

## REVIEW ARTICLE

# Extending the shelf life of tomato through hurdle technology – a review

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## ABSTRACT

This paper is a review on little history of tomatoes, nutritional profile of tomatoes, health benefit, hurdle technology, application of hurdle technology and Hurdle technology in the postharvest preservation of fresh tomatoes. Furthermore, the paper explains the various ways the principles of hurdle technology can be applied in the preservation of the freshness and quality of fruits and vegetables considering tomato as a case study. In order to reduce the postharvest loss of this commodity, various researches have been carried out on the best methods to employ. These techniques are aimed at extending shelf life and preserving the freshness and quality of the product from the time of harvest to final consumption. Technologies such as Controlled Atmosphere Storage (CAS), passive and active Modified Atmosphere Packaging (MAP), cold storage, waxing, and chlorine treatment, have been employed all in a bid to extend postharvest shelf life and quality. Some of these techniques are used individually or combined.

**Keywords:** Tomatoes, Hurdle Technology, Hurdle Technology in the postharvest preservation of fresh tomatoes

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## INTRODUCTION

Tomatoes (*Lycopersicon esculentum*) is the second most important vegetable after potato in the family Solanaceae (FAOSTAT, 2012). It is said to have originated from the regions of Central and South America (Filippone, 2014). According to FAOSTAT, (2012), Nigeria is the largest producer of the crop in sub-Saharan African, with an estimated production of approximately 1.5 million tonnes. It is a popular part of the Nigerian diet and is widely consumed fresh and cooked. Tomato is a rich source of fibre, folates, antioxidants (such as ascorbic acid, vitamin E, and carotenoids), phenols, flavonoids etc. (Rao, 2006). These inherent nutritional properties makes it very important as a part of the diet. Epidemiological and clinical studies has shown that the nutritional consumption of this vegetable can help in the prevention and management of some diseases such as some forms of cancers, degenerative eye defects and also the risk of developing some cardiovascular diseases (Basu and Imrhan, 2006).

Despite the high production rate in Nigeria and its nutritional benefits, it has a short postharvest life resulting in high losses (Shankara et al., 2005). It is estimated that about 50% of the harvested fruit is lost before it reaches the final consumer (Mashav, 2010). High perishability of the crop, results in a decrease in its quality by the time it eventually gets to the hands of the consumers. This occurs when proper postharvest practices are not employed. Postharvest losses have serious economic impacts, such as direct financial losses on the part of the growers and also for the marketers. It also indicates a waste of productive agricultural resources such as

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land, water, labour, managerial skills and other inputs that have been channelled towards the production of the crop. In most developing countries, postharvest losses of food crops have been faulted as a major cause of food insecurity and food shortage. In a country such as Nigeria, where most farmers and marketers are ignorant of the best postharvest methods to employ, spoilage of the tomatoes is a popular scenario.

In order to reduce the postharvest loss of this commodity, various researches have been carried out on the best methods to employ. These techniques are aimed at extending shelf life and preserving the freshness and quality of the product from the time of harvest to final consumption. Technologies such as Controlled Atmosphere Storage (CAS), passive and active Modified Atmosphere Packaging (MAP), cold storage, waxing, and chlorine treatment, have been employed all in a bid to extend postharvest shelf life and quality (Anthon and Barrett, 2012). Some of these techniques are used individually or combined. However, it has been observed that even with the application some of these technologies, some challenges still exist such as the case of chilling injury in cold storage below 10°C (Cantwell et al., 2009), and inhibition of sugar development of in harvested fruits due to cold storage (Gomez et al., 2009).

Hurdle technology is the combined application of new and existing techniques which can be used to extend the shelf life of food as well as maintain its quality (Leistner, 2000). In the past, hurdle technology has been popularly applied to various kinds of food products such as meat and meat products, milk and milk products, fruits and vegetable etc. (Malik and Sharma, 2014; Gómez et al., 2011; Panjagari et al., 2007). Also, the application of hurdle technology has been mainly focused on ensuring microbial stability of food products. This review therefore aims to state the various ways the principles of hurdle technology can be applied in the preservation of the freshness and quality of fruits and vegetables considering tomato as a case study.

### **Nutritional profile of tomato**

Tomato is a nutritious vegetable crop that is low in calories. It has been reported that one medium-sized tomato has only 35 calories (Gao et al., 2010). The vegetable is rich in micronutrients such as; vitamins E, certain minerals (notably potassium) and carboxylic acids, including ascorbic, citric, malic, fumaric and oxalic acids (Preedy, 2008). These vitamins are all important in the normal metabolic activities of the body. It is also a rich source of bioactive compounds in the form of antioxidants (lycopene,  $\beta$ -carotene,  $\alpha$ -carotene etc.); flavonoids; polyphenols etc. (Dewanto et al., 2002; Slimestad, 2008). The major antioxidants in tomato is lycopene which is responsible for its red colour and the pro-vitamin A beta carotene (Frusciante et al., 2007; Raffo et al., 2006). Tomato is the main source of the antioxidant lycopene in the human diet with lycopene constituting an estimated 90% of the total carotenoid contents (Radzevicius et al., 2009). This vegetable crop also represents a relevant source of soluble and insoluble fibres (<http://www.whfoods.com/genpage.php?tname=foodspice&dbid=44>).

### **Health benefits**

Epidemiological and clinical studies have shown that the increased consumption of tomatoes was able to prevent the occurrence of some certain forms of diseases (Silaste et al., 2007; Paran et al., 2009). This is due to its abundance in phytochemical compounds such as carotenoids, phenols, flavonoids etc. (Dewanto et al., 2002). These compounds have been reported to be able to play important roles in inhibiting reactive oxygen species responsible for many important diseases, through free-radical scavenging, metal chelation, inhibition of cellular proliferation, and modulation of enzymatic activity and signal transduction pathways (Eldahshan and Singab, 2013) The health benefit of tomato has been mostly attributed to its lycopene content (Agarwal and Rao, 2000). Although there is said to be a synergetic contribution by other antioxidants notwithstanding, there is need for more research on the mechanism of this process.

Lycopene which is the major antioxidant in tomato, has been studied to possess great antioxidant potentials. It has been found that

the antioxidant capacity of lycopene is 1.16 times higher than  $\beta$ -carotene and 2.9 times higher than antioxidative capacity of L-ascorbic acid (Arao et al. 2001). Beta-carotene as an antioxidant has proven to be protective against many types of cancers, especially cancer of the lungs and studies have shown it may help to protect the eyes from the damage that can lead to cataracts and also in the protection of phagocytic cells from oxidative damage (Null, 2009). Tomato is also rich in flavonols, which are highly concentrated in the tomato skin as conjugated forms of quercetin and kaempferol (Stewart et al., 2000). These bioactive compounds acts together to contribute to the health benefits of tomato.

### Postharvest quality indices

Tomato is a climacteric fruit and its ripening process is induced by ethylene which affects physical, chemical, and physiological properties of the fruit (Alexander and Grierson 2002). At the onset of ripening there is an increase in the synthesis of ethylene which causes changes in fruit skin colour, sugar content, organic acid metabolism, and tissue generally (Giovannoni 2001). At harvest the fruit begins to respire and this results in a series of biochemical and physiological changes which involves the oxidative breakdown of organic reserves in the fruit (Ravindra and Goswami, 2008).

Tomato quality is measured based on sugar content, titratable acid (TA) content, colour, firmness, total soluble solid (TSS), and ripening index (TSS/TA) (Majidi et al., 2014). Tomato contains organic acids such as citric acid (which is the main organic acid), malic acid, and glutamic acid. In most cases the amounts of these acid are dependent on level of maturity and type of tomato cultivar (Suarez et al., 2008). A decrease in TA and a rise in pH indicates maturity and a reduction in the citric acid content (Fernández-Ruiz et al., 2004; Anthon, et al., 2011). High quality tomato is judged from the intensity of its red colour and the prominence of its flavour (Kader, 2008). The flavour is influenced by the sugar to acid ratio of the fruit (Siddiqui, et al., 2015). The main sugars found in tomato are glucose and fructose, which are usually present at equimolar ratios (Beckles, 2012). The sweetness of tomato becomes more intense when the sugar content is maximum, at which stage the red colour is most pronounced. The red colour is as a result of increase in the amount of lycopene (Giovannoni, 2004). Fruit firmness (texture) is also greatly influenced by ripening, which results in a progressive softening of the fruit flesh (Valero et al., 2005). The developmental changes as a result of ripening is illustrated in figure 1.

### Tomato production in Nigeria

The cultivation of tomatoes spans through all tropical, subtropical and temperate regions of the world and as a result, there are different cultivars of the crop available in the market. In sub-Saharan Africa, Nigeria is the highest producer of the fruit with an estimated annual production of 1.5million metric tons (FAOSTAT 2012). Tomato is grown in most parts of the country, the best area being the Savannah agro-ecological zone, where diseases and pests affecting tomatoes are less common. The major producing areas lie between latitude 7.5°N and 13°N and within a temperature range of 25°C- 34°C (Ugonna et al., 2015). It is grown in the south-western part of Nigeria under rain fed condition and in the northern under irrigated conditions (Ayandiji et. al., 2001). Despite being the highest producers of this food commodity, records of postharvest loss is high. This is as a result of poor postharvest handling of the produce. The lack of adequate storage facilities, poor transportation and marketing channels are major factors that contribute to the losses. Also ignorance of the farmer in the packaging method (packing rotten and fresh fruits together), little or no capacity of the farmers to process their produce and lack of modern storage facilities, result in incidences of losses (Kader, 2005).

In addition, in the cause of transportation of the produce to the market, problems such as bad roads and poor road networks, use of dilapidated vehicles, and the use of baskets; results in reduction in product quality. Farmers are forced to sell at ridiculously low prices which is a loss on their part. There is the need for government intervention in these areas. This can be achieved when the

basic infrastructures such as good roads, adequate storage facilities and the likes are provided. Also the need to educate the farmers on various means of processing for value addition and how to utilize locally made resources to adequately store their produce.

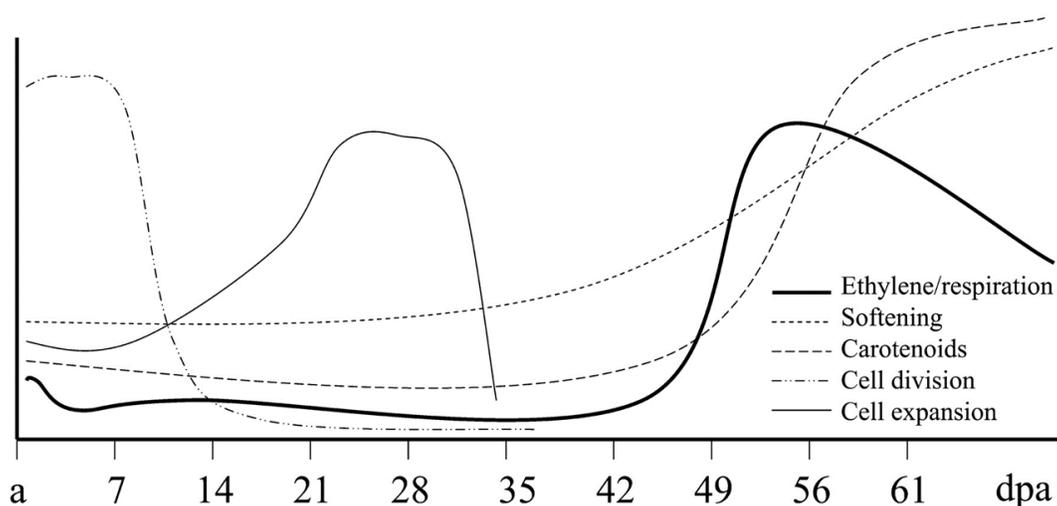


Figure 1: Developmental and Ripening Changes in Tomato Fruit (Giovannoni, 2004)

### Hurdle Technology

Leistner, (2000) defined hurdle technology as “an intelligent combination of hurdles which secures the microbial safety and stability as well as the organoleptic and nutritional qualities and the economic viability of food products.” In recent years the demand for fresh and good quality food products has increased. Food preservation and food security has become a major concern to the growers, food marketers and food manufacturers. This need therefore lead to the emergence of hurdle technology. Hurdle technology is basically the application of the principles of food preservation to ensure a shelf stable product.

### Principle of hurdle technology

Parameters such as temperature (high or low),  $a_w$  (water activity),  $R_h$  (redox potential), preservatives (sorbate, nitrites, sulfites etc.) and competitive microorganisms (lactic acid bacteria), are applied in hurdle technology. These tools or hurdles are used with the aim of achieving a self-stable food product. Some of these hurdle have been in use over the years in the preservation of food products such as meat, fish, dairy and vegetables (Liestner, 2000). In addition, novel hurdles such as nano-thermo-sonication, ultrahigh pressure, photodynamic inactivation, modified and controlled atmosphere packaging of both non-respiring and respiring products, edible coatings, ethanol, milliard reaction products are also being applied in most recent technologies (Gayán et al., 2012).

The basic principle is the deliberate application of combinations of these techniques (both existing and novel) to eliminate the growth of pathogens and spoilage microorganism in food (Gunathilake, 2006). This is done with the major priority of minimizing the possibility for the occurrence or growth of food spoilage and poisoning microorganism during the processing and storage of food.

The use of only one hurdle to achieve the desired product stability means applying such hurdle in high severity. This can result in significant damages to the nutritional and sensory quality of food. Since hurdle technology is all about maintaining the microbial safety and stability as well as the organoleptic and nutritional quality of food (Leistner, 2000), it is important to have a multi-hurdle approach. This approach will provide a control to microbial growth and spoilage, food poisoning and other undesired changes.

## Effect of hurdle technology

The main aim of the technology is to utilize the various preservation techniques to create a synergetic effect on preventing the proliferation of spoilage microorganisms and the overall degradation of the food product. The hurdle effect is illustrated by Leistner, (2000) as shown in figure 2.

From the figure, number 1 illustrates a food containing six hurdle, which are; high processing temperature (F), low storage temperature (t), low water activity ( $a_w$ ), acidity (pH), redox potential (Eh) in the product and preservatives (pres.). In this case, microorganisms present cannot overcome these hurdles, thus the food can be said to be microbiologically stable and safe. Looking at this scenario, all the hurdles are of the same height or intensity, which seldom happens. Therefore this case can only exist in theory.

Number 2 has  $a_w$  and preservatives as the main hurdles. Other hurdles which are of less importance are storage temperature (t), pH and redox potential (Eh). The microbial stability of this product is based on hurdles of different intensity. Therefore these five hurdles are sufficient to prevent the proliferation and thriving of the common types of microorganisms that usually constitute the microflora of such product.

The third example illustrates a process that has only a few microorganisms present at the beginning. To achieve a shelf stable product would only require a few number of hurdles, and at low intensity. This principle is applied in the aseptic processing of perishable foods (e.g. high moisture foods), in which the initial load of microorganisms has been reduced by blanching with steam.

Example 4 results from poor hygienic conditions, where too many undesirable microorganisms are present at the start. In this case even the naturally inherent hurdles in the product may be unable to prevent spoilage or poisoning.

A food rich in nutrients and minerals is presented in example 5. The inherent properties of the food will easily promote the growth of microorganisms, this effect is known as the trampoline effect. However, if the hurdles in this product are enhanced, the microorganisms present may not be able to overcome them.

Example 6 explains the activity of organisms that have been sub-lethally damaged. This happens when the food has been pre-treated by heat, which results in the lack of vitality of vegetative cells. This makes the inhibiting effects of few or low hurdles possible. Also some foods achieve stability during processing by a sequence of hurdle. These hurdles are important in different stages of the ripening or fermentation process to lead to a stable final product (e.g. in the production of yoghurt).

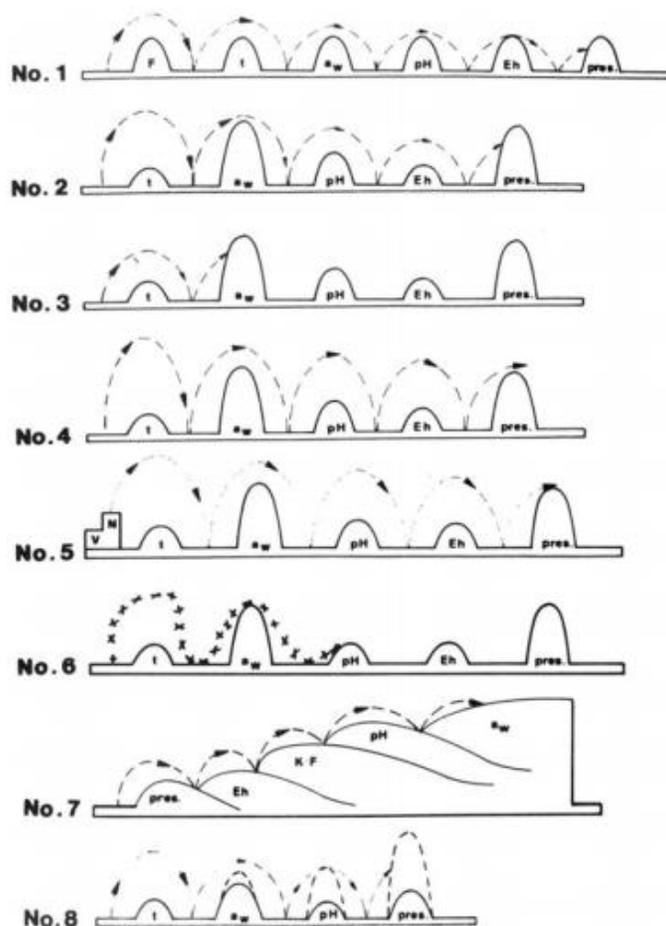
Example 7 illustrates the sequence of hurdles in fermented sausages and possibly in ripened cheese.

The possibility of a synergistic effect of hurdles is explained in number 8. These hurdles have the tendency to a multi-target disturbance of the homeostasis of microorganisms in foods.

## Basic aspects of hurdle technology

**Homeostasis:** It is the state or tendency of equilibrium or stability within a living cell or an organism. This usually occurs in response to the changes in the immediate or external environment. It can be in the form of adjustment to pH, regulation of body temperature etc. Most living cells go through this process and it is also experienced by higher organisms (Leistner, 2000). The application of different hurdles is basically to disturb the homeostatic balance of spoilage organisms in foods and as a result make them inactive or even destroy them (Haussinger, 1988). The disruption of homeostasis could either be temporary or permanent, the best way to achieve

this is usually by deliberately disturbing the several homeostatic mechanisms simultaneously (Gould, 1988). The repair of a disturbed homeostasis demands much energy. Therefore a restriction of the energy supply (e.g. through MAP or vacuum) will inhibit repair mechanism (Thippeswamy, 2011). This in turn results in the preservation of the food from microbial spoilage.



**Figure 2:** Explanation of the hurdle effect in food preservation using eight illustrations. Symbols interpretation: F (heating), t (chilling);  $a_w$  (water activity); pH (acidification); Eh (redox potential); Pres (preservatives); K-F (competitive flora); V (vitamins); N (nutrients). (Leistner, 1995).

### Metabolic exhaustion

This aspect of hurdle technology is focused on causing a stress in the microorganism leading to an auto sterilization effect on the microorganisms. The hurdles are applied in such a way that even when spoilage microorganisms are able to overcome or jump over them initially, the stable storage conditions of the food product can still prevent the survival of such microorganisms (Leistner, 2007). An explanation of this is given from studies made by Leistner, (2000), where he explained that spore count of bacteria that were able to survive heat treatment decreased during storage of the product. This was made possible because the product was store in an unrefrigerated and condition which did not favour the growth of such bacterial spores, consequently resulting in their deactivation. This is not far-fetched from the fact that microorganisms in such shelf stable foods struggle to survive by straining every possible repair mechanism available to attain a homeostatic balance. This causes them to completely use up their energy and eventually they die.

### **Stress reaction**

On their exposure to stress factors such as high processing temperature, low water activity, low storage temperature etc., microorganisms tend to generate stress shock proteins (Carrasco et al., 2012). This makes them become more resistance and even more virulent. This kind of response from microorganisms might hamper the effect of hurdle technology on the preservation of foods, since due to a particular stress, a microorganism becomes more tolerant to other stresses. Conversely, microorganisms would find it more difficult to activate genes that are responsible for the synthesis of stress proteins when they are exposed to different stresses at the same time. Exposure to different stresses at the same time will need an energy consuming synthesis of several protective shock proteins. This will consequently result in the metabolic exhaustion of the organism (Ohlsson and Bengtsson, 2002).

### **Multi-target preservation**

This aspect basically takes advantage of the synergetic effect of different hurdles. The synergetic effect can be achieved when the hurdles are targeted at different homeostatic factors (such as cell membrane, DNA, enzyme systems,  $a_w$ , Eh etc.) within the microbial cells (Walkling-Ribeiro and Rodríguez-González, 2010). Consequently, the repair of homeostatic balance and synthesis of stress shock proteins becomes impossible for the microorganisms. The major advantage of this approach is that the synergetic effect of multiple hurdles would create a product with optimal microbial stability.

### **Classifications of hurdles**

#### **Physical hurdles**

- High Temperature: Sterilization, Pasteurization and Blanching
- Low temperature: Chilling and Freezing
- Irradiation: ultraviolet and ionizing radiation
- Electromagnetic energy ( Microwave energy, Radio frequency energy, Oscillating magnetic field pulses and High electric field pulses)
- Photodynamic inactivation
- Modified atmospheric packaging (Gas packaging, Vacuum packaging, Moderate vacuum and active packaging)
- Packaging film (Plastic, multilayer, active coating and edible coating)
- Aseptic packaging
- food microstructure
- Ultrasonication

#### **Physicochemical hurdles**

- Preservatives: Salt, nitrate, nitrite, sulphate, phosphate, ethanol, chelators, lactate, acetate, propylene glycol, glucono lactones, smoke, phenols, surface treating agents, lacto peroxidase, lysozyme
- Low water activity ( $a_w$ )
- Low pH & redox potential (Eh)
- Gases: Oxygen, ozone, carbon dioxide
- Organic acids: Lactic acid, acetic acid, ascorbic acid,
- Maillard reaction products
- Spices & Herbs

## **Applications of hurdle technology**

Hurdle technology the application of hurdle technology, although it is still a relatively new concept was found some application in the food industry.

### **Meat and meat products**

In the storage of pork sausage at refrigerated temperature, hurdles such as pH, aw, vacuum packaging and post package treatment were employed. The combined effect of these hurdles was able to prevent the growth of yeast and molds for 12days. But when another hurdle in the form of potassium sorbate (as preservative) was added, the sausage was able to store for 30days (Thomas et al., 2010). Malik and Sharma, (2014), confirmed the positive effect of hurdles such as pH, water activity, proximate composition, FFA, soluble hydroxyproline, TBA values, nitrite content and protein solubility on the shelf life of shelf stable ready to eat pickle type spiced buffalo meat products.

### **Dairy products**

In the dairy industry, hurdle technology is also being applied to enhance shelf stability. "Brown peda", a traditional Indian heat desiccated milk khoa based product was prepared and preserved through hurdle technology. The effect of tools (hurdles) such as conventional cardboard boxes, modified packaging and vacuum packaging techniques on the sensory, physicochemical, biochemical, textural and microbiological characteristics of the product during its storage for 40days at 30°C, resulted in a stable shelf life due to low moisture content, higher amount of sugar and severe heat treatment applied during its preparation (Panjagari et al, 2007).

### **Fruits and vegetables**

The principles of hurdle technology have also been applied in the preservation of fruits and vegetables such as carrot, pawpaw, pineapples etc. Osmotic dehydration, infrared drying and gamma radiation have been applied in the development of shelf stable RTE (ready-to-eat) intermediate moisture pineapple. These hurdles were able to reduce the microbial load of the product and extend the product shelf life for up to 40 days (Saxena et al., 2009).

Shelf-stable grated carrot products were developed by Vibhakara et al., (2006), using several hurdles such as antimicrobials, partial dehydration and packaging in polymeric bags the product remained fresh and microbiologically safe for more than six months at ambient temperature.

Fresh scrapped coconut was developed also using this technology. Hurdles used were humectants, acidulants and preservatives. The shelf life of the grated product that was hurdle treated increased by one month at ambient temperature and by three months at refrigerated temperature (5±2°C) (Gunathilake, 2005).

### **Fruit derived products**

Several have also been applied in the development of some fruit based products. Hurdles such as UV light, pulsed light (PL), ultrasound (US), and high hydrostatic pressure (HHP). These have all found use in the preservation of fruit derived products. Sugarcane juice developed by Sankhla et al., (2012) was preserved using hurdle technology.

### **Hurdle Technology in the Postharvest Preservation of Fresh Tomatoes**

An increase in ethylene synthesis induces ripening in tomato which culminates into different changes in the fruit such as a colour

change from green to red as chloroplasts are transformed into chromoplasts, chlorophyll is degraded and carotenoids accumulate; fruit softening and textural changes occur as the fruit cell wall is modified and partially disassembled by enzymes and the ripe flavour develops as specific volatiles increase and the sugar-acid balance alters. (Giovannoni, 2001). A lot of research has gone into understanding the role of different intrinsic and extrinsic factors in the ripening process in climacteric fruits such as tomatoes (Giovannoni, 2004; Alexander and Grierson, 2002). Also importantly the roles of oxygen-carbon dioxide balance has also been studied, this is important since they play significant roles in the respiration and ripening of fruits (Kader and Ben-Yehoshua, 2000; de Wild, et al., 2003).

### Major areas of focus in preserving freshness of tomatoes

In a bid to meet consumer demand for fresh products with extended shelf life, postharvest technologists have been able to focus on influencing the development of some specific quality characteristics. This is done to slow down the event of ripening and eventual senescence of the fruit. Also in the area of inhibiting the action of enzymes involved in the breakdown of the fruit cell wall. The following are major areas of focus in postharvest preservation of tomatoes:

**Maturity:** Tomatoes are usually harvested at physiological maturity and allowed to ripen off the plant. The various stages of maturity can range from immature green to full red stage (Table 1; Cantwell and Kasmire, 2002).

**Table 1: Stages and classes of physiological maturity in tomatoes (Cantwell and Kasmire, 2002).**

Stage of Maturity	Description
Immature	Seed cut by sharp knife on slicing the fruit; no jelly-like material in any of the locules; fruit is more than 10days from the breaker stage.
Mature-green A	Seed fully developed and not cutting on slicing fruit; jelly-like material in at least one locule; fruit is 6-10days from breaker stage; minimum harvest at maturity.
Mature-green B	Jelly-like materials well developed in locules but fruit still fully green; fruit is 2-5days from breaker stage.
Mature-green C	Internal red coloration at the blossom end; but no external colour change; fruit is 1-2days from breaker stage.
Breaker	First external pink or yellow colour at the blossom end.
Turning	More than 10% but not more than 30% of the surface in the aggregate; shows a definite colour from green to tannish-yellow, red or a combination thereof.
Pink	More than 30% but not more than 60% of the, in the aggregate shows pink or red colour.
Light red	More than 60% of the surface; in the aggregate shows pinkish-red or red, but less than 90% of the surface shows red colour.
Red	More than 90% of the surface, in the aggregate, shows red colour.
Full red	Fruit has fully developed red colour; fruit is more aromatic then red stage.

**Ethylene:** The need to inhibit or slow down the rate of ethylene production is also very important in extending the postharvest life of fruits (Sammi and Masud, 2007).

**Temperature:** Due to respiration in plants and their fruits, there is a production of heat.at harvest there is a need to bring down this temperature, neglecting to do so may result in undesirable results such as a very fast process of ripening to senescence.

**Oxygen-carbon dioxide balance:** In order to slow down the rate of fruit ripening, the oxygen to carbon dioxide ratio is regulated. This is important since the ratio of these gases exert a great influence on the rate of fruit ripening (Kader and Ben-Yehoshua, 2000).

**Pathogens and spoilage organisms:** Ripening of fruits means production of some desirable nutrients which could enhance the proliferation of pathogenic or spoilage microorganisms, if proper postharvest measures are not put in place. The problems of pathogens and spoilage organisms are a major source of concern in postharvest food losses.

Important to note is that before applying the above principles, some important point of harvest factors need to be considered. Factors such as time of harvest (considering the level of maturity), reduction of mechanical damage as much as possible, the condition of water used for cooling of the harvested produce and sanitation of the packing house.

### **Techniques Used in Postharvest Preservation of Fresh Tomatoes**

Fruits remain alive after harvest, the climacteric burst of ethylene makes fruits palatable and therefore promotes senescence. The goal of postharvest technology is to manage the concentration and timing of the synthesis of ethylene so that the fruit quality is still at an optimal level by the time it reaches the consumer (Joas and Léchaudel, 2008).

#### **Storage temperature**

To maintain optimum quality and extend shelf life, tomato is stored at between 10°C – 15°C. Tomatoes stored at 10°C above the optimum temperature results in a deterioration of the fruit quality (Saltveit, 2003). Temperature storage below 10°C can result in chilling injuries consequently affecting the fruit quality. The severity of chilling injury is more pronounced in green tomatoes than the red fruit, this is dependent on the storage time and temperature (Cantwell, et al., 2009). The normal development of sugars and volatiles is inhibited in cold storage, this however is dependent on the stage of maturity (Gomez et al., 2009).

#### **Modified and Controlled Atmosphere Storage**

Ethylene related deterioration is inhibited or reduced when harvested fruits are stored in modified or controlled atmosphere. The use of controlled atmosphere (CA) or modified atmosphere (MA) entails the deliberate manipulation of the composition of the gaseous composition of the environment to optimize the product quality. In controlled atmosphere (CA) the gas constituents are more precise and stable while with modified atmosphere (MA) the air composition changes continuously (Majidi, et al., 2014). Carbon dioxide is increased and oxygen is reduced in CA and MA. The effectiveness of this method is dependent on the fruit variety, maturity and initial quality, storage temperature, and the composition and duration of exposure to MA or CA (Brecht et al., 2003).

#### **CO<sub>2</sub>, O<sub>2</sub> and Nitrogen ratio**

Optimal atmosphere modification for oxygen-carbon dioxide ratio to inhibit senescence in tomato is 3–5%(v/v) oxygen for Mature Green and ripe fruit, and 1-3% (v/v) and 1–5%(v/v) carbon dioxide for Mature Green and Ripe fruit respectively with nitrogen supplementation between (94–96% v/v) ((Artes et al., 2006; Sandhya, 2010). Kader and Saltveit, (2003), reported that low oxygen levels outside the above stated ranges can cause harm for the fruit by inducing anaerobiosis. In addition to these gases, the relative humidity of the storage area must be such that it will help to maintain the product quality (Cantwell et al., 2009).

#### **Modified Atmosphere Packaging (MAP)**

It is the use of specialized materials to enclose a product in an altered composition of gases without any other effort to modify the environment. The materials used for MAP allow free diffusion of gases, this helps to maintain an equilibrium between

the external atmospheric gas composition and that inside the package due to tissue respiration (Daş et al., 2006). Commonly used materials are low density (LD) polyethylene (PE), polyethylene terephthalate (PET) polypropylene (PP) polyvinyl chloride (PVC) and polystyrene (Artes et al., 2006; Sandhya, 2010). Modified atmosphere (MA) helps to control ripening, reduce water loss, improve the sanitation of the product, reduce bruising and spread of disease (Kader and Watkins, 2000; Cantwell et al., 2009). These advantages may be further enhanced if ethylene scrubbers or other chemicals are included in the packaging (Bailen et al., 2006; Kader and Watkins, 2000).

### **Methylcyclopropene (1-MCP)**

1-MCP is applied to fresh fruits to inhibit ethylene action. It reduces many of the changes associated with ripening such as respiration rates, cell wall breakdown and color change and is also able to irreversibly bind to ethylene receptors and block ethylene binding (Tassoni et al., 2006). The specific effects of 1-MCP depend on the length and intensity of exposure, the sensitivity of the cultivar and stage of fruit development when applied (Martinez-Romero et al., 2007).

### **Ozone**

Ozone is a well-known potent antimicrobial agent that can be used to simultaneously reduce pathogen attack and delay senescence. It has been shown to reduce ethylene in cold rooms thereby confirming its potency in reducing fruit aging (Aguayo et al., 2006). Ozone treatment of sliced tomatoes appeared not to exhibit any negative effects on the TSS (total soluble solid) content (Aguayo et al., 2006). Higher contents of fructose and glucose in ripe fruit 6 days after ozone-enrichment (0.05 or 1.0  $\mu\text{mol mol}^{-1}$ ) was observed as compared to the controls ( $<0.0005 \mu\text{mol mol}^{-1}$ ) and the treated fruits were found to be sweeter as judged by a sensory panel Tzortzakis, (2007).

### **Edible coating**

They are materials that are used to coat the surface of a food material and are eaten along with the product. These coatings exhibit positive effects on managing senescence in fruits (Vargas et al., 2008). Edible coatings comprise of natural compounds such as carbohydrates: starch and alginate; proteins: whey and casein from milk and zeins and gluten from maize and wheat seeds respectively; and lipids: beeswax, carnauba and candelilla wax and fatty acids, and their derivatives (Zapata et al., 2008; Zhuang and Huang, 2003).

Ali et al., (2010), studied the effect of the coating gum Arabic on mature green fruits of tomato cultivar 'moneymaker' stored at 20°C for 20 days. The taste of the coated fruit was judged by panelists to be better than that of the control. Another study found that coated mature Green tomatoes stored at either 5°C or 12°C tolerated chilling injury better than the controls however low temperature reduced TSS (Mejia-Torres et al., 2009).

### **Irradiation**

It is classified as non-ionizing or ionizing. Ionizing radiation is high frequency and causes loss of ions from the material with which it comes into contact. Radiation can also minimize the colonization of fruit with pathogens due to contamination, insect infestation, postharvest disease, as well as delay ripening (Allende et al., 2006; Bruhn et al., 2009). The three most commonly used are UV-C, X-ray and gamma-rays. Ultra violet ray is non-ionizing and is frequently used for postharvest management of fruit. Most experiments were done with UV-C but UV-B has recently been investigated (Charles and Arul, 2007).

### **Combined Effect of These Techniques on Tomato Preservation**

Fagundes et al., (2015), studied the combinations of active MAP and cold storage on the postharvest quality of cherry tomatoes. The produce was stored in bi-oriented polypropylene/low density polyethylene BOPP/LDPE bags (with a gas composition of 5% O<sub>2</sub>+ 5% CO<sub>2</sub>) at (5°C). The combined effect of these two techniques was effective in delaying maturity of the fruit and extending the shelf life for up to 25days, while maintaining the quality of the tomatoes.

The effects of 1-methylcyclopropene (1-MCP), modified atmosphere packaging and their combination were investigated on storage and quality maintenance of tomatoes at pink and red stages of ripening. The fruits were stored at 12oC with 90% relative humidity for 21 days. Parameters related to fruit ripening, such as skin color, lycopene, TA and SSC/TA were evaluated. The overall results indicated that the combination of 1,000 µL/L 1-MCP and modified atmosphere package was the most effective treatment in delaying fruit ripening at the two stages (Sabir and Agar, 2011).

Choi et al., (2014), reported that the combined application of ultraviolet-C (UV-C) irradiation, modified atmosphere packaging (MAP), and cold storage temperature on the microbial quality of cherry tomatoes. UV-C irradiation at 2kJ/m<sup>2</sup> was able to inactivate *Salmonella enterica* serovar Typhimurium which was used in the study. After 9 days of storage, the overall quality of the fruits was still maintained.

Different packaging systems developed by Sammi and Masud, (2007) were evaluated for their suitability to extend storage life and improve the quality of tomato fruits. Freshly harvested mature green tomatoes were packed in polyethylene packaging with or without treating with calcium chloride, boric acid and potassium permanganate. The storage life and quality of the fruits was maintained for up to 96days of storage.

The shelf life of tomato was extended for up to 17days as a result of treatments with chlorine with the combinations of MAP and two storage conditions (ambient condition: Temperature 20-25°C & relative humidity 70-90% and refrigerator: 4-5°C & relative humidity 60-65%) (Nasrin et al., 2008).

With various studies that has been done and those still being carried out, these techniques can be successfully applied as hurdles in extending the postharvest shelf life of fresh tomatoes and also simultaneously preserving quality (organoleptic, nutritional and microbial).

### **Conclusion**

Hurdle technology in the past, has majorly been focused on the physiological responses of microorganisms during food preservation. However, to successfully apply this technology in the postharvest technology of fruits and vegetables, other factor such as how to inhibit or slow down ethylene synthesis while slowing fruit ripening should also be considered. Since in the postharvest life of these products is not just about the pathogens but about the various biochemical and physiological changes that occurs as a result of ripening, all of which has a direct effect on the storability and shelf life of the product. It is very imperative to slow down these processes as much as possible to ensure that the freshness, nutritional and organoleptic qualities are intact by the time it gates to the final consumers.

Research carried out by different scientist on the postharvest technology of tomatoes has been able to prove that application of existing and novel techniques can successfully help to extend the shelf life of fresh tomato produce. Therefore, the onus lies on postharvest technologists to study these techniques and develop methods of intelligently applying them in the preservation of fruits and vegetables.

Unfortunately, developing countries such as Nigeria have a long way to go in this area. This is not far-fetched from the dearth of researchers who are actually interested in solving problems. Also, the lackadaisical attitude of the government in sponsoring research is of a major concern. The lack of the required infrastructure for the successful application of these technologies is also a major issue.

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