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Preservation of mature green tomatoes using controlled atmosphere storage under tropical conditions

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Preservation of mature green tomatoes in a controlled atmosphere (CA) was studied under semi-arid condition in Nigeria. Mature-green tomatoes were held in 5-litre glass jars filled with 4% oxygen and 96% nitrogen at ambient temperature of 24 to 29°C for 5 days or 10 days. The fruits were thereafter exposed to normal atmosphere and compared with fruits that were stored in normal air (control).. Fruits held in CA for 5 days (CA+5) showed fresh appearance, normal ripening, lowered weight loss and a significant reduction in spoilage (P< 0.05) compares those stored in ambient (24 to 29°C and 56 to 74% RH). CA holding for 10 days (CA+10) caused marked off-flavor in the fruits and they did not ripen to full eating also showed significantly higher decay than those held for 5 days. The shelf life of 5 days in the ambient was extended to 14 days and 16 days when initially held in nitrogen atmosphere for 10 days (CA+10) and 5 days (CA+5) respectively. The present study revealed that the CA storage of tomatoes (using nitrogen) enhance the retention of the sensory qualities of Roma tomatoes when they were held for 5 days than for 10 days before normal storage in air.

Key words: Spoilage, fruit holding period, shelf life, sensory quality.

INTRODUCTION

Tomato (*Lycopersicon esculentum* (L.) Karst) is the most important fruit vegetable grown in Nigeria and has become very important in the nation diet as an essential ingredient of soups and stews. It is a climacteric fruit with a short shelf life under ambient storage conditions. The major problems of tomato trade and distribution are caused by the perishable nature of the fruit resulting in rapid spoilage after harvest. When harvested at the mature green stage, ripening sets in thereafter and reaches full-ripe stage within 8 days and later shrivels thereby losing firmness and fresh appearance. This is accompanied with physiological loss in weight, structural disintegration, and, sometimes, nutritional loss. The fruits eventually become susceptible to rotting, particularly, as they ripe. According to FAO (2010) Nigeria ranks 16th in the world ranking of tomato producing countries. The

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country produces about 1.8 metric tonnes which accounts for about 68.4% of West Africa, 10.8% of Africa's total production and 1.28% of world's production. Although tomato is consumed across the country it is cultivated in the Northern region of the country. The major producing states are; Kano, Jigawa, Kaduna, Gombe, Sokoto, Bauchi, Zamfara, Kastina, Kebbi, Borno and Benue states (Ugonna et al., 2015).

Studies in controlled atmosphere (CA) storage have shown that storage life of tomatoes could be extended in low oxygen (O_2) atmosphere and thus reduce wastage (Daş et al., 2006). Controlled atmosphere (CA) slows down the natural rate of respiration, inhibits many ripening process and prolonged storage life. Removal of oxygen and enrichment of the atmosphere surrounding stored tomatoes with nitrogen can reduce deterioration from softening (Majidi et al*.,* 2014).

The actual benefit and effects of CA storage on crops vary with such factors as concentration of gases, species and cultivars of crop, storage of ripeness of the climacteric softening. Typical storage conditions were given as 3-5% O_2 with 3-5% CO_2 at 10-15°C (Bishop, 1996). However, Kader (1985), recommended 3-5% O_2 with 0% CO_2 for mature green tomatoes, which proved effective. Their flavour, however, was becoming poorer after 4 days (in 100% N_2) or after 10 days in 99% N_2 with1%). Fellows (2009) recommended a minimum of 3% O_2 and a maximum of 2% CO_2. Other recommendations of CA storage by various workers were recorded by Thompson (1998). Recommended concentrations of gases generally fall within ranges of 2-10% O_2 and 0-9% CO_2 with nitrogen presumably making up space volumes. These resulted in shelf life of between 6 and 12 weeks at recommended temperatures of 8 to 20°C.

The objective of this study is to determine the effects of a controlled atmosphere of low O_2 concentration in nitrogen on the storage of mature-green tomatoes under tropical conditions.

MATERIALS AND METHODS

The experimental material consisted of tomato fruits, var Roma, showing the first change to orange near the blossom scar (referred to as "just turning" state of maturity). The tomatoes were harvested from a garden farm in Kano, Nigeria. 360 uniformly mature fruits were selected, washed and randomly divided into nine groups of 40 fruits. All fruits were pre-cooled over night in air-conditioned room at 21±1°C.

Three lots of fruits were used, as replicates, in each of the following treatments: Control fruits stored at normal atmosphere, controlled atmosphere (CA) storage for 5 days (CA+5D) followed by air storage and controlled atmosphere storage for 10 days (CA+10D) followed by air storage. Each controlled atmosphere (CA) storage treatment used three 5-litre glass jars, which were connected with nitrogen (N_2) supplied from a pressure cylinder equipped with pressure regulator and flow meter. The jars containing fruits were sealed such that N_2 could be applied at constant pressure through capillary tubes filled through rubber stoppers. Air tightness of the supply system was secured by checking with a foaming leak detector of soap solution. A pressure relief valve, simply comprising a smaller glass jar filled with water, was fitted to the base of each jar. This prevented excessive pressure build-up within the jar by providing an exit for excess gas. The jars were flushed with purified N_2 at a flow rate of 5 L/h. Flow rate during gas supply was reduced to 2.5 L/h at constant pressure. The level of oxygen in jars was maintained at 4% concentration by replenishing the flowing N_2 manually with oxygen (O_2). To add O_2, outside fresh air was briefly introduced through a control valve.

As this additional air mixed with N_2 in the jars, the O_2 level was measured and the valve opened again for more intake of O_2 if required. In doing this, a tolerance limit of ±0.3% was allowed. Thus, whenever the O_2 concentration (of 4%) dropped to 3.7% during operation, fresh outside air was introduced to raise this to 4.3%. Oxygen concentration in the jars was measured with Taylor Servomex Oxygen analyzer, type OA 272. Tomatoes were removed from CA jars after 5 and 10 days for treatments CA+5D and CA+10D respectively. Three lots of control fruits were held each in a clean plastic basket cushioned lightly at the bottom with polystyrene foam. All samples were stored at the ambient temperature of 20 to 29°C.

The fruits were examined for decay, sensory quality (ripening and firmness) and nutritive value (ascorbic acid (vitamin C) and titratable acidity) after 10 days of storage and at subsequent holding periods of 2, 4 and 6 days in normal air of 20 to 29°C and 34 to 64% relative humidity. For sensory evaluation, the 15 trained panelists were staff of the Nigerian Stored Products Research Institute, Kano. Ripening was assessed subjectively by skin color rating based on 8 point color scale of 1 = mature green, fruits with completely green skin; 4 = pink, fruits with about 50% or more pink skin; 6 = firm red (fruit fully red but with firm skin) and 8 = table ripe (fruits fully red with soft skin). The eight ripening stages used are equivalent to the indicated color levels 1to 8 on the recommended color chart that has been produced by the Organization de Cooperation et de Development Economiques, Paris, to facilitate grading standards for tomatoes (Thompson, 2003). Tomatoes that are fully ripe beyond levels 8 on the chart were soft and obviously more susceptible to handling damage and, so, considered over-ripe. Firmness was assessed by gently applied finger pressure and rated as 1 = very firm, 2 = firm, 3 = fairly firm and 4 = soft. Decay incidence was taken as the percentage of visibly diseased fruits. Decaying fruits were discarded and a treatment with 20% decay terminated. The experiment was laid out in completely randomized design. The data of the fruits of all treatments (storage in ambient, control atmosphere storage and length of holding) were subjected to analysis of variance and the treatment means compared using Dunca's New Multiple Range test at a significant level of $P<0.05$..Total titratable acidity was determined as percent citric acid by direct titration against decinormal NaOH using phenolphthalein as indicator. Ascorbic acid was quantified by AOAC (1984), using 2, 6 - dichlorophenon dye.

RESULTS

Oxygen levels in the controlled atmosphere (CA) storage chambers were maintained at 4±0.3% during storage of tomatoes. However, the O_2 and N_2 levels were continually maintained by flushing and venting. CA treatments were beneficial in suppressing tomato decay. Tomatoes held in CA for 5 or 10 days showed significantly less decay, before opening and after subsequent airing than those that had been stored

Table 1. Effect of controlled atmosphere on decay of stored tomatoes.

Treatment	Decay (%)				
	Initial storage period (days)		Subsequent holding period (days)		
	5	10	2	4	6
Air storage	15.4[b]	86[c]	100[b]	-	-
CA+5D	2.0[a]	7.4[b]	10.5[a]	11.60[a]	14.0[b]
CA+10D	2.0[a]	4.0[a]	8.0[a]	13.0[a]	19.0[a]

Means followed by the same letter in each letter in each column do not differ significantly at P<0.05.

Table 2. Effect of controlled atmosphere on colour index of stored tomatoes.

Treatment	Colour Index (CI)				
	Initial storage period (days)		Subsequent holding period (days)		
	5	10	2	4	6
Air storage	7.2[b]	8.0[c]	8.0[c]	-	-
CA+5D	2.3[a]	4.4[b]	4.8[a]	5.6[a]	6.2[a]
CA+10D	2.2[a]	2.4[a]	3.6[a]	4.4[a]	5.0[a]

Means followed by the same letter in each letter in each column do not differ significantly at P<0.05.

continuously in air (Table 1). The percentage of decayed tomatoes in CA reduced significantly from air stored tomatoes (control). In air, 86% of the tomatoes were decayed after 10 days. Averages of only 7.4 and 4.0% were decayed during the same period in CA+5D and CA+10D treatments respectively. The benefit observed in 5-day nitrogen treatment became more pronounced before 4-day exposure to air. Thereafter, decay became more rapid and higher than in 5-day nitrogen treatment. When holding in CA was extended to 10 days (treatment CA+10D) mature green tomatoes still kept better (firmer and greener) than CA+5D fruits which had already been exposed to air for 5 days.

The trends of ripening of tomatoes held in CA and in normal atmosphere (control) are shown in Table 2. CA treatment was effective in slowing down fruit ripening as indicated by low values of colour index. Noticeable changes in colour first occurred in air-stored fruits after 2 days and progressed rapidly to the end of storage. However, after exposing CA+5D fruits to normal air initially for 5 days, a rapid increase in skin colour change was observed and this became significantly (P = 0.05) higher than in fruits left continuously in CA. The rapid change in skin colour of control fruits brought them to the table ripe stage (CI 8) after 9 days (Table 2). Much less and non-significant (P <0.05) change in colour was observed in tomatoes stored continuously in CA for 10 days (CA+10D) fruits. In this treatment, colour developed in mature–green tomatoes more slowly and the fruits ripened only to and remained at the pink stage (CI 5) after 5 days of transfer to normal air. Tomatoes removed from CA+5D treatment ripened more evenly to dark pink after additional 5 days in air.

Firmness decreased with storage days in all treatments (Table 3). Fruits treated in CA+10D maintained their firmness better than those of CA+5D treatment. The tomatoes held up to 10 days in CA showed no significantly impairment of texture and general appearance but did not ripen fully to eating quality. Marked off-flavour was apparent immediately after removal from gas after this extended storage period, indicating the onset of fermentation. The objectionable flavour faded away after fruit exposure to air for about 16 h. Previous workers (Boukobza and Taylor, 2002; Polenta et al*.,* 2006) have noted that subjection of tomatoes to anoxia for extended time adversely affected fruit quality due to the accumulation of acetaldehyde and ethanol. The degradation of ascorbic acid in tomatoes was retarded by CA storage when compared with air storage (Table 4).

DISCUSSION

Controlled atmosphere storage of fresh vegetables is concerned with prevention of decay and maintenance of market quality of the commodities, particularly with respect to firmness, texture and general appearance. The results show that tomatoes retained these basic characteristics of the fruits with the possibility of reducing

Table 3. Effect of controlled atmosphere on firmness of stored tomatoes.

Treatment	Firmness Index (FI)				
	Initial storage period (days)		Subsequent holding period (days)		
	5	10	2	4	6
Air storage	1.8[b]	3.1[b]	3.3c	-	-
CA+5D	1.2[a]	1.8[a]	4.8[a]	5.6[a]	6.2[a]
CA+10D	1.2[a]	1.3[a]	3.6[a]	4.4[a]	5.0[a]

Means followed by the same letter in each letter in each column do not differ significantly at P<0.05.

Table 4. Changes in ascorbic acid (vitamin C) and titratable acidity of tomatoes held in controlled atmosphere for 5 and 10 days.

Treatment	Ascorbic acid (mg/100 g)	Tritrable acidity (ml, 0.0 m NaOH)
Initial	23.15	8.4
Air storage	15.92	7.23
CA+5D	19.53	7.63
CA+10D	20.72	8.02

losses during storage in controlled atmosphere of 4% 0_2 with 96% N_2. This is in line with the benefits of CA of low oxygen (3% $O_{2)}$ and high (20%) reported by Wang (1990) and Kapotis et al. (2004).

The onset of ripening in fruits enhances senescence, which renders them susceptible to infection by pathogens. The delay of ripening achieved in CA tomato enhanced their resistance to decay. The results presented above agree with those results for the other `fruits in which low-O_2 treatment delayed the maturation process and prolonged shelf life (Teixeira and Durigan, 2004). Mature-green tomatoes held under low oxygen colored normally when transferred to air at 18.3°C (Madhavi, and Salunkhe, 1998). Fewer than 5% of the fruits decayed compared to 90% decay of tomatoes held in air. These workers, however, stored tomatoes at low temperatures, which may account for the much longer shelf life achieved. The present work was carried out at higher temperature, the ambient (20 to 29°C). Fallik et al. (2003) observed that, although similar treatment (at 20°C) delayed the colour development of tomatoes, it did not affect their organoleptic characteristics; this was also noted by Passam et al. (2007). Moreover, results of Majidi et al. (2014) showed that the ability of control atmosphere storage to retard the ripening process in tomatoes was more than cold storage. With regard to maintaining texture and color, the treatment was also better than cold storage.

The improved retention of green colour in mature–green tomatoes under the tested CA conditions is perhaps due to reduced breakdown of chlorophyll. Wang (1990) reported that the activities of enzymes associated with fruit ripening were reduced in CA storage. The work of Goodenough and Thomas (1980) showed that suppression of degreening of tomatoes during ripening in CA of 5% O_2 combined with 5% CO_2 was due to a combination of suppression of chlorophyll degradation and the suppression of the synthesis of carotenoids, lycopene and Xamthophyll. Jeffery et al. (1984) also showed that lycophene synthesis was suppressed in tomatoes stored in 6% O_2 combined with 6% CO_2. Kapotis et al. (2004) observed that tomato fruits stored under low O_2 conditions remained firm and green with low polygalacturonase (PG) activity throughout storage, whereas, during storage in the air, PG activity increased and the fruits softened and developed their characteristic red color. Sozzi et al. (1999) particularly noted that the low O_2 atmospheres prevented the rise in ethylene production, total carotenoid and lycopene biosynthesis and α- and β-galactosidase activity and slowed down chlorophyll degradation and loss of firmness ($P < 0.05$). After transfer from the atmosphere to air, flesh firmness decreased and ethylene production, total carotenoids, lycopene and β-galactosidase II activity increased which could determine most of the ripening parameter behaviour under controlled-atmosphere storage. Other attributes of controlled atmosphere storage of tomatoes, though not within the purview of this study but noted by Daş et al. (2006) is the control of infection that are caused by microorganisms such as *Salmonella enteritidis.*

Future developments in CA storage of tomatoes could, therefore, lie in the control of the initiation of ripening which has been demonstrated here. Otherwise, even short-term storage of red, almost fully ripe tomatoes under conditions of low or zero O_2 (such as in N_2 for 35 h) adversely affects fruit aroma, due to a reduction in C-6 compounds and isobutylthiazole, and an increase in ethanol and acetaldehyde (Boukobza and Taylor, 2002). Practical use of the CA storage described may depend on some technical and economical considerations, which are just evolved. These include development of appropriate cooling systems, contained gas tightness, maintaining the CA and Nitrogen supply system. The nutritional importance of ascorbic acid lies in the effect of CA storage upon its retention of ascorbic acid because of the low affinity of ascorbic acid oxidase to oxygen.

Conclusions

The procedure of applying ca tested in this study has demonstrated a potential for extending shelf life of mature green tomatoes. The storage system may be a practical substitute in situation where cold storage is not feasible. Our results indicated a tendency of the anoxic condition to induce anaerobic respiration and softening of intact fruits with continued holding under nitrogen. The minimal effects of anaerobic respiration encountered in the process were averted by exposing the fruit for airing at an appropriate time in storage. Anaerobic respiration of the fruit, was thus easily adjusted to such a level that does not damage the fruit. Loss of fruit firmness was considerably controlled by excluding the factors that contribute to fruit softening. Transpirational water loss was also controlled. These findings confirm that the ca storage method is feasible for storage of fresh intact tomatoes with prolonged shelf life under nitrogen.

Conflict of Interest

The authors have not declared any conflict of interest.

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