American Journal of Food Science and Technology, 2024, Vol. 12, No. 2, 42-64
Available online at http://pubs.sciepub.com/ajfst/12/2/1
Published by Science and Education Publishing
DOI:10.12691/ajfst-12-2-1

Quality Attributes, Physiology, and Postharvest Technologies of Tomatoes (Lycopersicum Esculentum) – A Review

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Received February 18, 2024; Revised March 19, 2024; Accepted March 26, 2024

Abstract One of the horticultural crops that is grown and consumed extensively worldwide is the tomato (*Lycopersicon esculentum*). Tomato is rich in dietary fibers, phosphorus, iron, essential amino acids, minerals, vitamins, and sugars, which underscores its high nutritional value. From consumer perspective, visual appeal, firmness, taste, and dietary value are the attributes that determine the desirable properties of fresh tomatoes. Quality losses after harvest of tomato are attributed to a complex mix of physiological, pathological, microbiological, and mechanical processes. The rate of physiological processes such as respiration, transpiration and ethylene production markedly affect the rate of senescence in fresh tomatoes. Postharvest handling systems are designed to decrease the consequences of these degradation activities on the quality of fresh tomato. To preserve quality and lengthen storage life, management procedures including plucking, cleaning, sanitizing, initial cooling, sorting, and classifying, packing, storage, and shipping are crucial. Low temperature preservation, modified atmosphere packaging, 1-Methylcyclopropene, heating treatment, ultrasound treatment, UV-radiation, edible coatings are some of the techniques for physical preservation of tomatoes, while chlorinated water, oxonated water, electrolysed oxidizing water are chemical methods. The aim of this review paper was to x-ray the quality attributes of tomatoes, as affected by natural processes of its physiology, and postharvest preservation technologies for fresh tomatoes.

Keywords: *tomatoes, postharvest physiology, senescence, preservation*

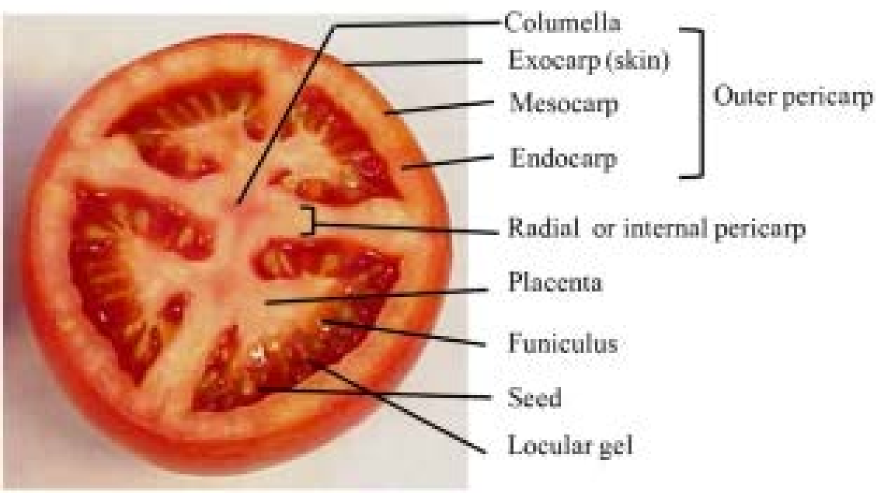
Cite This Article: Uchenna Emmanuel Umeohia, and Abiodun Adekunle Olapade, "Quality Attributes, Physiology, and Postharvest Technologies of Tomatoes (Lycopersicum Esculentum) – A Review." *American Journal of Food Science and Technology*, vol. 12, no. 2 (2024): 42-64. doi: 10.12691/ajfst-12-2-1.

1. Introduction

Among the most significant commercial and dietary crops grown all around the world is the tomato (*Lycopersicum esculentum*), which is known for its luscious fruits [1]. Tomato is native to seashore areas up to the Andean piedmont in western South America, with Peru as its main growing region. This extended south and then to the northern part of Chile and Ecuador-north to central [2]. The indigenous people later spread tomato into the present Colombia, Mexico, south American nations, and Plurinational State of Bolivia [3]. Presently, this specie of tomato is cultivated worldwide from sea level to height 4000 meters [4]. Several other associated species are also seen South America within the same areas. The tomato is a beneficial horticultural produce that is cultivated and consumed all over the world. It gives the body a wide range of nutrients and other health advantages. Losses after harvest make production of tomatoes in developing countries unprofitable. The losses are because of improper harvesting, excessive field heat, poor sanitation, improper packaging materials, inadequate access roads, the wrong type of transportation system, lacking facilities for processing and trustworthy market data.

2. Structure of Tomato

Modern market tomato varieties for processing and direct consumption into other economic by-products are predominantly red and come in various fruit shapes, sizes, and colours. These includes small type otherwise known as "cherry" and grape-shaped-like tomatoes commonly referred to as "grape" tomatoes and, the large, spherical tomatoes, tomatoes with pear shape, and oblong "roma" or "plum" tomatoes [4]. The tomato is a berry made up of two (2) to quite a lot of carpels. The seed are carried on the stalks of the placenta which is around locules. The seeds are also enveloped by the gel at the locule. All these are housed inside a fleshy pericarp as depicted in Figure 1.



Source: Ramesh *et al*. [5]

Figure 1. Anatomy of tomato fruit structure

3. World Tomato Production Statistics

The FAO reported in 2020 that the production of tomatoes in the world stood at 189,133,955 tonnes. According to this report top six producers of tomatoes are China, India, Turkey, USA, Italy, and Egypt as seen in Tables 1. Tomato is an essential and among the most prevalent horticultural commodities cultivated globally. *Lycopersicon esculentum* ranked first in the world production of vegetable in terms of weighted quantity in metric tonnes [6].

Table 1. Highest producing countries for tomatoes in 2021

Rank	Country	Production (Tonnes)
1	China, mainland	67538339.77
2	India	21181000
3	Türkiye	13095258
4	United States of America	10475265
5	Italy	6644790
6	Egypt	6245787.13
7	Spain	4754380
8	Mexico	4149240.67
9	Brazil	3679160
10	Nigeria	3575968.23
11	Iran	3392153.48
12	Russia	3059885.4
13	Ukraine	2444880
14	Uzbekistan	2206641

Source: FAOSTAT [6]

Notably, in terms of value and quantity consumed, tomato fruits are now one of the top horticultural produces [4]. The fresh tomato fruit is highly susceptible to deterioration with poor postharvest handling practices, storage, and transportation condition. Therefore, appropriate preharvest and postharvest management practices are non-negotiable for high product quality, and success in the market [7]

Nutritional value and fruit composition of tomato

In addition to high economic importance with regards to the status of cash and industrial crops, tomatoes possess nutrition components valuable to nourish the body [8]. Tomato is rich in dietary fibers, phosphorus, iron, essential amino acids, minerals, vitamins, and sugars. The Table 2 presented fifteen major nutritional components and their respective amounts that can be derived from eating a 100g of ripe tomato fruits.

According to USDA National Nutrient database, 100 g of fresh tomatoes provide 28% recommended dietary allowance (RDA) for vitamin A. The This is attributed to high presence of provitamin A compounds in the forms of different carotenoids. Beta and alpha carotene are the primary precursors of vitamin A. Similarly, about 21% is recommended dietary allowance (RDA) for vitamin C can be provided by 100 g fresh tomatoes [9]. The fibers are majorly located at the structural parts of the tomato fruits and represent 1g in 100g fresh weight, which meet about 3% recommended dietary allowance (RDA).

Table 2. Selected nutritional value of tomatoes (roma type)

Nutrient	Amount/100 g
Protein (gram)	0.7
Total lipid (fat) (gram)	0.42
Carbohydrate (gram)	3.84
Fiber, total dietary (gram)	1
Calcium (milligram)	10
Iron (milligram)	0.1
Magnesium (milligram)	8.1
Phosphorus (milligram)	19
Potassium (milligram)	193
Copper, Cu (milligram)	0.032
Vitamin C, total ascorbic acid (milligram)	17.8
Niacin (milligram)	0.533
Vitamin A, RAE (microgram)	24

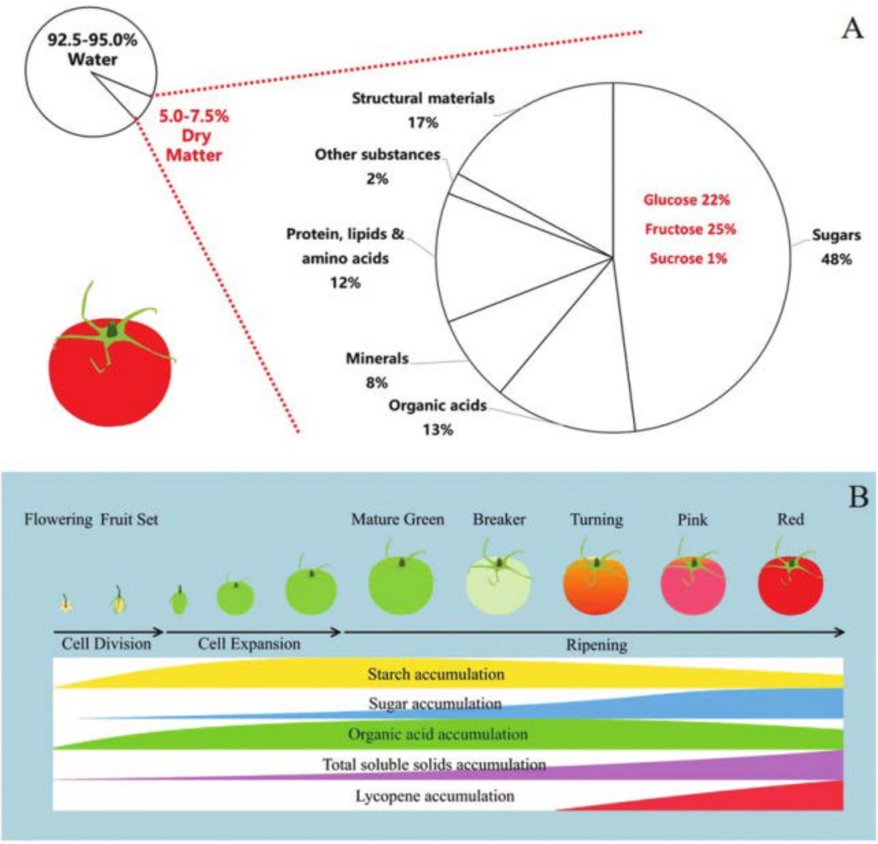
Source: The United State Department for Agriculture, National Nutrient Database [9]

In terms of composition, tomato fruits have only 5 to 7.5% solids; close to 95% of the fruit is water. Of about 5 to 7.5% solids in fresh tomatoes, more than half are sugars, and about one-eighth are organic acids. These two components are extremely important to tomato flavour. Elevated sugar levels and comparatively elevated acid contents are needed for full flavour. Elevated acids and small sugars bequeath a tart tomato, which is not desired by the consumers [10]. Conversely, elevated sugars and little quantity of acids do not give a sweet tomato but a bland one. This is because the sugar levels in tomatoes are usually insufficient to bring about a sweet taste. If both sugars and acids contents of the fruits are small, the outcome is a tasteless, bland tomato fruit. The composition of dry matter in *Lycopersicum esculentum* fruits is illustrated in Figure 2. As tomato develop from mature green to red ripe stages, there general accumulation of starch, sugar, organic acids, total soluble solids, and lycopene content. On the order hand, there is decline in chlorophyll, pectin, and acid content of the tomatoes from mature green to red ripe maturity stages [10].

4. Tomato Cultivars

Tomato is a berry with many loci, grooved or smooth, having many shapes ranging from round, elongated, pear-shaped and varies in shades from green to red based on the degree of maturity and ripeness. The choice of cultivar for tomato plant is based on ease of germination, ability to withstand cold, lack of defects, uniformity, reduced axillary buds, resistance to diseases and pests. On the other hand, homogeneous size, shape, and colour, consistency, resistance to cracking, and good taste, little seed, uniform calibrate, and ability to transport and conservation are some of the desirable qualities of the tomato fruit. Around 7500 different tomato varieties exist globally. The popularity of heirloom tomatoes is increasing, especially among growers at home and farmers who do organic cultivation system. This is because of its ability to produce more intriguing and flavourful harvests while still being disease resistant.

In general terms, tomato varieties are categorised into two key groupings according to shapes, viz: oblong and round. Oblong variety has smaller cross section compared to the longitudinal diameter. On the other hand, round variety has less longitudinal diameter when compared with the cross-section. Table 3 show four major type of tomatoes.



Source: Hou *et al*. [10].

Figure 2. Composition of dry matter in tomato fruits

Table 3. Four major types of tomatoes

Picture	Name	Characteristics
	Round Tomato	The most common tomato kinds are round tomatoes, which have two or three locules, a round form, with a typical weight of 70 to 100 g and diameter ranging from 4.7 to 6.7 cm. Utilised as a salad element, in baking and frying. Also used in grilling, soups, and sauces.
	Cherry Tomato	Compared to traditional tomatoes, cherry tomatoes are smaller, weighing between 10 - 20 g and measuring between 1.6 and 2.5 cm in diameter. Cocktail and cherry tomatoes are similar in high levels of sweetness but differ in that cocktail tomatoes are larger than cherry tomatoes. Although cherry tomatoes are often red. Some other types have yellowish, orange, and golden colour. It is normally cooked or taken raw.
	Plum and baby plume	The classic oval form of a plum and baby plum tomato is their unique property, but the plum type is bigger. In the center, the flesh is less luscious and harder. Plum and baby plum tomatoes are processed for use in barbecues and in pizza and pasta meals.
	Beefsteak variety	Compared to traditional round tomato type, beefsteak variety is larger in size. It has characteristic >= 5 locules and weighs between 180 and 250g.

Source: Pinheiro [11]

5. Tomato Quality

A wide range of tomatoes in all sizes, colours, and forms are now available on the fresh market. The varieties having round, and reddish flesh are perhaps the commonest, but there are also yellow and orange round varieties in addition to cascade (that is, ripe while still attached to the vine and marketed in a clump alongside the stem), plum (a roma-style tomato), and the little red varieties like mini-pears, cherries, and grapes that can be found in the produce market [12].

Quality characteristics of fresh tomato implies many things to various people.

- It's important to farmers and exporters that their tomatoes look excellent and have minimal cosmetic flaws. They, however, place a high value on production, resistance to disease, ease of harvest, and transportation qualities in a viable tomato cultivar.
- Recipients and marketplace dealers place a high value on aesthetic appeal, and they are also quite concerned with stiffness and lengthy storage stability.
- Customers define premium tomatoes as those that have a pleasing appearance, are hard, and have nice flavour and nutritional content. Customers purchase based on sight and feel yet satisfying them requires high-quality food [13].

Therefore, from consumer perspective, visual appeal, solidity, taste, and dietary value are the attributes that determine the desirable properties of fresh tomato. This is because consumers buy tomatoes essentially centered on outward show or appearance. Fruit should indeed be fully developed, uniformly coloured from orange to crimson or to deep red, without greenish shoulders, and with a smooth look [12]. Quality components that are important for tomatoes are both external (colour and texture) and internal (flavour and nutritive value) (Table 4).

5.1. Colour

The utmost vital quality parameter that affects appearance of tomato is colour. Pigmentation of skin and flesh determine colour [14]. The colour of tomatoes varies from green at the unripe/immature stage and to deep dark red when in full maturity. Apart from the popular red colour, tomatoes are available in pink, yellow and orange colours. Whereas a tomato that is orange could be because of yellowish skin and reddish flesh, a pink tomato may be attributable to red flesh and uncoloured skin [15]. Lycopene and phytoene are the most abundant of the pigments in ripened tomatoes. While lycopene is reddish in colour, phytoene is colourless. The red colour of tomatoes and its health promoting antioxidant properties is attributable to lycopene pigment. Thus, breakdown of lycopene is relevant from the perspective of both health and organoleptic quality of tomatoes. The major cause of degradation of lycopene is isomerisation and oxidation. This is because lycopene in fresh tomatoes occurs majorly in trans-configuration. This makes them susceptible to degradation processes [16]. This change in colour is correlated to the lycopene content of tomatoes. Significant increase in concentration of lycopene have been observed from full-grown greenish phase to reddish phase in tomatoes [17]. Fresh tomatoes typically have a lycopene level of 30 to 50 mg per kg, although vivid red types have > 150 milligram per kilogram and the yellow cultivars have only around 5 milligram per kilogram [18]. The kind of tomato, the level of maturity and the surrounding circumstances in which the fruit ripened all have an impact on how much lycopene is present in fresh tomatoes.

Stem end of the fruit contains higher carotenoids and lycopene concentration when compared to the blossom end [19]. Also, the concentration of lycopene was found to be dependent on the season of the year as higher amounts were observed in warm weather tomatoes than in their wintertime counterparts [20]. Gould [21] reported that tomatoes collected during the green maturity phase and subsequently ripened during storage, typically possess decreased quantities of carotenoids when compared to the ones ripened at the vine. This is a result of the fact that fruits that have been allowed to mature in storage are not subjected to the ideal temperature needed for the formation of the pigments. Also, environmental factors within the plant where the ripening of the fruits occurred could limit the colour development while on the contrary, lycopene synthesis can be promoted by optimizing certain circumstances around the produce after postharvest [14]. Presence of ethylene gas in the environment of fresh tomato after postharvest promotes lycopene formation, while in contrast ethanol suppress lycopene production [22]. Ideal harvesting season, fertilizers and choice of varieties can also enhance lycopene content of fresh tomato [23].

Table 4. Quality components of tomatoes

Major factors	Components
Appearance (vision)	Size: dimensions, weight, volume Shape Colour Defects: physical, physiological, pathological
Texture(feel)	Firmness, softness
Flavour (taste, smell)	Sweetness Sourness (acidity) Aroma (volatile compounds) Off-flavours and off-odours
Nutritive value	Carbohydrates Proteins Lipids Vitamins

Source: Salunkhe *et al.* [24]

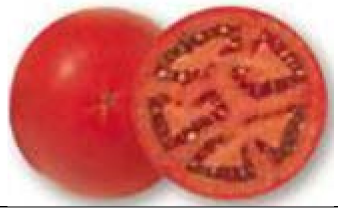
Different empirical techniques have been postulated to explain the relationship between the visual perception and measurement of colour in tomatoes. One of such propositions was put forward by Shewfelt *et al.* [25], who proposed that gauging of colour is directly associated with how consumers visually percept tomatoes. By this proposition, surface colour of tomatoes can be measured using tristimulus colorimeter, otherwise known as the Hunter method. Tristimulus colorimeter provides three values for each colour measurement. These values are derived from three scales defined as *L**, a*, *b** (CIELAB) [26]. "*L**" represents brightness/lightness on a scale 0 - 100, with 0 being absolute black and hundred (100) being perfect white. On the horizontal axis, the "*a**" scale progresses from green (i.e., negative values) to red (i.e., positive values). On the vertical axis, the scale "*b**" covers the range from blue to yellow. Yellow is represented by a positive "*b**," and blue by a negative "*b**". Lower *L** values, a shift from *-a** to *+a** values and reduced *+b** values are indicators of colour space alterations when tomatoes transform from green to red [27].

In addition, calculation of hue angle (h°) has been postulated as an effective and more appropriate method to determine the extent of colour development and ripeness in tomato. The hue is the actual colour (for instance, red, yellow, blue, etc.), which is useful for visualizing the colour appearance of food products [26]. Pure green is represented by a hue of 180 degrees, and pure red by a hue of 0 degrees [25] and is calculated from the arctangent of *b**/*a**, designated h° as shown in Figure 3. Arctangent, on the other hand, anticipates that the first and third quintiles will have positive number, whereas the second and fourth quintiles will have negative numbers. For a useful interpretation, h° should be a positive value between 0° and 360° [15]. The best objective means of ripeness is provided by the hue angle. According to Shewfelt *et al.* [28], the ripeness stage of tomato can be represented by a corresponding hue angle providing opportunity for empirical differentiation and identification. Shewfelt *et al.*, [28], proposed classification of ripeness stage of tomato as thus: 'mature-green' ($h° > 114°$), 'breaker' ($101° < h° < 114°$), 'turning' ($85 < h° < 101°$), 'pink' ($64° < h° < 85°$), 'light red' ($36° < h° < 64°$), and 'red' ($h° < 36°$). Also, Shewfelt *et al.* [28], noted that hue angle at the blossom end was 2-12° lower than at the circumference because of starting of colour development at the blossom end. According to León-Sánchez *et al.* [29], the sensory assessment of colour can frequently be linked to objective measures. Additionally, a variety of arbitrary scales and colour schemes have been established to categorize ripeness in accordance with fruit colour. There are six acknowledged tomato ripening phases, starting from mature green, as indicated in Table 5.

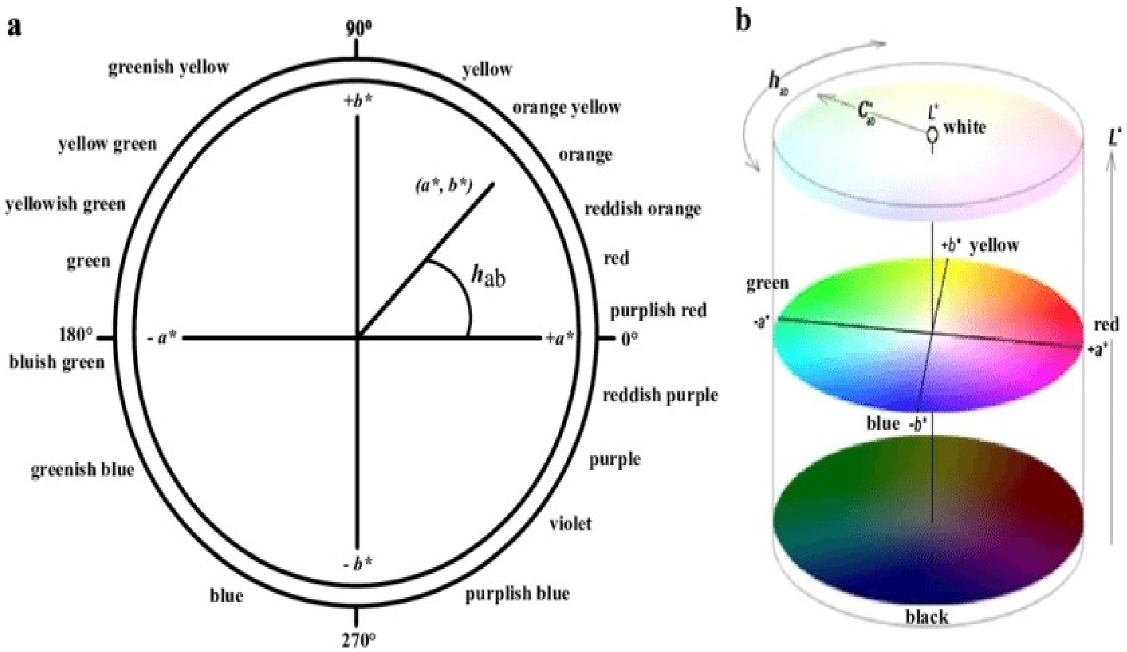
Other empirical measurements of colour of tomato are obtainable. This includes transmittance of light and reflectance methods in addition to pigment (lycopene, chlorophyll, and β-carotene) determination by chemical techniques. Colour measurement using portable chroma meter on *L**, *a**, *b** system. Different colours as it relates to hue *a** and *b** colours are shown in Figure 3.

Table 5. Classification of tomatoes based on degree of ripeness

External Colour	Ripeness stage	Characteristics	Colour Change	Percentage colour change
	Mature green	Fully matured seeds. Evidence by resistance to cut on slicing. Formation of locular jelly-like substance	Greenish	NA

	Breaker	First pigmentation of red appears	Green to red, pink or tannish yellow	<10%
	Turning	Start of visible change in colour in the internal locules of the fruit	High degree of change from green to red, pink, or tannish yellow	> 10% <= 30%
	Pink	Deeper and larger portion of pink or red colour.	Pink or Red	> 30% <= 60%
	Light red	Penultimate ripening stage	Pinkish red or red	>60% < 90%
	Red	Last stage of ripening	Reddish	>90%

Source: Yahia and Bretch [15]; Pinheiro [11]



Source: Maximiliano *et al*. [30]

Figure 3. Hue angle, *a** and *b** colour chart

5.2. Size and Shape

Another important appearance attribute of tomato that affects consumer perception is size and shape. The shape of tomato varies between cultivars. Spherical, oblate, elongated or pear-like are the most common shape of tomato. Notable, fruit ripeness and flavour are not affected by shape. Defects in shapes are caused by irregular development of some of the locules and poor pollination, Preharvest defects in tomatoes includes but are not limited to irregular ripening, sunscald, radial and concentric growth syndrome, bug stains, bloating, catfacing (a fruit goldfleck deformity with a wrinkled appearance and brown scars), or pox syndrome [15].

5.3. Texture

This is another vital quality features that affects overall acceptability by consumers and preferences of tomato. A firm tomato is desirable by the consumer. There is close relationship between rigidity, quality and as well as ripeness of tomato. Picking of tomato fruits that can sustain sound firmness further than the table-ripe phase can be deferred till advanced stage of ripeness. This practice can confer on the tomatoes better flavour development [15]. Among the factors that can affect firmness of tomato are mineral nutrients, cultivar, irrigation, water content and tugor, relative humidity, cell wall composition, temperature, and ethylene. The hardness of tomatoes declines as they mature. Because of this, ripe fruit is more tender than matured, green tomatoes [31]. A fit for consumption tomato ought to be rigid and resistant to deformation brought on by over ripeness-related softness [12]. Fruit firmness, the fruit internal structure (ratio between amount of pericarp and locular tissue), and skin toughness (cuticle thickness), to large extent influence the fresh tomato texture [32]. The flexibility of the seed coat tissues, the robustness of the cell walls, and the enzyme activities that causes fruit to soften during the ripening activity may all affect how rigid (firm) it is [31].

Measurement of firmness of tomato using objective techniques can be achieved by measuring resistance to penetration force using fruit firmness tester or penetrometers or by resistance to force of shearing using shear press as well as by compression and/or cutting [33]. These techniques are destructive and therefore the need for non-destructive approach for the measurement of firmness of tomato is required. Measurements of the fruits' resistance to compressive force exerted at a one or numerous places are used to do this.

The tomato fruit softening enzyme activities, pericarps tissue extensibility, cellular wall tissue stability, including the degradation of pectins are correlated to tomato firmness. Degradation of cell wall during fruit softening has been attributed to be caused by polygalacturonase (PG), though Wang *et al*. [34] noted that substantial fruit softening is not prevented by genetic suppression, reduction of PG mRNA buildup, or its enzymatic activity, suggesting that there are other factors responsible for fruit softening. Apart from PG, pectinases are implicated in demethylation of the pectins in the cell walls of a commodity and facilitate hydrolysis of the cell walls by polygalacturonase [15].

In addition to PG and pectinases enzymes, β-galactosidases and expansions contribute to fruit softening. Though expansions do not have hydrolyitic activities, they have been implicated to be responsible for depolymerisation of pectin and their influence on hemicellulose and cellulose cell wall linkage by the hydrogen bonds. This results to the swelling of the cell walls and increase in porosity for degradative enzymes, with consequent attack by them in the substrate fruits [35].

5.4. Flavour

Flavour is a vital attribute that impacts eating quality of tomato. The components of flavour included complex mix of many taste and aroma constituents. Tomato eating attribute is a vital element that impact on the consumer acceptability. This in conjunction with colour and firmness. To choose for a tasty combination of sweet and sour characteristics in tomatoes, measures of TSS concentration, sugar-acid proportion, and acidity are also utilized [36]. The primary monosaccharide in tomato fruits—fructose, glucose, and sucrose—are what give the fruit its level of sweet taste. However, sour taste is caused by organic acids like citrate and malate acids. The complex interactions between the sugars and organic acids gives rise to the ultimate threshold of the tomato flavour [37]. For the optimum flavour, there must be both an elevated sugar level and a somewhat elevated acid concentration. On the extreme ends, a tart tomato is produced with elevated acid with decreased sugar content, while bland taste and tasteless tomatoes is because of high sugar with low acid content. Also, low sugar and low acid will produce insipid flavoured tomato [15]. Stevens *et al*. [38] reported that compared to the locular section, the tomato's seed coat has much more small sugars and fewer organic acids. Because of this, tomatoes with big locule sections and elevated levels of acids and sugars possess superior flavours than those with tiny locule sections.

The amount of sugar of tomatoes increases as ripening progresses. This happens due to degradation/liquefaction of complex carbohydrate into monosaccharides that accompanies the ripening process. On the contrary, malic acid reduces rapidly as the tomatoes ripen to the red maturity. However, the concentration of citric acid content in the fruits remains unchanged during all stages of maturation [39]. The flavour of the tomato is best described as fruity, and it is connected to decreased glutamic acid content and elevated levels of reducing sugars. According to some research, ethylene and carbon dioxide generation have little impact on the alterations in the acid and sugar quantities of ripening tomatoes [40]. Also, about 30 aromatic (volatile) components have been identified through research to be accountable for giving tomatoes their distinctive smell. Organic compounds such as trans-2-hexenal, β-ionone, 1-penten-3-one, 3-methyl butanol, n-hexanal, cis-3-hexen-1-ol, 2-isobutylthiazole, 3-methyl butanal, as well as other unnamed C12-C16 volatile compounds. Mathieu *et al*. [41] identified the following compounds to be responsible for the aroma of tomato and the intensity of these components upsurge as ripening progresses. These include *trans*-2-hexenal, hexanal, 2- isobutylthiazole, geranylacetone, 2-methyl-2-

hepten-6-one, and farnesyl acetone.

Several factors could be responsible for the lack of tomato flavour. These factors include but are not limited to variety selection based on yield without cognizance of the effect on the flavour, disease resistance, visual characteristics, and slow ripening [42]. Also, picking of fruits when they are not mature, physical damage, ripeness stage, ineffective treatment after harvest, condition of storage, and internal bruising can negatively impact the flavour of tomatoes post ripening. Furthermore, low storage temperature adversely affects the aroma and taste of tomatoes [43].

5.5. Nutritive Value

The attention in the nutraceutical values of tomato and tomato products has intensified throughout the last 20 years. Tomatoes are vital for human health and well-being. Nutritionally, tomatoes are ladened with vitamins, especially ascorbate and Beta-carotene, and antioxidizing agents like lycopene [44]. The fat content, calories and cholesterol is low. Tomatoes is an excellent fiber-rich food source, vitamin A in the forms of beta carotin and a few more carotenoids which are regarded as provitamin A. In addition, tomatoes are ladened with vitamin C, potassium, and lycopene. As a result of these special attributes, tomatoes and products produced from tomatoes are regarded as nutraceuticals [45]. The vitamin C content of tomato is about 230 mg/Kg which is relatively not as high as in other fruits. However, because of the extensive use of tomatoes in daily foods and diets, their importance in providing vitamin C for the body is highly recognized. About 20-40% of the United States highly suggested per day allowance of vitamin A and Vitamin C can be provided by 100g of tomato [15].

Numerous studies had been conducted in the recent past by scientists that translated into the application of several breeding techniques, selections, and biotechnology to grow tomato with improved and high contents of vitamin A and C, carotenoids, and lycopene. In terms of health benefits, studies have shown that tomato fruits have health promoting effects. Risk of cancer, and cardiovascular diseases are shown to be prevented by adequate consumption of tomatoes [46]. Notably, the main component that gives tomatoes their distinctively rich red colour is lycopene. Fresh tomatoes have a lycopene level of 7.2 – 200 mg per kg weight. Approximately 30% of the overall carotenoids in plasma of fresh tomato is lycopene [47]. Unlike other carotenoids found in tomatoes, lycopene is found majorly at the outer portion of tomato [48]. An innate oxygen scavenger, lycopene in tomatoes helps reduce the chance of developing cancer and heart disease. Much evidence from clinical observations supports the micronutrient stand of lycopene due to its relevant health benefits. This is as result of lycopene role in preventing a wide range of cancer in walls of the epithelium [16]. Lycopene, unlike other carotenoids do not have pro-vitamin A activity. Cancer in the gastrointestinal tract is 50% less likely to occur in individuals that consume tomato-based products per day at a level of at least one serving [49]. Apart from the digestive tract, consumption of lycopene has also been linked to a lower likelihood of carcinoma in other locations, for instance, the bladder and the pancreatic organs. Martí *et al*. [50] review of research shows that frequent tomato intake lowers the chances of cancer development in elderly subjects. Up to 34% reduction of the chance of prostate cancer development was reported for 48000 guys who feed ten or greater serving of food made from tomato over a four-year period by Harvard School of Public Health [15]. Vitamin E, flavonoids, and folic acid are other constituents in tomatoes that are beneficial to health [51]. Other pigments which accumulate in the exterior territory of the seed coat and inner pulp are chlorophylls a and b, neoxanthin, violaxanthin, lutein and β-carotene.

6. Impact of Postharvest on Tomato Fruit Quality

The commencement of postharvest period is marked by excision of tomatoes from its parent stock i.e., medium of its immediate growth. Postharvest continues during handling practices and stops when the food item is moved to final preparation stages toward consumption or further preservation [12]. Quality losses after harvest of tomato is attributed to a complex mix of physiological, pathological, microbiological, and mechanical processes. Postharvest handling systems are designed to decrease the consequences of these degradation activities on the quality of fresh tomato. These factors are discussed in detail below.

6.1. Physiological

Physiological factors such as respiration, ethylene and transpiration affect to a very large extent the postharvest quality of fresh tomato. Like every other living plant, cells of tomatoes continue to exhibit arrays of biological processes after harvest. These activities continue from maturity, through ripening, senescence and finally culminate with death. Quality degradation happens due to the inability of the tomato cells to replenish energy and stored materials lost to biological process because it is detached from the paternal plant.

The transpiration, respiration and C_2H_2 gas generation are the usual physiological events that leads to deterioration of fruits and vegetables. At room temperature (20 – 25°C), tomato ripens quickly and consequently deteriorates rapidly. As a result of this knowledge, tomatoes are stored at cold conditions (< 12°C) to retard the physiological processes that accelerate decay. Chilling damage is among the main problems with the deterioration of tomato freshness. The longevity is shortened by these physiological defects and thereby limits the extent of application of cold temperature storge [12]. physiological elements including breathing, ethylene production, and water loss affect to a very large extent the quality of fresh tomato after harvest.

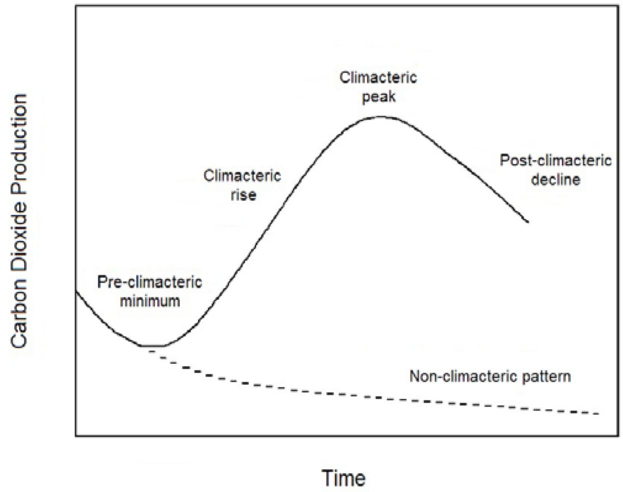
- **Respiration**

Fresh fruits and vegetable maintain life by continuous utilisation of stored food (mostly carbohydrate) to produce ATP, which is a type of energy by process of breathing. As far as the leaves keep creating carbohydrates, the developing plant will always be respiring; it is impossible to halt this activity without harming the plants or the fruits and vegetable produce. Fresh fruits and vegetable cannot replenish carbohydrates or water once it has been harvested. Once stocks of accumulated carbohydrate or monosaccharides are depleted, respiration stops using them; as a result, the product ages and decomposes [52].

Notably, tomato is climacteric in respiration patterns. This means that tomato experience peak in respiration during ripening and possesses the ability to ripen off and on plant. This increase in respiration rate that accompanied ripening caused degradation of stored materials in fruits leading to the ultimate death and quality deterioration of tomato [53].

Pathogen attack, growth regulator, water stress, radiation and light are the types of environmental factors that impact the rate of respiration. The most relevant factors after harvest are physical stress, constituents of the atmosphere and temperature. The temperature of the storage environment is directly correlated to the rate of respiration within the physiological region of the commodity [54]. To slow down quality deterioration caused by increased respiration; fresh tomatoes are subjected to cooling after harvest. Also, other atmospheric composition modifications were invented to decrease the speed of respiration and thereby prolong the storage period of fresh tomato [55].

Unlike non-climacteric fruits, tomato follow climacteric pattern during ripening. Speed of respiration decreased at the beginning of ripening and increase to climacteric peak before decreasing to senescence and ultimate death and decay as shown in Figure 2.5.



Source: Saltveit, [56]

Figure 2.5. The pattern of respiration during repining by climacterics fruits

- **Transpiration**

Like most fresh fruits and vegetables, fresh tomato contains 70-95% water. Owing to vapour pressure differential between the molecules of water interior the tomato and that in its environment, water inside the fruit evaporates to the surrounding leading to shrinkage, weight loss, loss of texture and crispiness (softening), and fading of appearance. This phenomenon resulting to loss of water by fresh tomatoes is referred to as transpiration and leads to wilting. To prevent this quality degradation process, the storage environment of fresh tomato is modified to drastically reduce or eliminate the vapour pressure differential amongst the internal and external environmental conditions of the commodity.

This is done with adequate cognizance of the fact that occurrence of water deposition or condensation on the surface of the fruits would lead to proliferation of spoilage organisms and therefore balance must be struck in application of this principle for tomato quality shelf-life extension. The most favourable R.H during storage and distribution of tomatoes is 90 to 95%, while 75 to 78% relative humidity is most suitable for ripening. Infection by fungi and decay development aggravates with high relative humidity. The suitable R.H of the packing house of fresh tomato should be 85–95% [15], as shown in (Table 2.12).

Table 6. Storage conditions for fresh tomatoes

Stage of Ripeness	Temperature (°C)	Relative Humidity (%)	O_2	CO_2
Green	12.5-15	85-95	3-5	2-5
Light red	7-10		3-5	3-5

Source: Silva *et al*. [57]

- **Ethylene production**

In fruit, the chemical regulator ethylene gas (C_2H_2) controls growth, maturation, and ageing. Climacteric fruits exhibit increased ethylene production as well as an upsurge in the breathing rate at the commencement of ripening. Tomato is a climacteric fruit and undergoes this transition process [58]. Increased ethylene production resulted to accelerated ripening and associated respiration rate, leading to rapid senescence, death, and decay. To increase the shelf life of tomato, activities that encourage excess ethylene production is avoided. Increase in temperature, incidence of injury and ripeness are the factors that favour an increase in ethylene gas production [15]. Ethylene gas has both deleterious and beneficial effects on fruits and vegetables after harvest. These effects depend on a couple of environmental elements and physiological components. Advantageous effects of ethylene include promotion of the development of colour; stimulation of ripening process in climacteric fruit; promotion of citrus fruits degreening; stimulation of seed separation in nuts; alteration of expression of sex; promotion of flower formation, reduction of the permanent displacement of cereal stems from their vertical position [59]. Deleterious impact of ethylene includes acceleration of senescence; enhancement of too much softening of fruits; stimulation of loss of chlorophyll causing yellowing; stimulation of sprouting in potatoes; promotion of negative change of colour (discoloration) such as browning; promotion of dropping of leaves and flowers otherwise known as abscission; stimulation of metabolism of phenylpropanoid [22].

The capacity of postharvest scientists and researchers to design treatment protocols and packing house settings to regulate C_2H_4 during commercialisation warehouse operations and distribution of agricultural crops has significantly increased with better knowledge of ethylene's synthesis route and mechanism of action. To create circumstances that maximise both shelf life and quality of commodity, straightforward approach like temperature control and airflow can be supplemented with more complex ones like modified atmosphere packing (MAP) and suppressors of certain triggered enzymes [59].

6.1.1. Physiological Disorder

The physiological disorder resulting to postharvest tomato quality deterioration is chilling injury. It is an irreversible process observed in plant tissue that results from exposure of chilling-sensitive plants or fruits to temperatures below some critical. Tomato is very vulnerable to chill harm when exposed to temperature less than 12 to 13^{o}C [60]. As a tropical fruit, exposure to low temperature impacts tomato negatively. At temperatures below 10 ^{o}C, chilling injury occurs in ripe fruit. Also, chilling injury affects mature-green fruits below temperatures of 12.5 degrees. The effects of injury from cold temperatures of chilling are cumulative and it is directly proportional to time of exposure and temperature. At storage condition of 5 ^{o}C (41°F) and duration of more than 6 days, tomato fruit is damaged. Increased postharvest decay, off-flavour development, browning of seeds, water-soaked lesions, surface pitting, premature softening, and irregular colour development are the negative consequences of chilling injury on tomato fruits [61]. Tomatoes become weaker since they cannot continue their regular metabolic activities at relatively low temperature. In reaction to cold shock, many physiological and biochemical changes as well as cellular disorders take place in cultivars that are susceptible to cold [62]. These changes include, accelerated breathing rate, elicit of ethylene generation, interference in ATP production, slowing of the movement of the fluid substance (cytoplasm) within the plant, rise in activation energy, increase in permeability, reduction in creation of oxygen and energy in the form of sugar, enzyme deactivation, modification of cellular architecture and membrane dysfunction. If such chilling pressure is prolonged, these changes and disorder will result in the emergence of a range of signs associated with cold stress, including interior discoloration, water-soaking or the inability to ripen properly, skin blemishes, structural deterioration, and off-flavour [63].

6.2. Mechanical Damage

Mechanical damage is a very crucial factor that affects postharvest quality of fresh produce including tomatoes. Fresh tomatoes are susceptible to physical injury during harvest, management practices after harvest, including transportation. Harvesting practices and methods should produce little harm as far feasible. It is crucial to prevent unnecessarily injuring, bruising, smashing, or otherwise harming vegetables by machinery or containers used for packaging [23]. Furthermore, lack of adequate transportation mechanism and packaging in the developing countries contributed immensely to the postharvest loss of tomatoes along physical distribution chain. When loading, discharging, and arranging operation activities, as well as when they are being transported, they might sustain damage [64]. Injuries in fresh tomatoes would induce series of physiological and morphological reactions. The wounds may be visually noticeable and simple to find. The above shows up as discoloration of the skins as well as tissue with odd flavours. Because the surface colour's ability to conceal interior bruises, the lesions may not be apparent from outside [65]. According to FAO (2018), physical damage is a key contributor to post - harvest wastages. As a result, effort should be made to reduce physical stress throughout post - harvest operations. Additionally, physical damage stimulates ethylene gas synthesis and respiratory metabolism in tomatoes, which accelerates ageing [66].

6.3. Pathological/Microbiological

Microbial spoilage constitutes another key factor responsible for postharvest losses in tomatoes. Microbial contamination may occur prior to or following harvest. **Quiescent** contamination, or **latent** contamination, is the scenario in which a commodity becomes contaminated before picking but does not show any symptoms until the microorganisms are revived by the start of favorable environments, such as suitable temperatures or fruit ripening [67]. An excellent semblance of a disease with hidden contamination is anthracnose, which is induced by the fungus *Colletotrichum gloeosporioides*. Because contaminated product is difficult to separate before storage, it frequently results in quick and acute postharvest degradation [68][66]. Due to absence of protection mechanism in the tissue of commodities, coupled with loads of moisture and nutrient that support their growths, microbes easily infect commodities and proliferate quickly [65]. Microbial spoilage is mostly aggravated when the natural fruit skin in tomatoes is damaged through cuts and/or abrasion, leading to creating an entrance for the spoilage microorganisms. Coelho *et al*. [69] reported that post-harvest diseases are mainly caused by fungi development. Over-ripe tomatoes are more susceptible to microbial attach than the matured green counterparts. Microbes, for example Penicillium spp., which are typically not thought of as tomato rot causing agents, might very well infect and damage fully ripe fruits [65]. *Buckeye rot*, *Alternaria solani*, *Rhyzopus stolonifera*, *Botrytis cinerea*, *Alternaria alternata*, *Colletotrichum coccodes*, *and Phytophthora infestans* are examples of fungal infections, whereas *Pseudomonas syringae* and *Xanthomonas campestris* are responsible for bacterial degradation. The following are the most typical degradation issues with tomatoes as listed in Table 5.

Alternaria alternata is the most common fungal pathogen of tomatoes. *A. alternata* can enter fresh tomato before, during and after harvest through wounds and fruit's natural openings [70]. The dematiaceous fungus *A. alternata* is responsible for the black spots on tomato fruit. It is characterized by lesions at the fruit's blossom end or close to the stem scar. They are flat or sunken, and the fungus's sporulating black mycelium typically covers them [15].

The genus *Xanthomonas* encompasses various bacterial species that are responsible for the bacterial spot. This condition is most frequently brought on by *X. euvesicatoria*, a species that belongs to this genus [71]. On leaves and stems, the disease manifests as round to asymmetrically shaped patches with a mild oily texture. The spots are often present at first, but as the lesion spreads, they frequently start to be encircled by a golden halo. The leaves wilt and become brown as several spots combine to grow larger.

Table 7. Pathological disorders of tomatoes

Pathological Disorder	Causative agent	Symptoms	Control/Preventive Measures
Black mould or alternaria rot	*Alternaria alternata*	Lesions at the fruit's blossom end or close to the stem scar. They are flat or sunken, and the fungus's sporulating black mycelium typically covers them.	Prevention of mechanical injury and chilling conditions.
Grey mould	*Botrytis cinerea*	Typically, the damaged tissue is hard, dry, and brown to black in colour.	Application of the proper pre-harvest fungicides, avoiding freezing and physical harm, and using a correct storage temperature are all important considerations.
Bacterial soft rot	*Erwinia carotovora* subsp. *Carotovora*. Also by other pectolytic strains of *Erwinia*,	Areas that are soft and appear soaked with water, that eventually turns to liquid. Leakage of bacterial ooze from thew wounds. Scars on the stem and pores on the styles of the flower.	Control measures include cleanliness to lower population numbers, odors, avoiding unnecessary soaking in dump tanks, minimizing fruit injury, and harvesting fruit with cuts, punctures, huge scars that can allow the disease access, and lacerations
Sour rot	*Geotrichum candidum*	Green tomato fruits that are fully mature have the appearance of pale blemishes that are dull, wet, and have a sour (vinegar) odor. The diseased tissue is u sually black, mushy, and liquid.	A vital preventative approach is to keep mechanical injuries at bay.
Hairy or Rhizopus rot	*Rhizopus stolonifera*	Lesions that are soft, water-soaked, discolored, and smell fermented It's possible to see a thick, white mold that later turns black.	Ensuring proper sanitation in the greenhouse and on the packaging line as well as preventing fruit damage Rhizopus is a fungus that develops extremely slowly at temperatures of 10°C and below.

Table 2.13. Pathological disorders of tomatoes Contd

Pathological disorder	Causative agent	Symptoms	Control/preventive measures
Early blight rot	*Alternaria solani*	Lesions with a dark brown colour that often develop at the fruit's stem end although they can also develop at the blossoming end or along the side. In green tomatoes, the disease appears sunken and leathery.	Treatment of seeds chemically before sowing.
Late blight rot	*Phytophthora infestans*	Lesions that are rigid, lumpy, and reddish-brown may form throughout the fruit, but more frequently towards the stem terminal.	Proper ventilation and lowered humidity
Bacterial speck	*Pseudomonas syringae* pv. tomato.	Lesions that are dark, little (less than 1 mm), and the skin may seem gritty	Seed treatment with hot water or with chemicals and greenhouse sanitation
Phomopsis rot	*Diaporthe phaseolarum* var. *sojae*	Tender lesions that have been wet. The infected tissue may become stiff, shriveled, and black.	One line of defense is to maintain a clean greenhouse and handle things carefully.
Pink mould rot	*Trichothecium roseum* Link	Firm grayish-brown blemishes are seen near the fruit's bloom end. Typically, water-soaked, lesions produce distinctive orange-pink spores when humid circumstances prevail.	Avoiding fruit damage, using suitable storage temperatures, and providing the greenhouse with enough airflow
Pleospora rot	*Pleospora herbarum*	Brown to black blemishes along the stem scar's border or on any fruit parts that have been cut	Careful handling
Ring rot	*Myrothecium roridum*	Lesions that are circular to oval, firm, and somewhat depressed with clearly defined edges This rot penetrates the fruit deeply.	Treating seeds before sowing, maintaining cleanliness in the greenhouse and packing house, and preventing mechanical harm

Source: Yahia and Brecht [15]

7. Postharvest Handling Systems of Tomato Fruit

Harvesting and handling practices can cause injury to tomato fruits. Adequate care must be taken to issue those fresh tomatoes are harvested and handled to reduce physical and physiological injuries. Elevated and low temperature storage damage fresh tomatoes through excessive respiration, transpiration, and chilling injury.

To preserve quality and lengthen storage life, management procedures including plucking, cleaning, sanitizing, initial cooling, sorting, and classifying, packing, storage, and shipping were crucial [72]. For preserving decent level of quality and prolonging the commercial life, appropriate postharvest distribution and storage techniques are crucial [61]. The various postharvest handling systems of tomato fruit is reviewed below.

7.1. Harvesting

Picking the right time to pick the fruit is crucial for obtaining the highest quality since the physiological maturation of a fruit at point of harvest has a substantial impact on the qualities of the commodity [72,73]. Postharvest scientists divide the duration of fresh produce's shelf life into 3 distinct phases: maturation, ripening, and senescence. The fruit's phase serves as an indicator that it is ready to be harvested [74]. One of three states—matured green, half ripe, or ripe—can be used for tomato harvesting [73]. Harvesting of tomatoes at mature green stage offers the farmer extended time for transportation to market and reduce mechanical injury. On the other hand, fully ripe tomatoes are susceptible to mechanical injury with subsequent reduction in shelf life.

The typical duration for large-fruited varieties between transplantation to harvesting ranges from sixty to seventy days for early varieties to and from seventy to eighty days for mid-season varieties and to more than eighty days for later varieties [61]. The internal and external indices of tomato fruit maturity is applied in making decision of the time to harvest based on targeted market, in addition to the amount of time required to market the produce. The interior indicators are premised on loci gel production and seeds growth, whereas the exterior fruit ripeness indicator is predicated on the skin colour [61]. Manual harvest with the hand is employed for market-bound tomatoes. To avoiding the scorching sun of daytime, this is typically executed in the morning. Gentle twisting, devoid of tearing and pulling is applied to remove individual fruits from the vine. Cutting of the whole fruits is done for cluster tomatoes and sometimes for cherry tomatoes [15]. After harvest, tomatoes are removed from the field heat to discourage high respiration and transpiration rates. To distinguish greenhouse tomato from the field ones, the former is reaped with the calyx. In addition, the quality of greenhouse tomatoes is adjudged from the freshness level of the calyx. Physical injury form handling practices, and transportation increases the rate at which ethylene gas is produced, respiration rate and transpiration. Pathogens find their way into fruits through physical injury and proliferate [15].

7.2. Precooling After Harvest

Heat from the harvest field is usually high. Prior to actual beginning of any post-harvest handling operations, the residual heat from the field should be dissipated as quickly as practicable since it negatively affects the quality of numerous fresh commodities [54]. Excessive hotness from the field results to an accelerated metabolic process that are unwanted. So, rapid cooling upon harvest is crucial to maintain desired quality characteristics and ensure attainment of optimum storage life of the tomatoes [75]. The function of precooling is to minimise the impact of ethylene synthesis, breathing rates, metabolic functions, and microbe action. Precooling also prolongs the shelf life and preserves the freshness of picked tomatoes by reducing the pace of ripening, transpiration, and degradation [76]. At dawn and/or dusk are both suitable times to reach the recommended temperature band of around 13-20 C for harvesting and transporting tomatoes. If access to treated water is not a problem, hydrocooling—dipping fruits in chilled water laced with sanitizers like thiabendazole and sodium hypochlorite—can be economical but efficient method of cooling down freshly-picked tomatoes for growers in impoverished nations [72].

To decrease field temperatures in underdeveloped nations, particularly those in Africa, picked tomatoes are gathered beneath tree cover [77]. This approach of lowering tomato field heat is unreliable and ineffective; however, it achieves some level of cooling and reduction in the rate of degradation activities. According to Arah *et al*. [23], initial cooling of tomatoes after collection from the field in underdeveloped nations can be greatly aided using a tiny, thatched house as an on-farm construction.

7.3. Fruit Handling (Washing and Disinfection, Waxing and Packaging)

Dusts and foreign materials on tomatoes are usually washed off after harvest. To prevent chilling the immersed fruit, which in turn will enables water and microbes to be sucked into the tomato tissues, the water used for washings must be hotter than the pulp of tomato [78]. To sanitize the fruit exterior and avoid microbiological infiltration, the water used for washing may be treated with free chlorine content between 100 ppm and 150 ppm [79]. To retain the compound predominantly in the most potent disinfectant form, hypochlorous acid, the pH of the sodium hypochlorite solution should be standardized at around 7.0. When tomatoes are disinfected with NaOCl prior to packing, microbiological deterioration is greatly reduced [80]. Post-treatment contamination of tomatoes is still effective in causing spoilage as chlorine evaporates and leaves no residual effects. Trans-cinnamaldehyde is a natural-derived plant compound and when dissolved with water and applied to fresh produce have fungicidal effects [81]. A one order of magnitude reduction in bacteria and fungi was reported for tomato fruits after treatment with 12 mMol cinnamaldehyde within 10 to 30 minutes. Also, storage of tomatoes under modified atmosphere at 18°C after treatment with cinnamaldehyde for 30 minutes, resulted to delay in visible mould growth by seven days [15].

Application of wax is done after washing and disinfection. Prior to waxing, the washed and disinfected tomatoes are hot air dried. Some of the benefits of coating of fresh produce with was include enhancement of gloss of the fruits, reduction in transpiration and may enhance the appearance. Extracts from insect or plant, such as candellila, are frequently utilised to make food-grade waxes (i.e., shellac, beewax). To protect fruits against rot pathogens, fungicides may be added to wax before application.

All tomatoes must be sorted and graded after wax coating before being packed for the sale. Sorting can be described as the separation of unhealthy, sick, or decaying tomatoes from the nutritious and ones without defects. The nearby commodity may be impacted by the significant volumes of ethylene that the defective or infected produce can release [82]. Additionally, separation into grades involves classifying fresh produce into distinct colour, size, and stage of ripeness [72]. The main characteristics of the fruit applied to grade tomatoes are firmness, shape, size, colour, and appearance. In large commercial greenhouses and packinghouses, sorting is done automatically based on weight and colour.

To reduce wastages of fresh produce after harvest, wrapping or packing is another critical factor to consider. It serves to enclose food products to shield them from meddling, physical harm, and infection from physico-chemical, and microbial causes [83]. Based on the level of maturation, kind of fruit or phase of ripeness, kind of market, and customer needs, tomatoes are packaged in various ways. Based on the aeration method utilised in shipping or storing, the material used ought to be sufficiently sturdy and suitably built for appropriate air movement or circulation. Dual wall corrugated fiberboard having at minimum 2.75 Mega pascal force of tearing is frequently used to make tomato packaging [15]. Some common materials used for packaging of tomatoes in the most developing countries include but are not limited to polyethene bags, jute sacks, plastic crates, nylon sacks, woven palm baskets, and cardboard boxes [84]. Palm baskets is mainly used in Nigeria for transportation of tomatoes. The disadvantage of palm basket is that it exposes the tomatoes to compressive force from the layers of baskets on top. Interior damage brought on by these undesirable compression pressures eventually reduces the desirable attributes of fresh [23]. Tomatoes packaged in palm woven baskets are susceptible to punctures or bruises, because of sharp edges lining the inside. The above undesirable compression pressures lead to damage to the interior tissues, which eventually lowers the tomatoes' desirable attributes. Cleaning of Vine-ripe or cluster tomatoes is usually done using air blast. After cleaning the tomatoes are packaged into plastic netted nags or other available packages. Physical stress is minimised during transport as it stimulates CO_2 and production of ethylene gas by tomatoes [85].

7.4. Storage, Transportation, and Ripening

Through storage the length of season can be prolonged. In addition, storing contributes to seasonal supply stability. Temperature impacts many aspects of quality of tomatoes, such as colour, flavour and firmness. Inhibition of ethylene production is observed at high temperatures i.e., 38°C and above, whereas cold, chilled temperatures prevent the inception of ripening in fruits as well as retard ethylene formation [86]. Owing to variations in fruit ripeness and the susceptibility to chilling damage, the ideal storage air temperature fluctuates over time. The storing conditions (time-temperature) for various tomato degree of maturity or ripeness, depending on how vulnerable they are to chilling damage, are listed below.

- Maturing green tomatoes' freshness after storage at 12.5-15°C would be maintained up to 28 days.
- Pink tomatoes can last for 7-14 days at 10 – 12.5°C
- Light-red tomatoes at 9-10°C have storage duration of 4-7 days.
- Firm ripe stored at 7-10°C will only last for 3-5day; and
- Pink-red, firm red or vine ripen can only last for 2-4days at 7°C [15].

Tomato fruits may typically be kept at room temperatures for a brief time frame if there is sufficient air circulation to prevent the buildup metabolic heat. Tomatoes that are at ripe stage may be kept for a prolonged period at temperatures of around 10 to 15°C and RH of 85 to 95 [87]. Keeping of tomatoes at this temperature would minimise the chilling injuries and rate of ripening. Notably, the facility for storage at this temperature and relative humidity is rarely available for farmer in developing countries. Most tropical nations find it challenging to achieve such temperatures, hence loss of sizable amounts of cultivated tomatoes have indeed been documented [88]. Applying a dehumidification cooling system made of woven jute bags allows tomato farmers in tropical regions to keep the fruit for short - to - medium periods. Additionally, knowing the proper temperature control throughout distribution and storage is essential for elongating the fruit's storability while preserving fruit quality [72].

Many tomato producers' manufacturing facilities are in rural, far-flung areas of underdeveloped nations, far away from the commercial hubs. Production companies and wholesalers have significant challenges when transporting harvested tomatoes to markets due to poor road infrastructure and a near absence of sufficient equipment like cold-conditioned vans [72][89]. The time to reach market is delayed due to this challenge of bad or inefficient road and train networks. Particularly, any lag in eating or conversion to stable products after harvest may result to enormous damages [90]. The lags in transit cause growers to suffer losses after harvest as high as 20% [91]. Manual laboring, camels, public transit, hired vehicles, vehicles, haulage, gasoline tankers, articulated trucks, and vans are a few examples of conveying methods [92]. Unlike in developed countries with cold chain transportation systems and good road networks, the poor quality of most third world nations' road systems creates unfavorable conditions all through shipping, leading to significant losses. The bad road networks cause excessive vibrations to the fresh tomatoes leading to mechanical injury and accelerated decay. Even if distributors from underdeveloped nations might not be able to employ refrigerated vehicles, Arah *et al*. [72] argue that they should be well-informed on the effects that using any other mode of shipping might have on their goods.

The biological ripening agent C_2H_2, which every climacteric fruit, including tomatoes naturally produces, causes tomatoes to begin to ripen. To encourage the quicker and more even ripening of mature tomatoes, extra exogenous ethylene may be applied. Fruit that has passed the breakers phase does not derive benefits from additional ethylene since its ripening activities have hitherto been started by the inherent endogenous ethylene [61]. To treat fruit with ethylene, mature green tomato fruit must be exposed to 150 mg/l of the gas for 24-72 hours duration at temperatures ranging from 18 to 21 ^{o}C and 90-95 percent humidity levels. How quickly red-colored fruit is needed determines the temperature and duration of application that are used. When exposed to ethylene for extended periods of time and at greater temperatures, the ripening activities moves accelerate more quickly. When kept between 19 and 20 degrees Celsius, mature green tomatoes begin to turn red in five to seven days [61]. Either a flow-through system or a catalytic generator is used to apply ethylene in a hermetic environment, with the ethylene coming from an elevated gas cylinder. To avoid a CO_2 gas accumulation of more than 1 percent, excellent temperature management, air movement, and sufficient ventilation are guaranteed. Atmospheric CO_2 concentrations above 1 percent inhibit ethylene's ability to stimulate ripening.

8. Postharvest Technologies for Preservation of Fresh Tomato

Post-harvest management practices are closely connected to losses after harvest of climacteric fresh commodities. Loses of fresh fruits after harvest is also linked to inappropriate transportation, mechanical damage, harsh handling, and insufficient storage systems. Contrarily, throughout post-harvest management practices (precooling, packing and distribution) physiological modifications in tomatoes, such as altered respiratory rate, pigmentation, taste alterations, and loss of firmness, have an impact on the quality of fresh tomatoes [67].

The fundamental purpose of post-harvest technologies is to minimise product degradation throughout the supply and distribution chain and to ensure that the fresh commodities is sold for the highest feasible price [67]. Series of conventional, advanced, and alternative techniques have been employed to achieve extension shelf-life tomatoes after harvest. Each of these techniques has diverse functions or modes of preservation, merits, and demerits of applications in terms of ease and cost. Manipulation of the activities of degradation enzymes and inactivation of microorganisms as well as eliminating physiological disorders are employed to achieve preservation of fruits. This can be achieved by treatment with chlorinated water, low or high temperature, ozone, UV radiation, ultrasound, edible coatings, modified atmosphere packaging, 1- methyl-cyclopropene and Calcium Chloride [65].

8.1. Preservation by Physical Actions

Myriads of physical preservation methods have been employed through the years to achieve extension of shelf life of fresh tomatoes. These methods are used single or combined in way of hurdle technology and are selected by farmers based on couple of factors which include cost, ease of application, sophistication of consumer demands and presence of technologies and amenities to support the methods employed.

8.1.1. Low Temperature Preservation

Temperature is largely responsible for the biochemical, physiological, and microbial processes that cause the quality of product to deteriorate [93]. Harvested climacteric fruits, such as tomatoes, have respiratory and metabolic processes that are closely correlated with atmospheric temperature [23]. Elevated temperatures can speed up the rate of CO_2 production and oxygen take u in picked or warehoused commodities. Even though it is dependent on other parameters such as oxygen or CO_2 concentration, exposure period, and maturity phase, the synthesis of ethylene in preserved climacteric items like tomatoes can be triggered by the generation of CO_2 [94]. Even at concentrations of tens of nano liter per liter, small quantities of ethylene can induce fruits to ripen [95].

Therefore, temperature management is one of the most potent techniques used to minimise the rates of spoilage processes and thereby prolong the useful life of tomatoes. Notably, every commodity has its optimum temperature for storage. The ideal temperature repeatedly based on the commodity's place of aboriginal. Tropical plants naturally cannot endure low temperatures during warehousing because they were raised in warmer environments. Most tropical fruits and vegetables must be stored above 12°C in cold storage. Unlike fruit and vegetable that have developed in temperate, colder settings, which can be preserved at $0^{o}C$, this is the opposite [96].

- **Precooling**

Initial cooling activity is the first step in effective temperature administration. Precooling is the technique of quickly removing heat from food before it is transported, stored, and processed. Freshly picked fruit, particularly tomatoes, have a longer shelf life when quickly cooled after harvest. It is crucial to have practical mechanisms in place to limit the level of field heat buildup in picked fruit during active harvest times and to have a reliable technique in place to remove that heat at the cold store [11,96].

Precooling can be achieved using several techniques including but are not limited to forced air cooling, vacuum cooling and hydrocooling. The relative cost-benefit and the variety of the produce in question, are some of the major determinants of the choice of cooling technique. Factors to be considered in choosing the method for precooling includes (i) inherent attribute of the produce e.g., sensitivity to chilling, (ii) temperature of the fruit or vegetable when it was harvested, (iii) desired storage life, (iv) yield of the product, (v) material type of packaging, (vi) cooling time needed and (vii) other contemplations, such as comparison of optimum energy conservation, accessibility, and accompanying operating and CAPEX cost [97]. Room cooling and forced air are the two most known ways to cool tomatoes immediately after harvest [23].

• **Maintaining the Cool Chain**

Maintaining produce at cool temperature follows the right temperature has been achieved. In a storage space or refrigerator van, it's critical that there is enough ventilation and air circulation. Controlling fruit and vegetable's rate of respiration is among the most crucial benefits of cold storage. The temperature at which product is stored has a direct relationship with the respiration rates. But it's important to prevent very low storage temperatures because they might cause chilling damage [11].

Temperature exercises a relevant function in protection of quality of produce after harvest. The impact of surrounding temperature on the physicochemical characteristics and variations in qualities of tomatoes changes from variety to variety, time of exposition and condition of harvest. Storage of pink maturity stage tomato at temperatures between 85 and 95 percent relative humidity between 8.9 and 10 degrees extends the shelf life to 7 – 14 days [98].

8.1.2. Modified Atmosphere Packaging

Other methods to slow down metabolic processes leading to senescence and eventual deterioration of fresh produce includes modification of the storage environment of the produce. This is achieved by raising the CO_2 content and lowering the amount of O_2 in the environment of the produce. Controlled atmospheric storage is differentiated from modified atmosphere storage by the fact that in CA, the concentration of storage gases around the produce is constantly monitored and moderated to achieve constant value. On the other hand, in modified atmosphere storage, the initial make-up of gas of the environment of the produce is modified and allowed to change during the storage time of the produce due metabolic processes of respiration, transpiration and ethylene ripening process [99]. Modified atmosphere packaging (MAP) is achieved by using semipermeable polymetric film or packages that possesses one or more pores for controlled diffusion of gases around products [100]. Passive modified atmosphere packaging is a scenario whereby the atmospheric gas composition of produce is allowed to gradually reestablish itself through the process of respiration. Furthermore, active MAP is a momentary flushing of the environment of the produce by flushing with nitrogen or gas mixture. This ensures a more rapid reestablishment of initial ambient atmospheric gas composition [15].

Additionally important is the gas composition of the surrounding air. By using packaging with adjusted atmospheres that are higher CO_2 and lower in O_2, the freshness of fresh fruit can be extended (MAP). By lowering ethylene generation and respiration speed, MAP delays degradation [101]. According to Mangaraj and Goswami [102], MAP is the best preservation technique for preventing product decay because it creates a suitable preservative environment surrounding the commodity [103].

The MAP approach for fresh produce works by replacing the air in the headspace of the packaging system with predefined atmospheric gases that are distinct from air in compositions and concentration [104]. Determining the product's inherent characteristics, such as respiration rate, ideal concentration of oxygen and carbon dioxide and barrier properties of the film, is necessary for fabrication of suitable MAP systems [105].

MAP systems had been applied as an accompaniment low temperature storage to achieve extension of storability of fresh commodities by the inherent capacity of films or plastic packaging to adjust the composition of the gas and minimise loss of moisture. Advantages of MAP (that is, lower oxygen and increase CO_2 concentrations of the environment of produce) are lowering of ethylene level, rate of respiration and reduction of symptoms of chilling injury [106]. This reduces ripening of the fruits and consequent prolonging of storage life of produce kept under MAP environment [107].

The major gases utilised in modified atmosphere packaging for injection into the pack's chamber are nitrogen, oxygen, and carbon dioxide. The commodity that is being stored has a remarkable impact on the selection and proportion of gases [108]. Three different combinations of N_2, O_2, and CO_2 are utilised to create altered air composition: inert blanketing with nitrogen, partly reactive blanketing with CO_2/N_2 or $O_2/CO_2/N_2$, or completely reactive covering with CO_2 or CO_2/O_2 [104].

8.1.2.1. Methylcyclopropene

Ethylene generation and the attendant effects during ripening and ageing of fruits has been successfully controlled by the application of 1-Methylcyclopropene (1-MCP) [109]. 1-Methylcyclopropene is a growth regulator like silver ion, which is extremely effective against ethylene production. The enzymes carboxylic acid synthetase shortened as ‘ACC synthase’ and carboxylic acid oxidase are less active when 1-Methylcyclopropene is present. This prevents the manufacture of ethylene which is ‘ACC oxidase’ [110].

The chemical, 1-MCP is applied prior to the start of ripening can stop tomatoes from reacting to exogenous ethylene, days after exposure. When compared to untreated fruits, 1-MCP-treated tomato fruit show reduced respiration rate, generation of ethylene, and loss of weight, slower pace of lycopene buildup, exterior colour change, and ripening indicator (SSC/TA). These traits also imply longer post-harvest life [111]. Exposure to 1-MCP at levels between 0.1 and 100 μl l^{-1} coupled with temperature at 20 degrees Celsius and 0.1 μl l^{-1} ethylene-containing air significantly slowed down the mature-green tomato ripening. The treatment duration and 1-MCP concentration were both directly related to the delay. A promising prospective commercial therapy, treatment using 5 μl l^{-1} 1-methylcylcopropene for 1 hour increased the time to mature by nearly 70% [112]. Fruit treated with 1-MCP had less titratable acidity loss during ripening than fruits not treated, lowering the brix to acid ratio as the resultant effects. Based on how the fruit appeared, 1-MCP sprayed for 2 hours to ripe tomatoes at doses of 5-100 μl l^{-1} increased postharvest life. Specifically, exposure of fruits to 20 μl l^{-1} of 1-methylcyclopropene extended post-harvest life by 25% [112].

At present, 1-MCP can be produced on a scale sufficient to the needs of the fruit industry to control ripening in both gaseous and liquid-solution form [113]. 1-MCP was recently applied pre-harvest in the field using a new formulation (HarvistaTM, AgroFresh, Inc., Dow Chemical Co.).

8.1.3. Heat Treatment

Heat treatment has been reported by many researchers as a workable substitute to application of chemicals in the preservation of fresh tomatoes after postharvest. Heat treatment applied to fresh tomatoes has been found by research to inhibit fungal deterioration, control pests, and alter responses of fruits to stress conditions. Heat treatment for short period has been shown to prolong commercial life and maintain desirable attributes of tomatoes after harvest. Susceptibility of tomatoes to chilling injury at low temperatures can be minimised by exposure of fruits to heat treatments. Heat treatments activates the apparatus for antioxidant activities in the cells of the produce and in turn, these antioxidants confer protection to fruits from reactive oxygen species that are harmful and are responsible for chilling stress [114]. Heat treatment (water at 42°C for one hour) of mature-green tomato fruits at pre-storage effectively reduce decay of fruit with only marginal deleterious effects on the desirable attributes of the commodity [115]. According to Fallik *et al*. [116] keeping infected ripe tomatoes that are green and pink for three days at 38 degrees Celcius totally suppressed Botrytis cinerea-caused deterioration.

Also, heat treatment of tomatoes has been found reduce damage due low tow temperature storage below 10°C. Short treatment of tomatoes with hot water at 42 ^{o}C for 1hr or hot-air (30-48^{o}C) treatment for long period, with exposure to cold storage ta 2 ^{o}C and subsequent transfer to storage condition of 20 ^{o}C ripen normally. Exposure of tomatoes to both short-term and long-term hot air treatment prolong shelf life of the produce, however, the later alter the profile of volatiles in the fruits [115]. In addition, heat treatment inhibits ethylene biosynthesis thereby retarding the rate of ripening, senescence, and decay [117].

There are 3 techniques applied to heat treat fresh produce: hot vapour, hot water, hot air. Vapor heat was created specifically for the purpose of controlling insects, whereas hot air has been used to examine how high temperatures affect various fresh commodities as well as to combat both insects and fungus. Conversely, hot water was initially employed for the suppression of fungi growth but currently been expanded to include the decontamination of insects. Vapor heat and hot air are divided into two categories: those with relatively stagnant air and those with strong air flow. Additionally, hot air can be endowed with system to moderate humidity [118]. The methods employed depend on the variety, intent, availability, and ease of application to a farmer or processor.

Heat treatment has some disadvantages, which include effects on several of the quality of tomato, such as firmness of the fruit, development of colour and flavour. Lycopene production is inhibited by exposition to high temperatures at 38°C. On other hand lycopene production and ripening are inhibited by low, chilling temperatures [86]. Also, modification of physiology and attendant disruption of cellular proteins and enzymes responsible for loss of quality of fresh commodities can be achieved by exposure to excessive temperature or heat shock above ambient [11]. Another disadvantage of treatment using heat as a technique to prolong the storage life of fresh tomatoes is the need for refrigeration after heat treatment. The luxury of refrigeration system is mostly not available in developing countries. To lengthen the shelf life of tomatoes in circumstances where refrigerated system is feasible, treatment of tomatoes with heat can be combined with storage at refrigerated conditions [72].

8.1.4. Ultrasound Treatment

High amplitude wave usually above 20 kHz frequency represent the range of ultrasonic (US) fields. Ultrasound treatment is generated through mechanical vibration process in a medium. The particles of biological structure through which US propagated are subjected to compression and depression and this impact large amount of energy [119]. Heating, cavitation, and mechanical actions employed in the food producing companies are used for cleaning with objective of disinfection of bacteria, and inactivation of virus and/or impaired cell covering of some microorganisms [120]. Thinning of cell membranes, localised heating, free radicals' production, for example ^{o}OH, HOO^{o}, and O^{o} and hydrogen peroxide formation [119] have been identified as the mechanism applied in ultrasound for microbial deactivation. Pinheiro *et al*. [119] revealed that ultrasounds treatment was effectual in retarding development of colour and loss of texture, protecting tomato organoleptic quality, with rise of total phenolic compounds (TPC) and a decrease of load of microorganism. Due to the high frequency (20-100 kHz) at which ultrasound operate at, its power transmission needs liquid medium [121]. Free radicals of hydroxyl and hydroxonium ions species and H_2O_2 can be formed if water is the medium for transmission. These free radicals possess beneficial bactericidal effects [119].

High level of effectiveness has been reported for application of US in conjunction with other disinfection techniques such chlorine treatment, subjection to extreme pH, application of pressure and heat. Ultrasound supplemented with thermosonication produces high levels of decontamination effect as regards to inactivation of enzymes and improving product safety, without compromising the dietary and organoleptic features of tomato. Thermosonication greatly increased the rate of inactivation of pectinmethylesterase [122]. According to Brilhante and Dantas (2012), treating fresh tomatoes with ultrasound and 40 milli gram per liter peracetic acid simultaneously led to a very marked decline in *Salmonella Typhimurium* (ATCC 14028) by 3.9 log cycle of colony forming unit per gram and a general decrease in the load of naturally occurring contaminants. However, disadvantages of ultrasound applications denaturation of polysaccharides and proteins, with resultant alteration in appearance, texture of the food and changes in functionality [123]. In addition, the disadvantage of using ultrasonic therapy to lengthen the postharvest quality of fresh tomatoes is the possibly large initial capital cost as well as the costly procedure of optimisation and water purification.

8.1.5. UV-C Radiation

Abiotic stressors like ultraviolet rays often harm plant growth because they can produce free radicals that can alter deoxyribonucleic acid (DNA) material [124]. However, stressors at low concentrations may stimulate favourable responses, a phenomenon regarded as hormesis [125]. The utilisation of UV-C radiation to activate useful postharvest responses in crops has become a signification area of attention. The magnetic spectrum range of UV-C is 200 – 280 nm and it is a non-ionizing radiation. The major application of UV-C radiation is surface treatment. This is as result of the facts that UV-C radiation has shallow penetration power to the tissue, usually in the range of 50-300 nm depth [126].

8.1.6. Edible Coatings

The coating of fruits and vegetables with waxes was the earlier form of application of edible films. Practices such as application of wax and other surface coatings, including wrapping with film are used to reduce water loss and, in some cases, alter the atmosphere (CO_2 and O_2) around the commodity [127]. Edible coatings offer a great opportunity for the prolonging of storage life of fresh produce utilizing biodegradable materials. Edible films produced from good formulations can provide an excellent barrier property to prevent activities that are unfavourable to postharvest quality of fruits and vegetable, such as exchange of gas and moisture loss [128]. Apart from the provision of appearance of glossy aesthetics, edible coatings maintain the desirable attributes of fresh food by modification of the internal environment of the produce through selective barrier to oxygen, moisture, and CO_2. Freshly harvested produce may benefit from extra layers of protection from edible coatings, which also have the same impact as altered atmospheric storage in terms of changing internal gas composition [129].

Edible films are made from various organic materials which include but not limited to proteins, lipids, starch, and their combinations. Each type of material type has merits and demerits and therefore, composite films majorly formulated with combination of proteins, lipids, starch, and their derivatives [130]. Films with good mechanical properties are formed from proteins and polysaccharides. However, protein and polysaccharide films possess poor gas permeability. In contrast, lipid films are brittle but possess improved gas barrier characteristics. Consequently, the goal of a newly created coating is to combine the polymer matrix with a water repelling element (hydrophobic material e.g., fat) [131].

The main purpose of applying protective coatings on fresh fruit is to either restore or replicate its natural barrier, which washing, and handling may have partially removed or changed [40]. Additionally, coatings can assist preserve the structural integrity of coated goods, retain volatile flavour components, and transport food additives like antimicrobials and antioxidants. They can also enhance the mechanical handling capabilities. Additionally, since they may be consumed with the fruit, edible coating technology has the significant benefit of decreasing packing waste [132].

In the recent past, extensive research has focused on the utilisation of different biological materials to produce edible coatings for fresh tomato packaging. Dos Reis, *et al*. [133] noted that an extension of the shelf life of cherry tomato using coatings that are edible made from 7.5 percent yam starch and 30 percent glycerol, as indicated by greater stability for loss in mass, soluble solids vis-a-vis total titrable acidity ratio, phenolic compounds, antioxidant properties, and lycopene concentration in comparison to newly picked fruit.

The physicochemical characteristics of tomatoes kept in an ambient environment as affected by composite edible coating were studied by Nandane and Jain [134]. The coated sample displayed substantial disparity in nearly all factors as weighed against the controlled sample. Within coating treatments, the film forming solution A containing 4% Soy Protein Isolate (SPI), 0.2% Carboxyl Methyl Cellulose (CMC), 1% Oleic Acid was found to be most suitable for all parameters except vitamin C content where coating treatment C containing 4% Soy Protein Isolate (SPI), 0.2% Carboxyl Methyl Cellulose (CMC), 1% Oleic Acid, 0.4% Ascorbic Acid was found to be more suitable.

8.2. Preservation by Chemical Application

While many chemicals possess ability to inactivate micro-organisms or suppress their proliferation but most of them are not food grade and therefore not permitted to be used to control spoilage organisms. Chemicals used as food preservatives are compounds that are used in very small amounts (up to 0.2 percent) and do not substantially alter the physicochemical and organoleptic properties of commodities [135]. The combination or synergistic activities of numerous additives, inherent product attributes (such as composition, water activity, and acidity), and external variables are often the foundations for extending the useful life of food items treated with chemical preservatives (for example, temperature applied during process, temperature, and conditions of the storage environment in terms of gas composition and RH) [135]. The success of chemical treatment in the reduction of population of microorganisms in fresh foods is limited by its inability to penetrate the hidden cracks, pockets and crevices that harbour and protect these microbial consortia. Common chemical treatments for postharvest extension of fresh tomatoes include the use of chlorinated water, oxonated water and electrolysed oxidizing water [11]. The drawback of use of chemical method as a method of preservation of fresh tomatoes is because of the adverse effect of chemical to humans, chemical treatments and preservations are increasingly discouraged, as they have been implicated with causing diverse health conditions.

8.2.1. Chlorinated Water

Chlorinated water is antimicrobial and therefore inhibits the growth and proliferation of bacteria and fungi. Sanitisation of fresh tomatoes with chlorinated water is effective in reduction of pathogenic and spoilage organisms and is routinely done using dipping or submerging methods. Ease of application, effective removal of pesticides and foreign substances, flexibility of application, broad bactericidal activity, and low cost are some of the benefits of treatment with chlorine [136]**.** Use of chlorinated water has some disadvantages which makes it less desirable as a method of preservation of fresh tomatoes and other commodities. These advantages include difficulty in monitoring of concentration using manual methods, corrosion of food processing equipment made with metals, sensitivity to variation in pH, generation of harmful halo-compounds form organic materials, and negative impact of organic materials on its effectiveness [137]. The quantity of freely accessible chlorine in the water that encounters the organism cells determines the suppressive or killing action of chlorine solution. Hydrochlorous (HOCl) dissociates depending on the pH, and chlorine breaks down in the presence of organic material. However, the temperature, concentration, length of the treatment, and stage of the harmful microorganism's development all affect how efficient the hypochlorite solution is [137].

Effects of chlorinated water on pathogenic organism are directly proportional to the concentration till 50 ppm, after which no significant effect of increase to 200 ppm was observed. Beuchat and Ruy [138] reported that the number of microbes did not reduce further with an increase in washing time from 5 to 30 minutes in hypochlorite solution. On the other hand, prolonging washing time using tap water results to decrease in microbial number when compared with chlorine washing [138]. In addition to concentration, effectiveness of chlorine treatment is influenced by pH and temperature. Postharvest treatment of tomatoes with chlorine is usually combined with other methods of preservation to provide synergistic preservative effects employed in hurdle technology. According to Nkolisa *et al*. [139] tomatoes sprayed with chlorine, packaged in 0.25 percent porous polyethylene bags, and stored at ambient temperatures and R.H levels of 70 to 90 percent significantly reduced loss of weight and decay-related losses.

8.2.2. Oxonated Water

Another chemical treatment method used for prolonging the life of tomatoes after harvest is the use of oxonated water. Ozone attained GRAS status for application in preservation of fresh produce [140]. Ozone (O_3) could be seen as a substitute for cold temperature storage to maintain tomato desirable attributes during storage in regions or countries where refrigeration systems are unavailable [141]. It is feasible to produce ozone by passing electrical discharge through high purity oxygen or dehydrated air. The generated ozone dissipated into fine bubble. Some of the characteristics of ozone includes that it is gas that has a characteristic blue colour. Generally, has a strong oxidizing power and possess pungent smell [142]. The mode of microbial destruction by ozone is debatable. While some authors posited that the molecule of ozone was implicated for inactivation of microorganisms, others point to the reactive byproduct of ozone such as $^{\cdot}O_2$. and $^{\cdot}OH$ [143]. Disinfectants including ozone is more efficacious in attacking vegetative cells than spore organisms. In aqueous solution, ozone, O_3 is relatively unstable. It degrades slowly and continuously to molecular oxygen (O_2). Increase in pH results to decrease in ozone stability. pH of tap water is high and therefore may easily destabilize ozone, and its solubility. The mechanism of inactivation of microorganisms by ozone is favoured at low pH and it is reaction with molecular ozone with cell structure of microorganisms [144].

Ozone is a potent compound against microorganisms with several uses in the food business [145]. In the U. S., it has been given approval to be categorised as a food additive with GRAS classification. It is generally recognised that ozone (O_3) works as a powerful disinfectant against all types of microorganisms, even at minute concentrations and ambient temperature. In the wastewater treatment process and potable water, ozone is frequently utilised as a sanitizer [141]. *Salmonella enteritidis* was managed by Das [146] by combining controlled atmosphere storage and gaseous O_3 treatment in CA and MAP of cherry tomato. Contrarily, application of O_3 for prolonging of storage life of fresh commodities has some advantages which make it less attractive as a method of fresh tomato preservation. Kim *et al*. [145] reported that due to lipid oxidation associated with ozone treatment, it had negative impacts on the organoleptic properties of some fresh produce and decreases ascorbic acid content. The mechanism of microbial inactivation is a complex process. It involves arrays of destruction of cell membrane and constituents of the cell wall (for instance, unsaturated fats) and the content of the nucleic acids in the cells, and the biological catalysts. The mechanism of destruction of microbes using ozone is by cell wall destruction or distortion, leading to seepage of the content of the cells. Disruption, also known as lysis, is a faster deactivation process than other disinfectants, which depend on the disinfectant ingredient entering the cell membrane for proper function [145].

8.2.3. Electrolysed Oxidizing water

By electrolyzing diluted sodium chloride solutions in an electrolytic chamber, electrolysed oxidizing water (EOW) is produced, with free chlorine serving as the primary disinfectant. Sodium chloride (NaCl) is the salt utilised for various food applications, although other salts can be used as well, such as potassium chloride (KCl) and magnesium chloride ($MgCl_2$) [147]. Given that treated water already includes chloride, it is also feasible to electrolyze the free chlorine back into a usable state. EOW is produced in a two-cell chamber by reactions taking place in electrodes that are positively and negatively charged. These electrodes are demarcated from each other by membrane permeable to diluted saline solution. The two electrodes are subjected to direct electric current to generate the two separate types of water—an acidic electrolysed oxidizing water (AcEW). Acidic electrolysed oxidizing water (AcEW) has been the predominantly type investigated due to its antimicrobial characteristics. AcEW, which is generated from the negative electrode, has a pH of 3, a high ox-redox potential (ORP), or 1,150 mV, and hypochlorous acid. AlEW is created on the cathode side, where it is a low ORP of -795 mV and a pH of 11.4 [148].

Notably, alkaline electrolysed oxidizing water (AlEW) has no antimicrobial, but is useful for prewash, acting as a good surface-active agent for easy spread of AcEW during application. As a result, AcEW would have an easier time touching the surface-level bacteria throughout a successive procedure [149]. AlEW can also be applied following AcEW to get rid of any remaining chlorine smell [150]. The EOW has direct and residual effects. Decontamination that takes place inside the electrolytic cell is the direct result of electrolysed water (EOW). It can be used to clean water of contaminants. The term "residual effect" describes when decontamination takes place away from the electrolytic setup. This implies that the EOW is generated in the cell, harnessed, and then applied to fresh produces. It has been discovered that the residual effect is helpful for cleaning veggies that have undergone minimum processing. The application of EOW for fruit sanitation offers a couple of benefits because it is produced by uncomplicated electrolysis utilizing purified water and no additional chemicals, other than a diluted saline solution, and as a result, has a lower environmental impact. It also returns to simple water after the application process devoid of emitting significant quantity of dangerous gases, for instance chlorine. According to certain reporters, AcEW physically destroys germs, they don't develop resistance, and after the upfront cost of the unit, ongoing costs are quite low [149].

9. Emerging Technologies and Innovations

To prolong shelf life, lower post-harvest losses, and preserve nutritional content, several cutting-edge methods and techniques are being investigated for tomato preservation. Listed below are a few noteworthy instances: nanotechnology, pulsed electric field (PEF) technology, high pressure processing (HPP), cold plasma technology, smart packaging, and block chain technology. It is noteworthy that the extent to which these technologies are used may differ depending on variables including local tastes, financial concerns, and legal policies. Furthermore, many technologies' acceptability in certain markets may be influenced by ethical and safety issues, particularly those pertaining to genetic alteration.

10. Conclusion

In this article, the quality attributes of fresh tomatoes, as affected by postharvest physiology and handling systems were reviewed. Quality attributes of fresh tomatoes which influence consumer appeal are colour, size and shape, texture, flavour, and nutritive value. Postharvest factors such as physiology, mechanical damage, and pathology greatly affect fresh tomatoes, resulting to losses. Post-harvest management practices are closely connected to losses after harvest of climacteric fresh commodities, such as tomatoes. To preserve quality and lengthen storage life, management procedures including plucking, cleaning, sanitizing, initial cooling, sorting, and classifying, packing, storage, and shipping were crucial. Series of conventional, advanced, and alternative techniques have been employed to achieve extension shelf-life tomatoes after harvest and they broadly categorized into preservation by physical action, using low temperature, MAP, 1-methylcyclopropene, heat treatment, ultrasound treatments, UV-C radiation, and edible coatings; preservation by chemical application, using chlorinated water, oxonated water, and electrolyzed oxidizing water.

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