Advances in the development of a tomato postharvest storage system: towards eradicating postharvest losses

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Abstract
The production of tomatoes has experienced a huge rise over the years as a result of its economic, nutritional and cancer reduction importance. Despite the rapid advancement of technology in the past century, storage of tomato fruits remains a major problem experienced in the postharvest chain in most developing countries. This study gives a survey of the various causes of tomatoes postharvest losses, the different methods used in storage of the fruit over time and their limitations. It was found that the conventional methods used in tomatoes storage, improved its shelf life but was accompanied by some significant losses in quantity and quality. Hence, generating a need for a postharvest storage system taking into cognizance the optimum conditions required for the fruit storage. The development of a thermally controlled postharvest storage system with the sole purpose of increasing shelf life and minimize the rate of deterioration becomes inevitable.

Key words: Energy systems, Thermal control, Tomato postharvest losses, Agriculture, Food preservation, Tomato storage system.

1. Introduction
Tomato (Lycopersicon esculentum, Mill.) is botanically classified as a fruit (berry) but often regarded as a vegetable to many [1]. It is an essentially vital vegetable crop grown in numerous countries across the world, second to potatoes and extensively used repeatedly in the vegetable economy [2]. The rate of tomato production has increased to about 163 million tons by 2013 due to its economical and nutritional value [3]. It is very important in the diet of humans around the world because of its lycopene content, a form of carotenoid having antioxidant properties [4] and bioflavonoid which acts as cancer-fighting agents and are good for liver health [5]. Lycopene is also responsible for the vibrant red colour in the tomato fruit [6] [7]. In a study conducted in Africa, it was discovered that Nigeria is a major producer of tomatoes with about 1.56 million metric tons second to Egypt with approximately 8.63 million metric tons [3]. It is a perishable vegetable crop with a shelf life of averagely one week at ambient temperature [8] and thus different storage and preservation methods are used to keep the harvested fruits in edible condition for a period of time. This helps in achieving the second goal of sustainable development agenda, which targets an end to hunger, food security, improved nutrition, and promotion of sustainable agriculture. The shelf life of a product refers to the time it takes in maintaining a predetermined level of quality under specified storage condition. Tomatoes are generally harvested at times of high moisture content and freshness [9]. The harvested fruit respires and lives until consumption or deterioration take place. Its quality is determined predominantly by colour, texture, flavour and nutritional quality [10]. The most useful benchmark for assessing its maturity is the colour and flavour of the fruit, as high quality is characterized by redness and prominence in flavour [11]. Full maturity is attained when the colour of the fruit is pronounced, with a high sugar content. Though it is considered to be acidic [12], its pH varies significantly by its variety and degree of ripeness. Generally, the riper
the tomato, the higher (less acidic) is the pH, where the pH of the ripe tomato varies between the
ranges of 4.3 to 4.9 [1]. A measurable degradation in the quality and quantity of tomato from its
point of harvest to the point of consumption is termed Postharvest loss [9]. The loss in quantity
involves loss due to the amount, and this is more common in developing countries [13] while that
of quality is as a result of its nutrients, caloric composition, acceptability, and edibility. This is
common in developed countries [14]. Tomato losses are encountered during harvesting, handling,
storage, processing, packaging, transportation and even during the marketing of the fruit [15].
Tomato losses that occur due to inadequate storage facilities, leads to quality loss and in utmost
cases, a loss in quantity. The primary causes of losses during storage can be classified into
biological, microbiological, chemical, mechanical, physical and physiological losses.

**Biological Losses of tomato fruits:**
This form of loss occurs as a result of consumption by rodents, birds, insects or animals that cause
a direct vanishing of the tomato fruit [16]. In some cases, the rate of fruit contamination by faeces,
feathers and hair of bird and rodents is relatively high. Rendering it unfit and inedible to humans.
Insects cause losses in quantity by consumption and quality by their frass, faeces, webbings,
unpleasant stench that could be imparted on the fruit [17].

**Microbiological Losses of tomato fruits:**
Microorganisms such as fungi and bacteria cause damage to stored tomato fruits [18] such that it
becomes intolerable because of rot and other defects. These microorganisms freely attack fresh
produce and spread quickly due to the fact that fresh produce lack natural defense mechanism in
their tissues and the presence of nutrients and moisture in abundance supports microorganism
growth [19][20]. A typical example of a fungus that affects the tomato fruit is *Aspergillus niger*
and it causes deterioration seemingly within an incubation period of 8 days by the secretion of a
protein exhibiting polygalacturonase and cellulose activities [21]. Though the skin of the fruit acts
as a means of protection if they are broken due to abrasion or cut. It can serve as an entry point for
microorganisms and thus lead to losses (quality and quantity). The mature green or unripe tomatoes
are relatively resistant to most microorganisms that cause decay than the ripe ones which are more
susceptible.

**Chemical Losses of tomato fruits:**
This occurs as a result of the spontaneous reaction of the chemical constituents contained in the
fruit causing a loss in colour, flavour, texture or its nutritional value [22]. Several enzymes
triggered reactions could take place during storage which could result in tainted flavours,
discouluration and fruit softening, with such reaction called a biochemical reaction. A typical
example is found in an unblanched frozen fruit or vegetable [17]. Cell wall degrading enzymes
performs an important part in the softening of the tomato fruit [23].

**Mechanical Losses of tomato fruits:**
This loss occurs as a result of mechanical activities such as cutting, bruising, excessive pulling or
trimming taking place on the fruit, therefore, affecting its appearance and thus making it
susceptible to microbial infection [24].

**Physical and Physiological Losses of tomato fruits:**
According to [25], this loss accounts for averagely 36.5% damage in a 10 kg basket of tomatoes
with varieties of species. When a fresh tomato fruit is harvested, its life process continues but
differently. There is no more addition of water or fruit material, it solely depends on its stored
reserves. If exhausted, a natural aging process that leads to breakdown and deterioration occurs.
Thus, making the fruit intolerable due to natural rot. Inappropriate physical conditions also lead to
a loss in quality of fruit. Such conditions include an excessive or insufficient heat or cold
(temperature) and the inappropriate atmosphere during storage. Normal physiological processes which cause tomato deterioration includes respiration, transpiration and ethylene production. These processes combined with an appropriate physical condition gives the basis required for storage of tomato.

Perishable produce generally has a very low shelf life since it readily decays due to deterioration, unless proper methods are carried out for storage. Fruits and vegetables are a typical example of perishables. The rate of spoilage, the quantity of the produce harvested, loss in quality, texture, and quantity, are motives which propagate the need for perishables preservation. Over time, there have been several methods of preservation of perishables that have been adopted with each possessing its pros and cons. In order for proper storage of perishables, different preservation methods are used. The methods include canning, freezing, fresh storage and traditional storage methods such as smoking, drying, salting and pickling [1]. Tomato storage is an essential aspect of its postharvest handling chain, but being a perishable crop the act of storing is quite difficult because of the high moisture content contained in its tissues [26]. According to [27], the quality of nutritional properties of tomatoes (perishables) depreciates with time. As a result, a proper system that minimizes quality loss by reduction of the metabolic or physiological property is required. [28], reported that losses due to inappropriate storage have the largest influence on the rate at which tomatoes postharvest loss occur. Storage of the fruit elongate the period of processing and also assists in its continuity and availability all year round. Usually, it is stored for short term at ambient temperature. This helps to reduce the heat accumulated from respiration. A proper storage environment is required for freshness and quality of the fruit to be properly sustained. There are certain factors that affect the maintenance of tomatoes freshness during storage. These factors include temperature, relative humidity, respiration, and ethylene production.

**Effect of temperature on tomato storage**

Temperature is probably the most important factor that affects the storage and sustenance of tomato fruit quality because it directly affects the rate of deterioration. Appropriate temperature control has been discovered to be the most efficient way of sustaining fruit quality from harvest to consumption [29]. The Maintenance of tomatoes at a relatively low temperature reduces the metabolic activities of the fruit. Thereby, reducing the rate of deterioration. An extreme increase in temperature increases the rate of respiration, the rate of ethylene production and the rate of transpiration. While an extreme reduction of temperature causes chilling injury and reduces fruit quality. In general, as temperature increases the storage life of the tomato fruit reduces. It increases the quantity of loss at the time of storage. Most factors responsible for a reduction in quality of the tomato fruit occurs at an enlarged rate as temperature increases [17]. [30] Reported on the effect of temperature on stored tomatoes. Matured green tomatoes were assessed using different temperature values of 2°C, 5°C, 10°C, 15°C and 20°C. The results showed that 10°C was an appropriate storage temperature for quality maintenance and delayed fruit senescence. [31] Reported on the impact of storage temperature on a variety of (grape) tomato and discovered that storing at a temperature of 10°C resulted in an excellent quality of fruit, while storage below 10°C showed chilling injury symptoms which included decay, poor colour formation occurred. [32] reported that a temperature of below 10°C reduced the lycopene and colour value of tomato fruit (water stressed and no water stressed). [33] Piloted a study on tomato fruit stored at 10°C and 12.5°C with the aim of evaluating the effect of those temperatures on its aroma profile, sensory quality, and consumers flavour perception. It was reported that, though the quality of fruit stored at 12.5°C reduced minimally with time, it maintained a better sensory quality such that consumers could not differentiate it from those stored at ambient. Thus the appropriate storage temperature
for matured green tomatoes varies between 10 and 13°C, while firm and ripe tomatoes vary between 8 and 10°C [34], [35] Reported that storage at 15°C helps maintains the fruit’s nutritional qualities.

**Effect of relative humidity on tomato storage**

Relative humidity is another key factor to consider in the storage of tomato fruit. At harvest, fresh fruit contains between 70-95% of water content. Evaporation of this water content from the tissues of the fruit results in dehydration called Transpiration [36]. Transpiration process begins after harvesting, with water and nutrients no longer nourishing it. Hence, deterioration occurs leading to a loss in quality of the tomato fruit. The quality of the harvested fruit can no longer be enhanced but maintained. Quality losses occur as visual changes, due to shriveling, weight loss, texture changes (softening) and a fading appearance [37]. Shrivelings of the fruit can become obvious with any minor percentage of moisture loss. The loss in the water content of the fruit is mostly affected by the amount of moisture content present in the ambient air, also known as its relative humidity [29]. A movement of water vapour occurs between the stored fruit and its surrounding. This interaction results into an equilibrium in water activity between the fruit and its environment [17]. At very high relative humidity, harvested fruits maintain their nutritional quality, appearance, weight, and flavour. Thus reducing the rate at which wilting, softening, and juiciness occurs [29]. The optimum value of relative humidity for green tomato is reported to be between 85-95% while for a firmer ripe tomato it is 90-95% [38][34]. An increase in the relative humidity in the storage environment is the best way to tackle the problem of transpiration. Common methods of increasing relative humidity include the adding of moisture to the air around the fruits as mist, spray or by wetting the floor of the system [39].

**Effect of respiration on tomato storage**

Respiration process is a phenomenon that involves the breakdown of organically stored materials such as carbohydrates, proteins and fats in vegetables into simple end products, releasing energy and carbon dioxide. It involves sugar oxidation that generates carbon dioxide, water and heat. Thus, making its storage life dependent on its respiratory activity [40]. When the tomato fruit is left to ripen, on or off the plant, a marked increase in its respiration is observed as it passes from the mature green phase to the ripe phase. During the process of respiration, there is a loss of organic matter, food value and an addition of heat load to the system. The loss of stored food reserve in the fruit during respiration quickens senescence as the required food for maintenance of living is exhausted [41]. The respiration rate of tomato fruit determines its transit and postharvest life. It is directly proportional to the rate of deterioration and such explains the phenomenon, the higher the respiration rate the higher the rate of deterioration which results in a shorter shelf life. The production of carbon dioxide through respiration can trigger the production of ethylene in stored climacteric products such as tomatoes, although it is also dependent on certain other factors like oxygen levels, exposure time and ripening stage [42]. Respiration and metabolic activities in the fruit are directly linked to the temperature of its environment [29]. The rate of respiration increases with a rise in temperature [43], ethylene exposure and physical and physiological stresses.

**Effect of ethylene production on tomato storage**

Ethylene is a normal product of plant metabolism produced by all tissues of higher plants and some microorganism [41]. It is a regulatory hormone of growth, development and senescence phase. It is the simplest organic compounds that affect the physiological processes in plants. Tomato fruit is characterized by an increase in ethylene production due to high respiration rate that occurs during the ripening phase. When maturation occurs, several structural and biochemical changes occurs that gives rise to specific organoleptic qualities which include modifications in external
aspects, texture, and flavour. Maturation process in the fruit is characterized by a change in the texture of the fruit. It is substantiated by a loss of firmness owing to structural changes in the principal cell wall components [44]. The rate at which ethylene is produced is increased with maturity, disease incidence, increased temperatures, physical or mechanical injuries and water stress. It is clear to say that reduction of both respiration rate and temperature of storage system would be an appropriate way of reducing ethylene production. Ethylene can be reduced in a system by proper ventilation, use of ethylene absorbers such as potassium, reduced temperature and a modified or controlled atmosphere where oxygen percentage is reduced with increased carbon dioxide. Certain treatments can also be carried out on the tomato fruit to reduce both ethylene and respiratory activities. Such treatments includes the use of gas absorbers such as potassium permanganate and activated charcoal [39] and the application of (8%) calcium chloride to the fruit [45]. [46] Reviewed the different modes of calcium chloride application; dipping, vacuum infiltration and pressure infiltration. It was observed that the application of calcium chloride through vacuum infiltration was the most effective, it was evident by shelf life increment.

**Tomato Storage Methods**

Tomato is susceptible to nutritional and organoleptic degradation and this brings about the need for various postharvest storage methods applied in retaining its quality, nutrients, colour, and texture. Although once harvested, there is a gradual loss in quality of the fruit. The following processes and conventional methods of storage can however be used to slow down deterioration and bring about an increase in shelf or storage life.

### Drying

This method of preservation is the oldest and it involves the dehydration or removal of water in order to increase shelf life. In this case, moisture contained in the fruits tissue is slowly removed until decay in the fruit is highly improbable. The process can be carried out by using the heat from direct sunlight in tropical regions. It is primarily the oldest method of drying but improved on by other drying methods due to the darkening of fruit tissues during drying [47]. Other forms of drying include oven drying which involves controlled temperature from the oven’s artificial heat source and a dehydrator dryer which also consists of an artificial heat source but with a controlled temperature, humidity and airflow. There are several conventional methods of drying that have been adopted over time. Low-temperature drying used for drying at a temperature range of between 15-50°C. High-temperature drying that dries at a temperature range of above 50°C. Freeze-drying which removes water from fluids such as fruit juice at a temperature range of -10 to -40°C. Osmovac drying includes a two-step process of osmosis and vacuum vaporization and desiccant drying [48]. The length of time the process of fruit dehydration would last depends on the tomato variety, the humidity of the air, the thickness of the tomato pieces and the efficiency of the dehydrator. [49] Designed a tomato dryer using heat from geothermal brine as the heat source. The heat from the geothermal brine separator was extracted at a certain flow rate and used to heat up water using a heat exchanger. The corresponding heated water, in turn, heats up the air in the drying room. A blower was used for circulating the heated air. The temperature needed for tomato drying was at a range of 50-70°C. This removes moisture from a range valued at 95.7% to 28%. [50] Reported on the effect of different drying method on tomatoes quality. Tomatoes were dried by sun drying, solar dryer drying, hot air drying and osmotic dehydration method. Certain attributes such as moisture content, titratable acidity, total sugars, colour and odour were used as a yardstick for determination of tomato quality. Results showed that the osmotically dehydrated tomato slice possessed better texture, colour retention and quality compared to other methods.
Also, there was a reduction in moisture content level from 93.91-8.9% and the titratable acidity reduced from 0.45-0.075.

**Canning**

This method involves storage in an airtight jar to increase its shelf life. It can be used for perishables fruits or vegetable that are acidic. It involves heating and storing in containers. The tomato fruit is immersed into a boiling water for about a minute in order for the skin to peel off and is stored in a can partially filled with citric acid, vinegar or lemon juice [1]. The process of applying vinegar or lemon juice is called acidification. Acidification is carried out to prevent the growth of *Clostridium botulinum*, which is a deadly bacterium

**Freezing**

This method of storage involves the placing of fruit inside a freezer. The process of freezing involves a phase alteration where a liquid turns into a solid at a temperature below its freezing point. This method increases the shelf life of the fruit by preventing the growth of microorganism thus reducing deterioration. An important factor in this storage method is the fact that nutritional quality of the fruit remains relatively good and there is also a good colour retention capacity by this storage method [1]. Numerous methods of freezing are utilized in freezers and cold storage rooms. They include, Air blast freezing, Contact (Plate) freezing, liquid immersion freezing and cryogenic freezing [51].

The method of freezing used mostly for fruits and vegetables is the air blast freezing method and the contact freezing method. [52] Conducted a research comparing the influence of refrigeration and freezing on eight fruits and vegetables. Attributes such as minerals, fiber, and total phenolic retention were compared. Samples from each fruit and vegetables were split in half and utilized. A portion was blanched and then frozen at a temperature of -32°C and stored at -27.5°C for 90 days while the other stored fresh in a refrigerator at a temperature of 2°C for 10 days. Results showed that frozen fruits and vegetable constituted a nutritionally feasible substitute to those stored in a refrigerator, as the given attributes were preserved compared to those stored fresh. Furthermore, [53] conducted a research on Micra RS tomatoes showing the effect of storage period and temperature on its chemical composition and organoleptic qualities. The tomato fruits were frozen at varying temperatures of -20°C and -30°C and stored for 12 months with analysis conducted at a 3-month interval. It was observed that after storage for 6 months at -20°C and 12 months at -30°C the tomato fruits were still edible for salad. The organoleptic qualities of the fruit stored at -20°C were preserved during a 9 month period while that of -30°C were preserved through the 12 months duration. Some chemical composition such as fiber, total nitrogen and PH were not affected by the storage. Unlike others such as pectin, vitamin C and lycopene which were affected.

**Fresh storage**

Fresh storage involves the maintenance of physical and physiological factors required for elongating shelf life. Stored fruits are maintained in their fresh condition. The method involves the reduction of deterioration process or metabolic mechanism of the produce to a minimum, allowing for a relatively fresh and extended shelf life. This process requires the use of cooling methods, to reduce the temperature of produce in the storage compartment. There are several methods of cooling that have been adopted in the storage of tomato fruits, this includes cold storages such as refrigerators, controlled atmosphere storage, and evaporative coolers.

**Refrigerators**

This storage is a very well established and known technology used for the storage of perishables in the world today. It is an efficient method of fruit and vegetable storage for some days [54]. Refrigeration involves the process of reducing temperature and maintaining the temperature of the
space lower than its surrounding. It utilizes a cooling process which involves the use of several methods such as vapour compression, vapour adsorption, gas cycle, thermoelectric and others in the removal of heat from one point to another. Most refrigerators located in homes today use the vapour compression cycle which involves the use of a refrigerant, an evaporator, a condenser, and a compressor for refrigeration process. It transfers heat from produce stored in it, to the refrigerant used in the refrigeration process. [55], reported that temperature maintained by a refrigerator is 5°C and relative humidity range of 45-75%.

Controlled Atmosphere Storage
The concept of a controlled atmosphere involves a reduction in the respiration process of a fruit by increasing the amount of carbon dioxide and reducing the amount of oxygen in the system. This causes a deviation from the normal composition of air and increases shelf life [37] if combined with the alteration of temperature in the storage compartment through refrigeration, then shelf life of fruit would increase further. The normal composition of air includes 21% oxygen, 78% nitrogen, 0.93% argon, 0.04% carbon dioxide and a variable amount of water vapor. Maintaining the controlled atmosphere configuration is balanced by an inert gas (nitrogen). [56], reported that a controlled atmosphere using nitrogen is viable for the storage of tomatoes. The application of this system would slow down the activities of cell wall degrading enzymes which are responsible for softening of the fruit and results to fruit strengthening. [57] Reported that the ripening of banana fruit can be delayed by a controlled atmosphere when there is a rise in carbon dioxide and a decline in oxygen. This inhibits the performance of ethylene, thereby delaying the rate of ripening. The banana fruit from this storage method where firmer with a relatively increased shelf life than those stored at ambient temperature. [58] Reported that a storage system with elevated carbon dioxide and reduced oxygen retarded ripening of the avocado fruit and also reduced chilling injuries when stored.

Evaporative coolers
This method is an economical means of reducing temperature while there is an increase in relative humidity in fruit and vegetable storage. As stated by [59] evaporative cooling of water is an ancient and effective method of cooling. This method is usually used by plants and animals to reduce their body temperature. The principle of evaporative cooling involves the conversion of sensible heat to latent heat [60] and cause the evaporation of liquid into the surrounding air thus cooling any substance in contact with it (solid or liquid). The conditions which would allow for evaporative cooling to take place include high temperature, availability of air movement (wind, fan), availability of water and medium for movement (reservoir, pumps, pipes) and low relative humidity [61]. The measure for the possibility of evaporative cooling is determined by the wet-bulb temperature in relation to the dry bulb temperature of the air. The larger the difference between the temperatures, the higher the evaporative cooling effect. This system cools the storage chamber by forcing hot air through a wet pad. Evaporation takes place in the water contained in the pad. Heat is eliminated from the air and there is an addition of moisture to the storage chamber. When there is too much saturation in the air surrounding the evaporative cooler, little or no evaporation can occur. Because an overly dry air absorbs a relatively large amount of moisture from the wetted pad thus, resulting in high cooling. The quicker the evaporation rate the higher the cooling effect. This method of cooling can also involve the use of water dripping over bricks or cooler pads utilizing the adiabatic principle in the storage system. Evaporative cooling thus involves the use of a wetted pad or a porous material with a water source flowing through it, with a flow of hot dehydrated air through the material thus causing evaporation which results in a cooling effect and increased relative humidity. There are two types of evaporative cooling. Direct
evaporative cooling (DEC), involves the passage of hot dehydrated air through a media swamped with water. Its cooling is effective when the temperature is high for its cooling effect to be high. Indirect evaporative cooling (IEC), involves the same principle as the DEC but a heat exchanger is used for removal of heat from the primary air stream. The effectiveness of the storage method is limited to the effectiveness of the used heat exchanger.

2. Recent advances in fresh tomato storage systems.

There have been several advancements in tomato storage over the years. The evaporative cooling system has been developed mostly because it is widely economical. [27] Performed an analysis on an evaporative cooling system designed by the Nigerian Research Institute [62] using a clay pot placed inside a slightly bigger pot. It was called a pot in pot evaporative cooling method. The space between the pots was filled with riverbed sand. The sand was kept moist regularly by the application of water. Oranges and tomatoes were stored in the cooler. The average temperature attained by the inner chamber was 20°C and relative humidity of 78%. Results after 21 days of storage showed that, though the nutritional qualities of the fruits changed with time, the storage method can be used as an alternative in rural communities. [63] Developed and measured the performance of an evaporative cooler for fruit storage using a pot in pot evaporative cooling method. Coconut fiber was used to fill the space between the containers. A water reservoir was used in keeping the fiber constantly wet. The temperature depression in the cooler from ambient air varied over the range of 0.1-12°C. Ambient air temperature during the period of test ranged between 22°C and 38°C. The result showed that the cooler improved the shelf life of fresh pumpkin vegetable from 12 hours to 60 hours. While it improved tomatoes from the onset of deterioration from 32 hours to 93 hours. [64] Developed an evaporative cooling storage system using charcoal. It used an open fiber frame with the door covered in mesh inside and out. The cavity between the mesh was filled with charcoal pieces, wetted with water for cooling. Tomatoes were stored in the system for 10 days. Results showed that the charcoal evaporative cooler can be used as a short-term storage method for enhancement of tomatoes shelf life. [65] Developed an evaporative cooling storage unit. Fruits and vegetables were stored in the system. It was reported that the temperature drop at the middle of the system was about 20°C. Relative humidity was about 10-65% and 15-78% in a no load and loaded condition respectively. Results showed that up to 10% loss of weight was observed in potatoes with a shelf life of about 50 and 62 days. A 10% loss in weight was accounted for in tomatoes that were stored for 4-5 days. Kinnow was stored for 25-30 days. [66] Designed an evaporator cooling system for tomatoes (Roma) storage. The system was solar powered. It comprised of an aluminum and a jute pad. The jute pad allowed for moisture addition through water flow from the perforated pipe. It was reported that the system maintained a temperature averaged at a range of 13.75 -14.75°C. With a relative humidity averaged 83%. On storage of tomatoes for 5 days, results showed that the loss in weight of tomatoes was 5.7 g, compared with ambient storage with a loss in weight of 12.4 g. [67] developed a zero energy cooling chamber (ZECC) for the storage of fruits and vegetables. Locally sourced materials were used. A double bricked wall was built and sand filled. It was used to store tropical fruits. The shelf life of fruits increased from 2-14 days (15-27%) when compared with fruit stored at room temperature. [68] Studied the behavior of tomato inside a ZECC. Designed, using block filled with zeolites. A pump and a low pressured micro sprinklers were used in keeping the system steadily moist. It was reported that the system reduced temperature to 13.8°C on the application of water and 25.4°C without water application. Relative humidity rose to about 91.7% and 64.1% with and without water application respectively. On storage of tomatoes in this system, the shelf life was enhanced to about 7 days. [69] Developed and assessed an evaporative cooler with locally
available materials such as wood (mahogany and akwamari) jute bag, wire mesh or gauze wire, aluminum sheet, glue and nail. The performance of the cooler was evaluated and results showed that average temperature of the cooling chamber was between the range of 20.5-23.5°C when compared with an ambient of 25-28.5°C for tomato storage. The chamber temperature for pepper was 20.5-26.5°C when compared with an ambient of 28-30.5°C. The mean relative humidity of the chamber was between the range of 51-93% and 49-95% for tomatoes and pepper respectively, while that of ambient varied at ranges of 47-58% and 47-57% for tomatoes and pepper respectively. It was reported that the cooler preserved both tomatoes and pepper for 8 days before any notable colour change, mould spotting and weight loss occurred. [70] Studied and evaluated the performance of the Indian Agricultural Institute (IARI) design Zero energy cool chamber (ZECC). A study was conducted for a period of two successive years. The performance of the cool chamber was compared against ambient room conditions. The average temperature in the cooling chamber was at a range of 5-6°C temperature lower than the ambient temperature. A 13.34 or 12.34% increase in relative humidity occurred at summer and winter months respectively. Fruits stored in the cooler, like bitter gourd, capsicum and cauliflower were improved by 5 days. While the shelf life of fruits like tomato, peach and pineapple was increased for about 6-9 days when kept in the cool chamber. [71] Developed an evaporative cooling system consisting of a cooling chamber, cooling fan, and transmitting medium (cooling pad). A water reservoir tank was used in wetting the cooling pad. Carrots and tomatoes were stored with its freshness observed daily. It was reported that the temperature and relative humidity in the system range from 16-26°C and 33-88% respectively. While ambient varied between 26-32°C and 18-31% respectively. This increased the shelf life of the tomato fruit by about 14 days relative to ambient storage. [72] Designed an evaporative cooler using an economical and efficient method. The system functions using the indirect evaporative cooling principle. Air is cooled freely without the addition of moisture to its content. The storage system comprises of two extraction fans, a cooling pad, a plate fin heat exchanger, water tank and the cooling chamber. Tomatoes were stored for a period of 14 days and compared with a refrigerator and ambient temperature. It was reported that the mean penetration depth for tomatoes was 13.43 mm, 13.82 mm and 18.26 mm for refrigerator, evaporative cooler and ambient storage respectively. Results showed that, though the refrigerator maintained skin firmness of the fruit the most, the evaporative cooler was the best method for storage of tomatoes in terms of acidity and total solubility solids. When compared with the refrigerator and ambient storage. [73] Reported that tomato ripens better in an evaporative cooling storage system, with a temperature of 20-25°C and a relative humidity of 92-95%. On the 15th day of storage, it reaches 100% ripening index (RI) and holds a high moisture retention capacity. When compared with those stored at ambient temperature with an 83.3% RI and a lower moisture retention capacity. [74] Developed an evaporative cooling storage chamber using plastic materials and coconut husk chips as the cooling media. Humidity was increased by a continuous flow of water under the influence of gravity and dripper arrangements. It was reported that the temperature drop in this system was maximum at noon time, with a drop of 11°C and 12°C before and after fruit loading respectively. It maintains an average relative humidity and efficiency of cooling of 91.90% and 95.83%. The temperature of the internal cooling chamber was at a range of 24-27°C. Results showed that the fruit retained 50% firmness for 18 days. [60] Developed an evaporative cooling system using clay and other locally available materials. Wood shaven was used as a cooling media. Water was circulated through the system by a perforated water trough which is positioned on top of the cooling pad. Results showed that temperature was reduced to a range of between 24 and 29°C, when compared with ambient temperature varied at 32-40°C. It was reported that a temperature
A drop of 10°C and an increase in relative humidity from 40.3-92% was attained. Freshly harvested tomatoes were stored in the system for 19 days before the process of deterioration became visible by a change in colour or mould spots. [75] Developed a solar powered evaporative cooling storage system (SPECSS) for the enhancement of shelf life of fruits and vegetables. Several fruits such as tomatoes, mangoes, bananas and carrots were stored in the system with a storage chamber temperature depression ranging from 7.8-15.4°C. The relative humidity in the storage system ranged from 44-96.8% when compared with ambient. The shelf life of the fruits stored in the SPECSS increased from 6, 5, 5 and 8 to 21, 14, 17 and 28.

Polyethylene films influence storage of fruits and vegetables when combined with cooling. Storage of the fruits in a polyethylene bag has been discovered to vary the range of storage life of fruits and vegetables. [76] Developed an evaporative cooler used for the storage of fresh tomatoes. The cooler possessed an average temperature drop of 8.2°C and an increased relative humidity of 36.6% when compared to the ambient temperature of 33°C and 60.4% respectively. Fresh tomatoes were packaged in a polyethylene film of thickness 0.05mm in both a perforated and unperforated bags, while some were unpackaged under cooler and ambient conditions. The tomatoes stored in the cooler without packaging had a shelf life of 11 days as compared to 4 days attained by the unpackaged fresh tomatoes stored at ambient condition. The shelf life of tomato fruit in the sealed but perforated polyethylene bag was 18 days compared to that of ambient which was 13 days. The completely sealed polyethylene bag had the shortest shelf life, with 8 days for those stored in cooler and 6 days for those at ambient temperature. Thus, showing that tomatoes stored in an evaporative cooler, rated higher for visual qualities and marketability than those at ambient. [77] Tested a double walled evaporative cooler built of bricks. Interspaces were filled with wet riverbed sand. It was used in testing of wrapped and unwrapped tomato fruits in perforated and unperforated polyethylene bags. The storage chamber temperature was within the range of 16-19°C with a relative humidity of 83-96% when compared with the ambient temperature of 20-36°C at 34-70% relative humidity. It was reported that the evaporative cooler reduced the mean weight loss and decay in the fruit by 53.7 and 41.2% respectively. Unpacked tomatoes storage life lasted for 13 days in the cooler, when compared to 5 days for ambient and they possessed higher sensory quality. Those stored in perforated polyethylene bags had a storage of 20 days when compared with 13 days at ambient. While those stored in unperforated bags had the lowest storage life of 9 days at the evaporative cooler and 7 days at ambient.

The evaporative coolers, though attain some level of cooling, do not cool as much as required for some specific fruits and vegetables. Thus, this has led to the combination of the direct method of evaporation with other methods of cooling. The use of heat exchangers has been integrated into the process of direct cooling to further step down the temperature to suit some certain fruits and vegetables. [78] developed a two-stage evaporative cooler with the aim of improving the efficiency. The design consisted of a heat exchanger and two evaporative cooling chambers. The double evaporative cooling chamber improved the temperature drop to the range of 8-16°C. This system increased the relative humidity to 90%. And the effectiveness of the system was at 1.1-1.2 over the single evaporative cooler. The ambient storage of the two-stage evaporative cooler was between the range of 17-25°C and 50-75% relative humidity. The system had a higher effectiveness than the single evaporative cooling system and thus is capable of increasing the shelf life of a wide range of fruits and vegetables. [79] developed a low cost and ecofriendly Zero Energy Cooling Chamber (ZECC) for storing fruits and it comprised of two cooling system, a solar adsorption refrigerator and an evaporative cooler. The combination of this two cooling methods reduces the average temperature inside the cooling chamber to about 12.07°C compared with an
ambient of 31.5°C and enhances the storage of tomatoes from 7-23 days. [80] Developed and tested a regenerative cooler. It involved a modification process on the direct evaporative cooler. A water to air heat exchanger was added to the system and thus, improved cooling. A performance evaluation of this storage system was evaluated and results showed that its efficiency and coefficient of performance (COP) increased by a range of 20-25% thus making its cooling capacity higher. [81] Developed a controlled atmosphere for the storage of fresh tomato fruit. A performance test was carried out on the storage system. Locally available materials were used in the construction of the controlled chamber. 1% L-Ascorbic acid was used as an antioxidant for ethylene removal. The temperature of the storage chamber was 20°C and the relative humidity varied between the ranges of 75-80%. Results showed that the shelf life of the tomato fruit was enhanced to about 42 days under the controlled atmosphere as compared with 35 days of storage in a refrigeration condition. The report showed that a controlled atmosphere storage can be used to enhance the shelf life of tomatoes. Improving the shelf life of the tomato fruit can also be achieved by the combination of some postharvest storage treatment activities such as washing with a chlorine solution, use of ethylene inhibitors, application of calcium and thermal treatments [37] in combination with proper cooling conditions (temperature and humidity). [82] Conducted a research on fresh tomato fruit, analyzing its quality when stored in a solar adsorption cooling storage as a function of low-pressure treatment. The cooling system maintained a temperature of about 10-12°C and an average of 80% relative humidity level. Fresh and treated tomato fruit were stored inside the storage system and results showed a 5% loss of weight after the first week. The fruits were treated with 0.08mpa and it was reported that its shelf life was increased from 7 days to 25 days in the solar adsorption cooling system. Thus, fruits quality was maintained. [83] reported that, heat treatment reduces the rate of moisture loss in tomato stored at optimum control temperature of 15°C. The application of a single heat treatment of 40°C, reduces the rate of moisture loss when compared with storage at control temperature of 15°C. A double heat treatment was found to reduce further the rate of water loss in the fruit. Thereby, increasing fruits shelf life. [84] Reported that the application of a double heat stress combining hot air and hot water was efficient for reducing water loss and also freshness preservation in the fruit.

3. Limitations in Tomatoes Storage Methods

The conventional storage methods generally increased the shelf life of the tomato fruit, but were also accompanied with some losses. Drying of tomatoes leads to a loss in quantity of the fruit, as water which makes up a large percentage of the fruit’s mass is removed. Canning does not necessarily lose as much moisture content as drying but as a result of the fruits acidification, there is a loss in flavour and sweetness. Freezing keeps the fruit whole but causes chilling injury. This occurs as a result of damages on the fruits membranes, resulting in loss of some flavours and a soft meaty texture when they are brought back to room temperature. This paper delves into the storage of tomatoes in its fresh and whole state, for a lengthy period of time. Wherewhich a good quality and quantity is maintained for as long as possible before deterioration occurs. The refrigerator, though important and popular amongst people in the world today cannot be used for storage of fruits and vegetables (tomatoes) for a long period of time, as they are susceptible to chilling injury [85] [75] [86]. Refrigerator maintains temperature of 5°C [55] or less and a relative humidity lower than required, for fruit storage. The use of the evaporative coolers though economical has a few limitations. [87] Showed that some certain factors affect the rate at which evaporation occurs. Firstly, relative humidity of the surrounding air affects the rate at which evaporative cooling takes place. A lower relative humidity will allow the surrounding air hold more moisture. Thereby, increasing the rate of evaporative cooling. Secondly, the temperature of the surrounding air
flowing through the system (wetted pad) increases the rate of evaporative cooling by absorbing enough energy that enables a phase change (liquid-gas). Thirdly, air movement in the system affects the rate of evaporative cooling, as moisture content in the air needs to be moved away for continuous evaporative cooling. Humid air needs to flow and not remain stagnant for increased cooling. The last factor is the surface area at which evaporation takes place. A large surface area results in a large evaporation rate and an increase in evaporative cooling. The major limitation encountered by the direct evaporative coolers from reviewed literatures is that, the maximum cooling potential (difference between wet bulb temperature and dry bulb temperature) do not meet the optimum temperature for tomato fruit storage (10-15°C), knowing that a 100% cooling potential is not possible. This shows that the temperature difference between the ambient and the storage system is relatively little as compared to the evaporative reduction that is achievable (theoretical or 100% cooling potential) [27] [63] [64] [66] [69] [70] [71] [73] [74] [60] [75] [76] [77]. Although, the indirect evaporative cooling achieved a temperature lower than the direct evaporative coolers from literature, it required a constant flow of water to the wet pads. Therefore, it cannot be used in every environment (inside the home). Also, the cooling effect achievable is not as great as that of the mechanical cooling [88] because its cooling is limited to the efficiency of the heat exchangers utilized [78] [79] [80] [72] [81] achieved a high storage life using a controlled atmosphere but had some constraints, as it did not achieve the optimum temperature and relative humidity for storage.

Optimum environmental conditions for an effective tomato postharvest storage system
Tomato storage is largely dependent on certain factors that determines its shelf life. These include storage temperature, relative humidity of the storage unit, rate of ethylene production and the rate of respiration of the fruit. The temperature at which the fruit is stored is important in the maintenance of tomatoes’ shelf life. It is directly linked to the other factors responsible for fruit deterioration. The shelf life of the tomato fruit at ambient temperature is averagely 7 days [8]. Tomatoes stored at 10°C maintained a good quality and delayed fruit senescence [31] [30]. [34] Reported that the appropriate storage temperature for matured green tomatoes varies between 10 and 13°C, while firm and ripe tomatoes vary between 8 and 10°C. At these temperatures, the pathogens responsible for deterioration of the fruits and the enzymes associated with cell wall degradation are not functional. [35] Stated that a storage temperature of 15°C helps in the maintenance of the nutritional quality of the fruit. Thus, a storage temperature of about 10-15°C is recommended for tomato storage, as any temperature below 10°C would lead to chilling injury and above 15°C would increase the deterioration rate of the fruit. The relative humidity of the storage unit is also an important factor that maintains the fruit’s quality. A low relative humidity leads to fruit wilting, softening and weight loss while a high relative humidity results in maintenance of good nutritional qualities, weight, appearance and flavour. The optimum value of relative humidity for green tomato is reported to be between 85-95% while for a firmer ripe tomato it is 90-95% [38] [34]. The respiration rate of tomato determines shelf life of the tomato fruit. An increase in temperature is accompanied by a marked increase in the rate of respiration and thus a faster deterioration rate [43]. Ethylene production is also a factor responsible for deterioration of the fruit. It is also directly linked with the respiration rate of the fruit. A high rate of respiration results in a higher amount of ethylene produced by the fruit. It is thus clear to say that reduction of both respiration rate and temperature of storage system would be an appropriate way of reducing ethylene production. Other methods of ethylene reduction includes the use of gas absorbers such as potassium permanganate and activated charcoal [30] and application of calcium chloride.
Taking into consideration the various factors, the development of a system will further enhance the shelf life of tomatoes thus reducing postharvest loss.

4. Conclusion
The postharvest chain of tomato fruit starts from the point of harvest until it is finally consumed or damaged. Although the quality of the fruit cannot be improved upon harvesting, the pace of its deterioration process can be slowed significantly using several methods. The shelf life of the tomato fruit largely depends on the storage conditions it is associated with. Temperature determines to an extent, the rate at which fruit respires, produces ethylene and loses moisture. However, by increasing the humidity of the storage facility, moisture loss can be effectively reduced. Although the evaporative coolers are economical for the storage of fruit, it is largely dependent on the condition of the environment in which it is developed. A hot and humid condition largely supports the cooling process provided there is a constant flow of water. The refrigerator poses the best artificial method of temperature reduction but causes chilling injury and moisture loss as it does not conform to the optimum storage conditions required for the fruits storage. Thus, the need for the development of a postharvest storage system that operates using mechanical process of cooling and maintaining the optimum storage conditions (temperature and humidity) required for tomato fruit storage

5. Recommendation
The highlighted limitations associated with the different storage methods, creates a need for the development of a solarized postharvest storage system. It is my recommendation that the system uses a mechanical process of cooling with a thermostat to maintain optimum temperature. Also humidity enhancing foams or water sprinklers be introduced into the system to increase humidity. The introduction of these processes would increase the shelf of the tomato fruit and combat rapid deterioration.

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