitting, browning of seeds, water-soaked lesions, off-flavour development, and increased postharvest decay [48]. Over cooling may result in failure to ripen, development of pits or sunken areas and development of off flavours in fruits [49]. Generally at higher temperature, spore germination, growth rate and other activities of pathogens are high. Storing the fruits at lower temperature can greatly reduce the incidence of pathogens.

2.2.8 Storage humidity: Since tomatoes have very high water content there is great risk of water loss from the fruits post harvest. Loss of water causes wilting, shrivelling and other textural changes in fruits. Water loss depends upon the relative humidity of the storage condition. Lower RH in the storage increases the rate of water loss (transpiration loss) and vice versa. So to prevent the water loss from fruits RH of storing place should be increased. And the most effective way of increasing RH is reducing the temperature of the storage. Alternatively moisture can be introduced into air around the fruits via mists, sprays or wetting the storage floor. The optimum relative humidity for mature green tomatoes is 85-95% and for firm ripe fruits is 90-95% [8].

2.2.9 Gases: Presence of different gases in storage condition can affect the post harvest life of fruits. There must be proper balance between gases in the storage places. It has been found that presence of CO increases the speed of ripening of fruit and thus decreases the storage life [50]. However, CO is commonly used in storage condition as it has been found to be beneficial in slowing down the post harvest pathogenic infestations whilst improving some quality traits of tomatoes. The tomato fruits stored at 5-10% CO and 4% O_2 have superior TSS and TA content than other tomatoes stored under normal atmospheric condition. So it is necessary to have proper balance of CO and with low O_2 to delay the senescence in fruits [51]. Very low supply of O_2 has detrimental effects on fruits as they undergo anaerobic respiration in absence of O_2 [52]. In some other studies it has been found that for maintaining proper post harvest storage life (i.e. inhibiting senescence), the atmospheric air should contain 3-5% O2, 1-3% CO_2, and 94-96% N_2 for mature green fruits and 3-5% O_2, 1-5% CO_2, and 9-96% N_2 for ripe fruits [53].

3. Enhancing the post harvest storage life of tomatoes

The post harvest quality of tomatoes cannot be improved but only maintained by various post harvest handling practices and treatment methods. There are two easy ways for maintaining the quality and extending the shelf life of harvested tomatoes. First one is through proper pre and post harvest management practices which are already discussed above; secondly through the use of various post harvest treatment methods. These treatment methods aim in slowing down the physiological process of senescence and maturation and minimizing the pathogen attack on tomato fruits. Some commonly used post harvest treatment methods are discussed below.

3.1 Heat treatment: Heat treatment is an important post harvest treatment method which is advantageous in many ways. It helps in reducing the chilling injury and delaying the ripening of tomatoes by inactivating the degrading enzymes [54]. It also helps in killing different contaminating insects and controlling fungal attack on tomato fruits [53]. It also has been found that heat treatment is helpful in maintaining the firmness of tomatoes [54,55,56]. Heat treatment can be done via hot air or heated water. Harvested tomatoes can be dipped in hot water prior to storage or marketing. This prevents various post harvest insect, pest and diseases and also improves the peel colour of tomato fruits. In hot air treatment, harvested tomato fruits are subjected to the steam of hot air. The temperature of air or water is adjusted such that it kills all the destructive stages of insects without damaging the fruits. It has been found that heat treatment of tomato at 37-42˚C prior to cold storage slows down ripening process and increases the resistance towards the attack of pathogen during storage [57]. Further TSS and TA content of heat treated tomato fruits before storage at 14˚C have been found to be increased as compared to the untreated tomato fruits [58].

3.2 Refrigeration storage: Tomato is a high moisture fruit. It cannot live for long at the ambient temperature after harvest as water loss is rapid and there is quick shrinking and shrivelling of the fruit. Storing the harvested tomatoes for extended period of time is a great challenge in most of the countries. The rate of deteriorative reactions doubles for every 10°C rise in temperature above the optimum temperature (Van't Hoff quotation i.e. Q_{10}). So higher the temperature higher the respiration rate and the need of post harvest cooling will be even more. Refrigeration is one of the most important methods of maintaining the post harvest quality and improving the shelf life of tomatoes [59]. Refrigeration storage i.e. low temperature storage helps in maintaining various quality attributes of tomatoes like nutrition, texture, aroma and flavour [46]. Low temperature slows down the metabolic activities and the activity of micro-organisms is also reduced. Low temperature decreases the vapour pressure deficit thus increasing the relative humidity of storage condition and as a result water loss from the tomatoes is minimized. But storing of tomatoes at too low temperature is also detrimental to the fruits, storing them at a temperature below their critical temperature of 10°C results in chilling injury to the fruits [60]. Chilling injury may result in pitting, uneven ripening and increased fungal infestation. It is therefore essential to store the tomato

fruits at optimum temperature. In refrigeration storage, tomatoes should be stored at temperature of about 10-15°C and RH of about 85-95% to avoid chilling injuries [47].

3.3 Controlled atmosphere storage: Storing of harvested tomatoes at controlled environment of atmosphere is CA storage. In CA storage, the composition of air surrounding the commodity is made different than that of normal air. Primarily, the level O_2 is reduced while the CO_2 level is elevated in CA storage. Reduced O_2 and increased CO_2 levels affect various physiological processes like rate of respiration, glycolysis, fermentation, ethylene production, metabolism of phenolic and volatile compounds [61]. CA helps in slowing down the rate of respiration, lowering ethylene production, delaying senescence and softening. At lower O_2 (less than 8%) and higher CO_2 levels (more than 1%), the action of ethylene is reduced. Prolonged exposure of tomatoes to O_2 level below 3% or CO_2 level above 5% for more than one month causes irregular ripening of fruits. Concentration of these two gases also affects the decay and pathogenic infestation of fruits. Too low level of O_2 or very high level of CO_2 can have negative effects on tomato fruits. It may cause faster decay and development of off-flavours in fruits. During CA storage, the concentration of O_2 and CO_2 gases is very important.

3.4 Modified Atmosphere Packaging: Modified atmospheric packaging means packaging of harvested tomato fruits in plastic film bags in predetermined composition of gases mainly O_2 and CO_2. MAP aims in limiting the supply of O_2 to the packaged fruits thereby reducing the respiration. The correct concentration of gases mainly of O_2 and CO_2 inside the packages can slow down respiration, senescence and the rate of deterioration thus helping in extending the storage life of fruits [62]. MAP also helps in reducing water loss [63], avoiding mechanical injuries and maintaining sanitation of fruits thus preventing the spread of food borne diseases [64]. Generally concentration of CO_2 is higher than that of O_2 in MAP. The concentration of gases inside the package depends upon perforations, thickness and permeability of plastic films. Plastic film bags are composed of various polymeric materials like polythene (LDP OR HDP), polyethylene terephthalate, polypropylene, or polyvinyl chloride [65], polystyrene [53,66] and some of their derivatives [50]. These plastic films have lower permeability to vapour. The water molecules evaporated from tomatoes will be trapped thus increasing the water vapour pressure inside the plastic package. Once the vapour pressure is saturated or near saturated, the shrinkage of fruit and water loss from it is reduced [38]. But a great risk arises if there is slight fluctuation in temperature which causes the condensation of water vapour leading to sliminess of fruits and microbial development inside the plastics [67]. So creating optimum atmosphere and reducing water condensation inside the package and lowering the weight loss pose a great challenge. Various efforts have been made to solve this problem. Hygroscopic additives, water vapour permeable films, biodegradable films, O_2 adsorbents, CO_2 and flavour releasing agents, etc. have been tried to sort out the problem. But care must be given while adding hygroscopic additives; they should not be used for fresh tomatoes that have high water activity in order to avoid

excessive weight loss. While packaging, the amount of humidity/moisture inside the plastic bags should be taken into consideration during MAP otherwise unwanted mould, fungal and bacterial development will occur [68].

3.5 Calcium chloride ($CaCl_2$) treatment: Calcium is very important element regarding tomatoes. Due to calcium deficiency tomatoes are subjected to calcium related disorders like blossom end rot [20,69]. Post harvest application of calcium can have positive effects on the quality and shelf life of harvested tomatoes. Application of $CaCl_2$ to the harvested tomatoes controls rapid ageing and delays senescence [70,71,72]. It reduces the respiration rate and decreases the ethylene production in tomatoes [73]. Calcium is a major cell wall component and maintains the rigidness of cell wall. So exogenous application of $CaCl_2$ helps in maintaining the cell wall integrity and prevents the cell from the action of degrading enzymes like polygalacturonase [74]. Similarly it also helps in maintaining the firmness and reducing the softening of fruits. The application of 1% $CaCl_2$ in storage condition was found to reduce the fungal and mould attack on tomato fruits [75]. Colour development in tomato fruits was also found to be delayed due to $CaCl_2$ application [15]. Since $CaCl_2$ is easily available, very affordable (low in cost) and preparation and application of $CaCl_2$ solution is very easy, most of the handlers especially in developing countries predominantly use this treatment method for maintaining the quality and enhancing the storage life of tomatoes.

3.6 Use of ethylene inhibitors: Even after harvesting of tomatoes there is continuous production of ethylene which leads to faster ripening and senescence. It decreases the storage life of tomatoes. So the primary objective in post harvest storage of tomato fruit is to minimize the ethylene production in fruits. Various chemicals have been identified that can act as ethylene inhibitors. Some of these ethylene inhibitors include 1- methyl cyclopropene (1-MCP), aminoethoxy glycine (AVG), silver nitrate, silver thiosulphate, cyclohexamide, benzothiadiazole, etc. Among these chemicals, 1-MCP is the most commonly used ethylene inhibitor throughout the world. 1-MCP slows down many metabolic activities associated with ripening such as respiration, colour change, cell wall break down, etc. and helps in extending the shelf life of tomato fruits [76]. Also when 1-MCP is applied to stored tomatoes, firmness of fruits is retained and both the lycopene accumulation and peel colour development is delayed [77]. If tomatoes are vine cut, 1-MCP treatment prevents the abscission and detachment of tomatoes from the vines [14]. Its drawback is seen when it is treated to immature green tomatoes which causes non uniform ripening of fruits [78,79].

3.7 Use of plant growth regulators: Plant growth regulators like gibberellic acid and 2,4-dichlorophenoxy acetic acid (2,4-D) are also helpful in delaying post harvest ripening of tomatoes and extending the shelf life of harvested tomatoes.

3.8 Wax treatment: In a study carried out to study the effect of tomato wax (99% food grade mineral oil + 1% water) treatment on post harvest quality of tomato, it was found that the wax treatment in tomato prevented the moisture loss and reduced the weight loss of

tomatoes [80]. It also slowed down the respiration rate, delayed ripening and enhanced the storage life of fruits. So application of edible coatings on the surface of fruits can help in maintaining the quality and enhancing the storage life of harvested tomatoes.

4. Conclusion

Tomato is one of the most important food crop consumed extensively throughout the world. Due to failure in proper pre and post harvest management of tomato, substantial amount of tomato (25- 42% of total production) has been reported to be lost every year. Storing of the tomatoes for extended period of time with good quality is a great challenge for tomato growers and handlers. It is to be noted that the quality of harvested tomatoes cannot be improved but only be maintained after harvesting. Quality as well as shelf life of harvested tomatoes depend upon both pre and post harvest management practices. Hence there is strong need for proper understanding of various pre harvest practices such as cultivar type, fertilizer application, irrigation, pruning, maturity stage at harvest, methods and time of harvesting and post harvest practices such as physical handling, pre cooling, cleaning and disinfecting, sorting and grading, packaging, transportation, storage temperature, humidity and combination of different gases during storage for maintaining the quality and extending the shelf life of tomato. In addition various post harvest treatment methods have also been developed so as to lengthen the shelf life of tomatoes maintaining good quality such as heat treatment, cold (refrigeration) storage, CA storage, MAP, treatment with $CaCl_2$, ethylene inhibitors like 1-MCP, plant growth regulators and wax treatment.

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