EXTENDING THE SHELF OF TOMATO THROUGH HURDLE TECHNOLOGY – A MINI REVIEW

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Abstract
Purpose: Nigeria being the second-largest producer of tomatoes in Africa and 13 in the world, has an estimated total postharvest loss of over 60%.To reduce the postharvest loss of this commodity, various researches have been carried out on the best methods to be employed in the preservation of tomato. In Nigeria, the method of storages adopted mostly depends on traditional knowledge. This method is risky as in some cases, a large percentage of the produce gets rotten before they take the produces to the market. Sprouting, desiccation and microbial spoilage are often observed in storage and it compels to choose advanced techniques like modified ventilated structures, modified atmospheric (MA) and controlled atmospheric (CA) storage. Some of these techniques are used individually or combined. These techniques 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 cold storage, waxing, and chlorine treatment have been employed all in a bid to extend postharvest shelf life and quality of tomato.

Keywords: Hurdle technology, tomato, preservation, postharvest

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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 second-largest producer of tomato fruits in Africa and the 13th in the world. It is a popular part of the Nigerian diet and is widely consumed fresh and cooked. Tomato is a rich source of fiber, folates, antioxidants (such as ascorbic acid, vitamin E and carotenoids), phenols, flavonoids etc. (Rao, 2006). These inherent nutritional properties make it very important as a part of the diet. Epidemiological and clinical studies have shown that the consumption of this fruit 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 and nutritional benefits, it has a short shelf life resulting in high losses (Shankara *et al.*, 2005). It is estimated that about 50% of the harvested fruits are lost before it reaches the final consumer (Mashav, 2010). In Nigeria, Kutuma et., al (2007) reported a loss of about 60% in tomato. High perishability of this crop results in a decrease in its quality by the time it eventually gets to the table of the consumers. This occurs when proper postharvest practices are not employed. Postharvest losses have severe 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 land, water, labor, managerial skills, and other inputs that have been channeled towards the production of the crop (Farooqi and Kumar, 2003). 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 tomato fruits 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 in the preservation of tomato. 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 maintain quality of produce (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 tomato can be cold storage below 10^{o}C (Cantwell et al., 2009), and inhibition of sugar development in harvested fruits due to cold storage (Gomez et al., 2009).

Hurdle technology is the combined application of new and existing techniques that 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 the microbial stability of food products. This review, therefore, aims to state the various ways the principles of hurdle technology that can be applied in the preservation of the freshness and quality of fruits and vegetables considering tomato as a case study.

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. 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 regions lie between latitude 7.5ºN and 13ºN and within a temperature range of 25ºC- 34ºC (Ugonna et al.,.2015). It is grown in the south-western part of Nigeria under the rain fed condition and the northern under irrigated conditions (Ayandiji et al., 2001). Despite being the highest producers of this food commodity, records of postharvest loss are high. This is as a result of poor postharvest handling of the produce. The lack of adequate storage facilities, inadequate transportation, and marketing channels are significant factors that contribute to these 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, resulting in incidences of losses (Kader, 2005).

Also, during transportation of produce to the market, problems such as bad roads and sparse road networks, use of dilapidated vehicles, and the use of traditional woven baskets; result in a reduction in product quality. Farmers are forced to sell at ridiculously low prices which are a loss on their part (Kader, 2005). There is a 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, there is a need to educate the farmers on the various means of processing for value addition and how to utilize locally-made resources to store their products adequately.

Health benefits of tomato

Studies have shown that the consumption of tomatoes was able to prevent the occurrence of 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 (Rao, 2000). Although there is said to be a synergetic contribution by other antioxidants notwithstanding, there is a 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 β-carotene and 2.9 times higher than the antioxidative capacity of L-ascorbic acid (Arnao et al. 2001). Beta-carotene is 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).

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 (notable potassium) and carboxylic acids, including ascorbic, citric, malic, fumaric, and oxalic acid (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, β-carotene, α-carotene etc.), flavonoids, polyphenols etc. (Dewanto et al., 2002; Slimestad, 2008). The major antioxidants in tomato arelycopene which is responsible for its red color 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 (Ravindra et al., 2008). This vegetable crop also represents a relevant source of soluble and insoluble fibers.

Postharvest quality indices

Tomato is a climacteric fruit and its ripening process is induced by ethylene which affects the 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 color, sugar content, organic acid metabolism, and tissue generally (Giovannoni 2001). The fruit begins to respire, and this results in a series of biochemical and physiological changes that involve 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, color, firmness, total soluble solids (TSS), and ripening index (TSS/TA) (Majidi et al., 2014). Tomato contains organic acids such as citric acid (which is the leading organic acid), malic acid, and glutamic acid. In most cases, the amounts of these acids are dependent on the level of maturity and type of tomato cultivar (Suarez et al., 2008). A decrease in TA and a rise in pH indicate 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 color and the prominence of its flavor (Kader, 2008). The taste 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 (Beckles, 2012). The sweetness of tomato becomes more intense when the sugar content is maximum, at which stage the red color is most pronounced. The red color is a result of an increase in the amount of lycopene (Giovannoni, 2004). Fruit firmness (texture) is also influenced by ripening, which results in a progressive softening of the fruit flesh (Valero et al., 2005).

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 (Cantwell and Kasmire, 2002). Table 1 illustrates the stages and classes of physiological maturity in tomatoes.

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 (Kader and Ben-Yehoshua, 2000)

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 the 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 needs 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.

Table 1. Stages and Classes of Physiological Maturity in Tomatoes.

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 color change; fruit is 1-2days from breaker stage.
Breaker	First external pink or yellow color at the blossom end.
Turning	More than 10% but not more than 30% of the surface in the aggregate; shows an exact color 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 color.
ht red	More than 60% of the surface, in the aggregate, shows pinkish-red or red, but less than 90% of the surface shows red color.
Red	More than 90% of the surface, in the aggregate, shows red color.

Source: Cantwell and Kasmire (2002).

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).

1 Storage temperature

To maintain optimum quality and extend shelf life, tomato is stored at between 10^{o}C – 15^{o}C. Tomatoes stored at 10^{o}C above the optimum temperature results in a deterioration of the fruit quality (Saltveit, 2003). Temperature storage below 10^{o}C can result in chilling injuries, consequently affecting the fruit quality. The severity of the 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).

2 Modified and controlled atmosphere storage

Ethylene related deterioration is inhibited or reduced when harvested fruits are stored in a modified or controlled atmosphere. The use of a 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 a controlled atmosphere (CA), the gas constituents are more precise and stable, while with the 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).

3 CO_2, O_2 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 could 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).

4 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 polyethylene (LDPE), 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 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).

5 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 the stage of fruit development when applied (Martinez-Romero et al., 2007).

6 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 solids) content (Aguayo et al., 2006). Higher contents of fructose and glucose in ripe fruit 6days after ozone-enrichment (0.05 or 1.0 μmol mol−1) was observed as compared to the controls (<0.0005 μmol mol−1) and the treated fruits were found to be sweeter as judged by a sensory panel Tzortzakis, (2007).

7 Edible coating

They are materials that are used to coat the surface of 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^{o}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^{o}C or 12^{o}C tolerated chilling injury better than the controls; however, low temperature reduced TSS (Mejia-Torres et al., 2009).

8 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. Ultraviolet ray is non-ionizing and is frequently used for postharvest management of fruit. Most experiments were done with UV-C, but UV-B has been investigated (Charles and Arul, 2007).

COMBINATION OF SOME 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% O2+ 5% CO_2) at (5^{o}C). The combined effect of these two techniques was effective in delaying the maturity of the fruit and extending the shelf life for up to 25days while maintaining the quality of the tomatoes.

The effects of 1-methyl cyclopropane (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 12^{o}C 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 nL/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 radiation at 2kJ/m^2 was able to inactivate *Salmonella enterica* serovar Typhimurium, which was used in the study. After nine 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 for extending storage life and improving 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 were 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 and relative humidity 60-65%) (Nasrin et al., 2008).

With various studies that have 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)

HURDLE TECHNOLOGY

Due to the inadequate technologies for post harvested food preservation, more than 50% of the harvested food is often lost due to spoilage in developing countries. It has been reported by FAO of the United Nations that one-third of the total harvested food of the world is lost before it is consumed. The current consumer demands natural & fresh food which urges the food manufacturers to establish a new preservation technique. Statistics show that 95% of the investment for agriculture resources has been allocated for production, while only 5% for the preservation of food. In the majority of cases, microorganisms are responsible for spoilage or poisoning. Despite the availability of a range of preservation techniques like freezing, blanching, pasteurization, canning etc. spoilage and poisoning of food materials by microorganisms is still a major cause for food spoilage. The microbial safety & stability of most foods are based on an application of preservation factors called hurdles & the technique applying the different hurdles is known as hurdle technology.

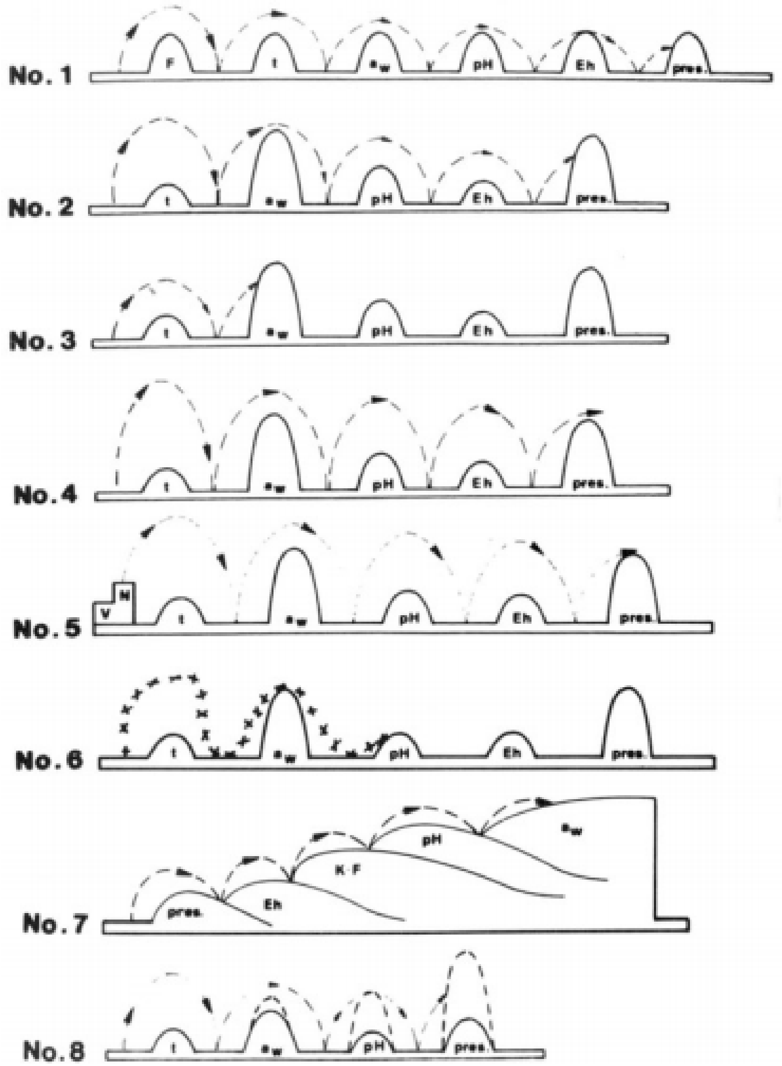
Hurdle technology is a concept that was developed to address the consumer demand for more natural and fresh foods (Leistner, 2000) defined hurdle technology as an intelligent combination of hurdles which secures the microbial safety and stability as well as retains the organoleptic, nutritional quality and economic viability of food products. Some of the hurdles such as temperature (high or low), water activity(aw), preservatives (nitrite, sorbate), competitive microorganisms (lactic acid bacteria) and acidity (pH) have been empirically used for years to stabilize meat, fish, milk and vegetables (Leistner, 2000).Various novel hurdles that are being applied in multiple food products include nano-Thermo- sonication, ultrahigh-pressure, photodynamic inactivation, modified atmosphere packaging of both non-respiring and respiring products, edible coatings, ethanol, milliard reaction products (Gayán et al., 2012). The basic concept is to apply combinations of existing and novel preservation techniques ("hurdles") in order to eliminate the growth of micro-organisms. Therefore, while the aim of effective food preservation is to control all forms of quality deterioration, the overriding priority is always to minimize the potential for the occurrence and growth of food spoilage and food poisoning microorganisms.

Hurdle technology has been developed to reduce the usage of preservatives in foods, and consists of the combined effect of hurdles to establishing an additional antimicrobial effect, thus improving the quality of the food (Leistner, 2000).This modern preservation technology has been developed for the consumers who demands healthy and fresh foods that retains its nutritional and organoleptic properties as well.

Parameters such as temperature (high or low), a_w (water activity), Rh (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 shelf-stable food product. Some of these hurdles have been in use over the years in the preservation of food products such as meat, fish, dairy, and vegetables (Liestner, 2000). Besides, 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 microorganisms in food (Gunathilake, 2006). This is done with the major priority of minimizing the possibility of the occurrence or growth of food spoilage and poisoning microorganism during the processing and storage of food.
The use of only one hurdle to achieving the desired product stability means applying such hurdles 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 control to microbial growth and spoilage, food poisoning, and other undesired changes.
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.

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).



Source: Leistner (2000)

From the figure, number 1 illustrates a food containing six hurdles, which are; high processing temperature (F), low storage temperature (t), low water activity (a_w), acidity (pH), redox potential (Eh) in the product and rio, all the hurdles are of the same height or intensity, which seldom happens. Therefore this case can only exist in theory.
les that 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 a 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 numbers 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 portion of 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 organisms 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

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 scena
Number 2 has a_w and preservatives as the main hurdles. Other hurd

fermentation process to lead to a stable final product (e.g., in the production of yogurt).
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 tend to a multi-target disturbance of the homeostasis of microorganisms in foods.

BASIC ASPECTS OF HURDLE TECHNOLOGY

Homeostasis

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 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.

Metabolic exhaustion

This aspect of hurdle technology is focused on causing stress in the microorganism leading to an auto sterilization effect on the organisms. 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 organisms (Leistner, 2007). An explanation of this is given from studies made by Leistner (2000), where he explained that spore count of bacteria that we're able to survive heat treatment decreased during storage of the product. This was made possible because the product was stored in an unrefrigerated and condition which did not favor 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 use up their energy, and eventually, they die completely.

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 more resistant 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, an organism becomes more tolerant of 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 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

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 40days (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 scraped coconut was also developed 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^{o}C) (Gunathilake, 2005).

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, Radiofrequency 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, sulfate, phosphate, ethanol, chelators, lactate, acetate, propylene glycol, glucono lactones, smoke, phenols, surface treating agents, lactoperoxidase, lysozyme
- Low water activity (aw)
- 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 IN DIFFERENT PRODUCTS

Preservation of various vegetables and fruits like carrot, pineapple, coconut & papaya to enhance their stability and shelf life. Shelf-stable grated carrot products are developed using hurdle technology. Used several hurdles such as antimicrobials, partial dehydration and packaging in polymeric bags to grow grated carrotsthat can remain fresh and microbiologically safe for more than six months at ambient temperature. Hurdle technology can also be applied to develop shelf-stable RTE (Ready-To-Eat) intermediate moisture pineapple with increased shelf life. Osmotic dehydration, infrared drying, and gamma radiation can successfully reduce the microbial load in pineapple slices increasing its shelf life up to 40 days. Hurdle technology Applied in the preservation of fresh scrapped coconut. Additives such as humectants, acidulants and preservatives were used. The shelf life of hurdle treated coconut gratings was increased by one month at ambient temperature and by three months at refrigerated temperature (5+2 C).

Minimally processed shelf-stable high moisture grated papaya is also prepared by hurdle technology using different hurdles like mild heat treatment, aw, pH reduction, and the addition of preservatives. This combined methods technology developed microbiologically safe and nutritionally intact papaya that is shelf-stable at ambient temperature for more than five months.

Several conventional hurdle strategies are effectively used along with the new ones for the preservation of various fruit products. Some of the hurdles applied in fruit processing include UV light, pulsed light (PL), ultrasound (US), and high hydrostatic pressure (HHP). Also, Hurdle or combined technology is applied in the preservation of high moisture fruit products such as peach, pineapple, papaya, mango and banana. The technology is based on the combination of heat treatment, aw and addition of antimicrobials. Also Hurdle technology has been applied to several meat products such as buffalo meat products.

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, another factor such as how to slow down ethylene synthesis while slowing fruit ripening should also be considered. 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 scientists on the postharvest technology of tomatoes has been able to prove that the 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. The lack of the required infrastructure for the successful application of these technologies is also a significant issue.

CONFLICT OF INTEREST

The authors have no conflict of interest to report.

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