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Physio-Chemical Properties of Tomatoes (Lycopersicon esculentum) Stored in Locally Constructed Postharvest Cold Storage House

Patrick Mulindwa[1,3]*, Ivan Lule[2,3], Christopher Adaku[1], Paul Okiror[1] and Peter Nkedi-Kizza[4]

[1]Department of Chemistry, Faculty of Science, Mbarara University of Science and Technology, Mbarara, Uganda

[2]Department of Chemistry, School of Physical and Biological Sciences, Makerere University, Kampala, Uganda

[3]Department of Chemical Engineering, Faculty of Engineering, Ndejje University, Kampala, Uganda

[4]Department of Soil and Water Sciences, University of Florida, Gainesville, FL, USA

***Corresponding Author**: Patrick Mulindwa, Department of Chemistry, Faculty of Science, Mbarara University of Science and Technology and Department of Chemical engineering, Faculty of Engineering, Ndejje University, Kampala, Uganda.

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Abstract

The quality of tomatoes (Lycopersicon esculentum.cv 'Padma') stored in a farmer cooling storage innovation in comparison with the ambient and fridge storage conditions were assessed for a period of 28 days. The temperature inside the storage house and that of the ambient environments varied from 23°C to 25°C and 20°C to 29°C, respectively. The relative humidity in the storage house and ambient also ranged from 79% to 87% and 53% to 93%, respectively. The temperature and relative humidity for the fridge were kept constant at 12°C and 90%, respectively. Nutritional composition analysis for the stored tomatoes had a weight loss rate of 8.9, 2.2 and 0.4 for tomatoes stored under the ambient, storage room and fridge conditions, respectively, for a period of 28 days. A significantly higher weight loss for tomatoes stored at ambient conditions was observed compared to tomatoes stored under storage room and fridge storage conditions ($P = 0.007$). Tomatoes stored under ambient conditions had more decrease in total carbohydrates, ascorbic acid, crude protein, ash content and titratable acidity compared to those stored under fridge and storage room conditions. However, a higher increase of 429 µg RAE/100g in total carotenoid content was observed for tomatoes stored under the storage house conditions, followed by tomatoes under ambient (366 µg RAE/100g) and fridge (141 µg RAE/100g) conditions. The pH range for tomatoes stored from all storage environments varied from 3.8 to 4.4. Therefore, a general decrease of nutritional quality in tomatoes stored under the ambient compared to those stored under storage house and fridge conditions were observed. Furthermore, the storage house preserved tomatoes for extra more 10 days compared to the ambient storage for tomato Padma harvested at green mature stage.

Keywords: *Postharvest Storage; Nutritional Composition; Tomato Quality*

Abbreviations

FS: Fridge Storage; SH: Storage House; AS: Ambient Storage; µg RAE: Microgram as Retinol Activity Equivalents; Padma: Tomato Cultivar; RH: Relative Humidity

Introduction

There has been increased interest in the study of storage requirements for fresh fruits and vegetables, mainly due to changes in production trends and marketing [1]. In order to increase food availability, an alternative can be provided by improved storage and conservation as a way of reducing postharvest losses and providing better quality to the consumer [1]. The environment, for safe and prolonged storage of perishable commodities, must be one of high humidity and low temperature [2].

In Uganda and in many other parts of the world vegetables form an essential part of a balanced diet because of their important health benefits. Due to consumers' increasing awareness and affordability of the health impacting vegetables, a need for longer market season for domestic as well as export markets is on the rise. This is especially true of many vegetables, including, tomatoes (*Lycopersicon esculentum*), which are a major sources of vitamins and minerals [3]. Today, tomato is recognized as one of the important commercial sources of vitamins A and C, and antioxidants such as lycopene [4]. The major quality attribute of ripe tomato is its red color, which is due to the lycopene content of the fruit. Other important physicochemical parameters, related to the quality of tomato, are Brix, acidity, pH, vitamin C, ash, dry matter, firmness, fruit weight, and flavor volatiles [5].

Most farmers in rural Uganda grow tomatoes at a small scale using rudimentary agricultural practices. As such, they follow the natural weather pattern, and produce tomatoes seasonally. Therefore, these farmers cannot meet the longer market season demands. In addition, a lot of tomatoes are wasted during the time of harvest due to lack of appropriate storage systems to store the excess harvest. Through technological advancement, the storage of fruits and vegetables at low temperature from harvest until consumption is an effective means of preserving quality and nutritional value. In the districts of Sheema and Rubirizi in Uganda, the rural farmers are using a storage facility which has been designed and constructed by local artisans, so as to increase the shelf life of stored vegetables. The senior author interestingly observed that the facility locally designed was able to preserve mature harvested tomatoes for seven (7) days without appreciable deterioration. According to Concellon [6], the quality of most fruits and vegetables originating from tropical areas are affected by poor storage conditions and the major causes of quality loss are decay of fruit, external injury during harvesting, handling and storage of vegetables. In addition, environmental factors such as soil type; temperature, and rainy weather during harvest can also cause severe effect on storage life and quality of vegetables [7]. The appearance, texture, flavor and levels of the important bioactive compounds in fruits and vegetables are greatly influenced by postharvest conditions such as precooling method, storage temperature, humidity and atmosphere composition [8].

Vegetables that are climacteric (e.g. tomatoes) in nature exhibit a characteristic rise in ethylene production during storage, which, in turn, triggers the changes in firmness, aroma and color depending on the storage temperature [9]. Ethylene is also known to accelerate the biosynthesis of carotenoids, which affects the quality composition of vegetables [10]. Naturally occurring carotenoids are biosynthesized by the same basic pathway, with later modifications to result in a variety of structures [11]. The biosynthesis pathway initiates with isopentenyl diphosphate (IDP) (C5) and its isomer dimethylallyl diphosphate (DMADP) followed by condensation of IDP and DMADP to generate the C10 geranyldiphosphate (GDP) molecule [12]. Storage temperature and atmosphere play a key role in the metabolism of fruits and vegetables, which in turn affect the quality composition of vegetables [13].

Metabolism in vegetables changes the appearance and color characteristics of vegetables hence affecting their acceptability. The understanding of the processes that lead to these changes is essential in developing better approaches to minimizing them and, hence, improving the quality of the stored vegetables [14]. In addition, quality parameters such as weight and appearance of most fruits and vegetables are affected by water loss during storage, which depends on the temperature and relative humidity conditions [15]. By measuring the aforementioned properties, one can determine the quality of vegetables and its variation under selected food storage conditions and environments. Therefore, the aim of this study was to determine the effect of the storage conditions of a farmer-friendly cooling room on the quality of tomatoes stored in it.

Materials and Methods

Description of the Study Area

The experiment was conducted at Makerere University Agricultural Research Institute Kabanyolo (MUARIK). MUARIK is located on spatial coordinates 0˚27'60''N, 32˚36'24'' E at an altitudinal range of 1250m to 1320m above mean sea level [16]. The study site is within the administrative boundaries of Nangabo Sub-County, Wakiso district and about 14 km north of Kampala, Uganda's capital city. Agricultural research and demonstrations are the main activities conducted at MUARIK by the Makerere University College of Agricultural and Environmental Sciences and collaborating institutions.

Construction design of the storage facility

A postharvest cold storage facility was constructed at MUARIK. The structure was round shaped with 2m diameter. Its height to the roof base was 2.1m and the height of the roof was 0.8m. The wall and roof were constructed with grass, reeds, eucalyptus poles, mud and dry banana fibre. The thickness of the mud wall was (inside thickness 0.04m and outside thickness 0.05m). The roof was made of dry banana fibre of 0.04m thickness and dry grass of 0.2m thickness as shown (Figure 1). At door bottom, an opening of (0.18m, height by 0.13m width) was made. Inside the storage house was a raised table with a height of 0.7m, where the vegetables were kept. The measurements and the construction materials (mud, reeds, grass) of the storage facility were based on the recommendation of the local artisans and tomato farmers. The temperature and relative humidity for storage environments (AS) and (SH) were measured using Sensirion-EK-H4 Temperature and Relative Humidity sensors. The results of the measurements are recorded in table 1.

Figure 1*: Constructed Storage House (SH).*

Storage environment	Temp. (Min)°C	Temp. (Max) °C	%RH (Min)	%RH (Max)
AS	20	29	53	93
SH	23	25	79	87
FS	12	12	90	90

Table 1: *Temperature and relative humidity.*

Sample preparation

Tomato vegetables (*Lycopersicum esculentum. cv. Padma*) free from previous post-harvest treatments were harvested from National Crops Resources Research Institute (NACCRI) famers association using locally made baskets. 160 tomato vegetables at a mature green stage were randomly picked according to size and immediately transported to the Experimental site at MUARIK as described by Znidarcic [17]. 10 tomatoes (mother sample) were immediately delivered to the Department of Food Science and Technology Laboratory of Makerere University for analysis. The remaining tomatoes (150) were divided into equal proportions (50) and stored under (AS), (SH), (FS) conditions, respectively. The vegetables were stored for 28 days. Eight tomato samples from the respective storage environments were randomly picked every after seven storage days (7 days) and delivered to the Department of Food Science and Technology Laboratory of Makerere University for analysis of the quality parameters. Samples were washed using tap water and sanitized in a 0.5 mg kg/L ozonized solution for 1 minute, then allowed air-drying at room temperature. Samples from each of the storage environments were replicated three times. However, tomato samples from (AS) storage environment started rotting after 21 days of storage.

Laboratory test experiments

Physiological Weight Loss

Tomato samples were weighed non-destructively on days 0, 7, 14, 21 and 28 using a digital analytical balance. The difference between initial and final fruit weight during each storage interval was plotted against storage period and the slope was used to calculate the rate of weight loss [18]. This was done for a period of 28 days to discover the effect of storing the vegetables in the different storage environment on vegetable weight.

Titrable acid

Titratable Acids of tomato juice extract samples was determined using the method recommended by Binstend [19] and Bigelow [20]. 10 ml of the blended juice was put in 100 ml conical flask. This was directly titrated with 0.1 M NaOH using phenolphthalein to the pink endpoint (the pink color persisting for at least 10 seconds). The acid value was expressed as percentage citric Acid.

Color

A random sample of 4 tomatoes from each storage environments were washed using tap water and allowed to air-dry at room temperature. The color of the tomatoes was assessed by means of the Lovibond Tintometer (Model F-V8-LR). Camera shots of the samples were also done for good Color comparison.

Total Sugars

Total sugars were determined by hot water extraction method [21]. 10 mls of each sample of blended extract were accurately weighed into 250 ml beakers to which 1 ml lead acetate was added followed by 70 ml of hot water. The beakers with the contents were then placed on a hot water bath at 800C and heated for 1 hour. The beakers where removed from the hot water bath and allowed to cool. To the cooled sample solution of sodium bicarbonate was added to precipitate all the excess lead acetate. The sample was then transferred to 100 ml volumetric flask using a funnel and shaken to mix well. A portion of the sample was poured into test tubes and centrifuged at 700 rpm for

5 minutes. For hydrolysis of the juice extracts, 5 ml of the clear solution, 1 ml of 1M H_2SO_4 and 20 ml of distilled water was added to 100 ml conical flasks and then heated to boiling on a hot plate for 10 minutes. The solution was removed, left to cool, and then 5mls of sodium bicarbonate was added to neutralize the solution. The neutralized solution was transferred to 50 ml volumetric flask, and made to volume with distilled water and shaken to mix well. To develop the color, 1 ml of sample was added followed by 1 ml of phenol (5%) and 5 ml of concentrated sulphuric acid to a clean test tube, and mixed well. The absorbance of the solution was read off at 470 nm using a UV-Visible spectrophotometer of UV-1700, recorded, and used to calculate the sugar concentration.

Ascorbic acid

A random sample size of 8 tomatoes from each storage environment was blended in a homogenizer; the juice filtered using a filter paper. Concentrated juice (5mls) was pipetted into a volumetric flask (50 mls) and was diluted to volume with an extracting solution (3% MPA and 8% acetic acid for MPA-acetic acid extraction and 0.1% oxalic acid for oxalic acid extraction). The mixture was homogenized in a blender for 1 minute and then centrifuged. Several precautions were taken in order to perform all the operations under reduced light and at 4oC temperature. 10 ml of the 3% MPA - 8% acetic acid extracts was titrated with indophenol solution (25% DCIP and 21% $NaHCO_3$ in water) until a light but distinct rose pink color appeared and persisted for more than 5 seconds. The indophenol solution was standardized daily with Ascorbic Acid solution. All determinations were repeated ten times. Vitamin C content in the sample was determined and reported as milligram ascorbic acid per 100 ml of juice.

pH

The pH of the blended samples was determined by a standard calibrated digital pH meter (Pinnacle 530 Bench top pH meter).

Ash content

Determination of ash content was based on AOAC [22] method. Sliced tomatoes of about (2) g were weighed into a crucible. The crucible was heated first on a heating mantle till all the material was completely charred, followed by incineration in a muffle furnace at 550°C for 3 - 5 hours. The crucible was then cooled in a desiccator and weighed.

Total pro-vitamin A/Beta-carotene content

Total pro-vitamin A carotenoid content for the stored vegetable samples was carried out using a procedure previously described by Rodriguez [23]. A random sample size of 8 tomatoes from each storage environment were blended in a homogenizer, the juice filtered using a filter paper. 10 ml were used for determination of Total carotenoids. 10 mls of juice extract were partitioned with 30 ml of petroleum ether. The solution was then put into a 500 ml separation funnel with Teflon stopcock and acetone 10 mls added. 300 ml of distilled water was added letting it flow along the walls of the funnel. After the two phases forming, the lower phase was discarded. Washing was done for 3 times with distilled water each round using 200 ml to remove the residual acetone. In case of emulsion formation, sodium chloride (5g) was used to break it. Petroleum ether (PE) phase was collected in the volumetric flask of 50 ml making the solution pass through a small funnel containing anhydrous sodium sulphate using around 15g to remove residual water. The glass wool plug was used to hold the sodium sulphate. A separation funnel was washed with PE, collecting the washings in the volumetric flask by passing through the funnel with sodium sulphate. Spectrophotometric (Genesys 10uv) reading and calculation; Absorbance at 450 nm was taken.

Protein Analysis

Crude protein content of the sample was determined using the standard Kjeldahl method. A sample of sliced tomatoes (0.2) g was digested using 5 ml concentrated sulphuric acid in the presence of Kjeldahl tablets as catalysts. The sample solution was heated first slowly for 6 minutes then heated rapidly after stabilization for 2 hours then left to cool. The digest was quantitatively transferred after cooling to a 50 ml volumetric flask and made to volume with distilled water, then shaken to homogenize the solution. The blank was also treated in the same way as the sample using 0.2g of water instead of the sample. The distillation of the sample was prepared by pipetting

10 ml aliquots of the digest in a Markham still (Foss, tecator, Britain), 20 ml of 40% sodium hydroxide was introduced into the distillation chamber and distillation was allowed to proceed for about 4 minutes. The distillate was then collected into the conical flask containing 10 ml boric acid (4%) containing mixed indicators (bromocresol green and methyl red); the end point marked by color change back to the original brown color.

Data Analysis

The measured quality parameters for the different samples were analysed using the SPSS statistical package (version 16). The means were compared using the student's t-test to determine whether there were significant effects of the different storage environments on the quality parameters. Also to show how the storage time affected the quality parameters of the stored tomatoes. Other statistical calculations to determine the mean, standard deviation and coefficient of variation were performed with MS Excel program.

Results and Discussions

Physiological Weight Loss

In this study, the weight loss of tomatoes stored in the different storage environments significantly increased. The rate of weight loss of tomatoes stored at (AS) was significantly higher (P = 0.007) than the tomatoes stored under (SH) and the rate of weight loss under (FS) conditions was significantly (P = 0.05) lower than that from the other two storage environments (Table 2). The percentage weight loss for the three storage environments was 9.2 - 13.59%, 3.09 - 5.5% and 0.6 - 2.22% for (AS), (SH) and (FS) storage environments, respectively. These results suggest that there was dehydration of the fruit during postharvest storage. Ponce [24] reported that weight loss was lower in tomato refrigerated at 12.5°C which is in agreement with the findings of the present study. According to Kumar [25], tomatoes stored at higher temperatures showed a significant greater weight loss during storage which is consistent with the results of the current study. Javanmardi [26] when evaluating the variation of weight loss of tomato during postharvest storage reported that higher rate of transpiration for tomatoes stored at higher temperatures compared to lower temperature-stored tomatoes could be the main cause for higher weight loss.

Storage Environment	Rate of weight loss (%) after 28 days	R^2-value
Ambient storage (AS)	8.9	0.90
Storage House (SH)	2.2	0.90
Fridge Storage (FS)	0.4	1.0

Table 2: *Rate of weight loss for tomatoes stored in three storage environments.*

Percentage Titratable Acidity

Titratable acidity generally decreased with increasing storage time but the decrease was not significant amongst the different storage environments (P > 0.05) most of the time (Figure 2). Tomatoes subjected to the fridge environment had better retention of titratable acidity than those stored in both ambient and storage house. Tomato samples stored under (AS) environment experienced a faster decrease for the first 7 days in titratable acidity of 14% compared to the 6% for the (SH) and (FS) environments, respectively. Determination of titratable acidity for tomatoes stored under (AS) conditions after 28 days was not possible because of tomato rotting. Ponce [24], studied acidity variations of tomatoes stored at 12.5°C. Under these conditions, the acidity balance of the tomato fruit was not affected. The slight increase obtained in this study under (FS) storage environment (12°C) could be explained by the difference in the cultivar and environmental conditions during tomato growth, and agrees with reports that indicate that acidity varies greatly with environmental conditions [27]. Kader and Ben-Yehoshua [28] reported that reductions observed in organic acid values in relation to ripening resulted from the utilization of acids in respiration and other physiological processes together with carbohydrates. According to Sadler and Murphy [29], the concentration of organic acids decreases during postharvest storage periods due to their use as a substrate in the respiration or their transformation into sugars. This report is consistent with the results of the current study.

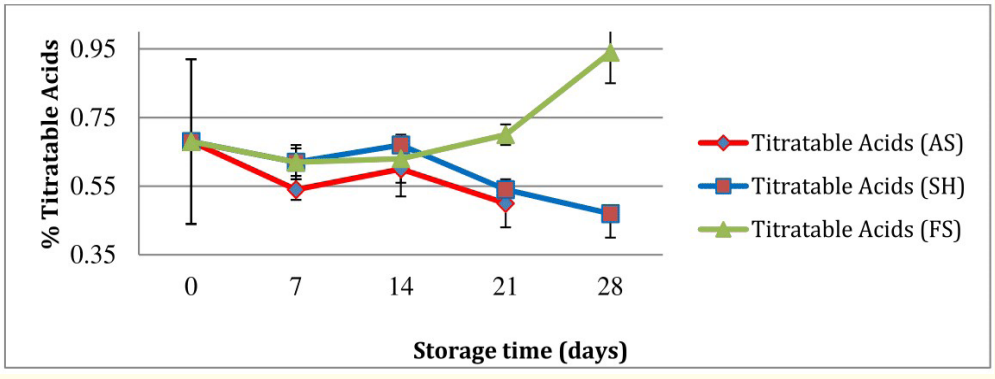

Figure 2: *Percentage titratable acids (measured as citric acid) for tomatoes stored under ambient (AS), storage house (SH) and Fridge (FS) environments.*

Total Carbohydrate

The total carbohydrate content of tomatoes from all storage environments significantly increased during the first ripening period (day 0 - 7 day of ripening) and decreased towards the end of the storage period (Figure 3). Results showed no significant ($P > 0.05$) difference in the amount of the ultimate total carbohydrates among all storage environments. Different authors have studied the effect of higher temperatures (ranging from 26 to 30 ◦ C) on stored tomatoes. In these conditions, an increase in total carbohydrates due to changes in carbohydrate biosynthetic enzyme activity (Walker and Ho [30], and increased transpiration [31] was reported which is consistent with the current studies for the first 7 days of storage. Wills and Ku [32], in their study reported a different range of (5.0% - 5.1%) in total carbohydrate. This difference can be attributed to the studied tomato cultivar, growth conditions and fertilization regime [33]. Similar to this study Fagundes [34], found an increase in sugar content after harvest and a decrease toward the end of the storage period.

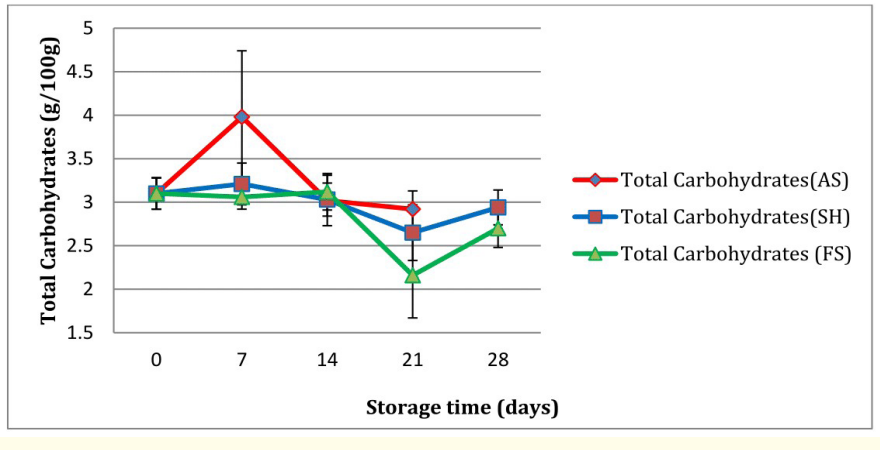

Figure 3: *Total carbohydrates (measured as sucrose) for tomatoes stored under ambient (AS), storage house (SH) and Fridge (FS).*

Ascorbic Acid

Overall ascorbic acid content for the stored tomatoes significantly increased in all storage environments (Figure 4). Ascorbic acid content slightly increased for tomatoes stored under (AS) and (SH) environments for the first seven days while for (FS) environment, the concentration in the first seven days doubled. However, there was no significant ($P > 0.05$) difference in the ascorbic acid content for tomatoes stored under the three storage environments. Ascorbic acid concentration for the tomatoes stored under (AS), (SH) and (FS) ranged between 3.28 - 23.15 mg/100g, 3.27 - 28.42 mg/100g and 3.8 - 13.55 mg/100g, respectively. This change can be attributed to the protective effect of phenolic substances which have been linked to the stability of vitamin C [35]. On the basis of fresh tomato weight, Olliver [36] reported an average vitamin C content of about 25 mg/100g. This is close to the results obtained from this work. Ana [35] studied the influence of three storage conditions (6°C, 12°C and 25°C) on the physicochemical properties of different tomato cultivars. In these conditions, the ascorbic acid content significantly increased with storage period. This is in agreement with the current studies.

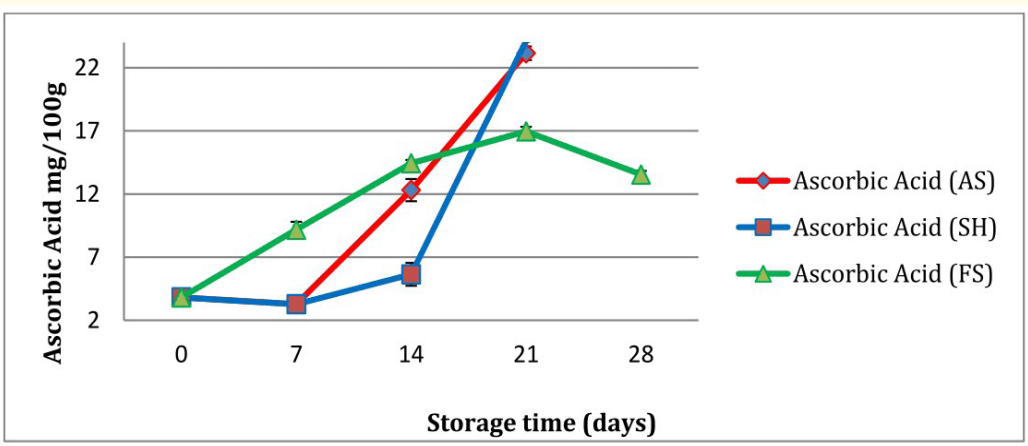

Figure 4: *Ascorbic acid for tomatoes stored under (AS), (SH), (FS).*

Total carotenoids

Data in (Figure 5) show the total carotenoid content of the stored tomatoes. In the course of storage a tendency to an increasing content of total carotenoids was observed in all storage environments. Overall carotenoid content of tomatoes stored under (SH) environment was significantly greater ($P = 0.05$) than those stored under (FS) environment. The amount of total carotenoids in tomatoes stored under (SH) environment showed a significant increase from 28 to 429 µg Rae/100g of fresh weight during the first three weeks of storage. Friedman and Levin [37], reported that the pigments of tomatoes include mostly the green pigments chlorophylls a and b, the yellow pigment beta-carotene, and the red pigment lycopene, which are metabolized during the ripening of tomatoes. For (AS) and (FS) stored tomatoes there was no significant difference ($P = 0.304$) between the total carotenoid contents. However, the amount of carotenoids in tomatoes stored under (AS) and (SH) environments were significantly higher than the (FS) stored tomatoes. This means that the rate of ripening processes associated with increased lycopene content, in low temperature stored tomatoes was slowed. The same result was reported for storage at 4°C and 12°C which inhibited tomato fruit ripening [26,38].

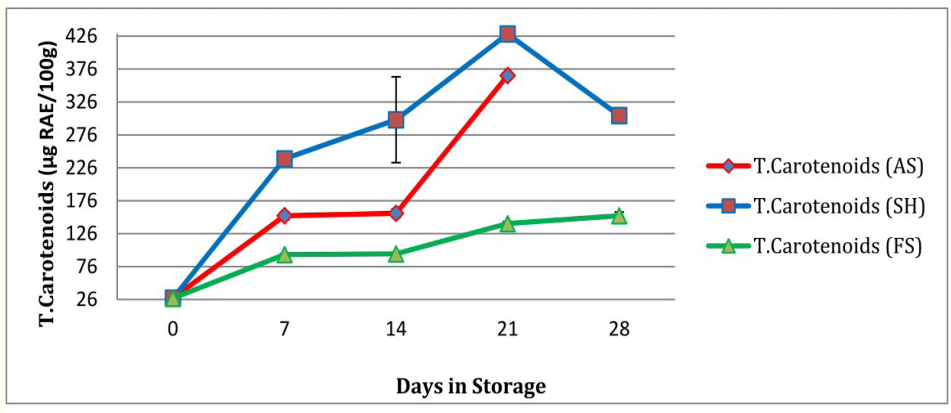

Figure 5: *Total carotenoids in tomatoes stored under (AS), (SH), (FS).*

pH measurements

According to the results presented in figure 6, tomatoes stored in all storage environments studied showed a pH decrease for the first seven days of storage, followed by a subsequent increase. This variation is more pronounced for tomatoes under (AS) environment. There was no significant ($P > 0.05$) difference in pH for tomatoes stored in the different storage environments. A similar pattern was observed by Gómez and Camelo [39] with reductions and consequent increases observed in the Diva tomato under storage conditions of 12°C of temperature for 21 days. The variations in pH (3.8- 4.4) observed in the present study compare well with the findings reported by Babitha and Kiramanyi [40] who observed pH range of 4.0 - 4.5 in different varieties of tomatoes. Batu [41] explained the temperature dependence observed as a result of a reduction in the metabolic processes when stored under low temperatures.

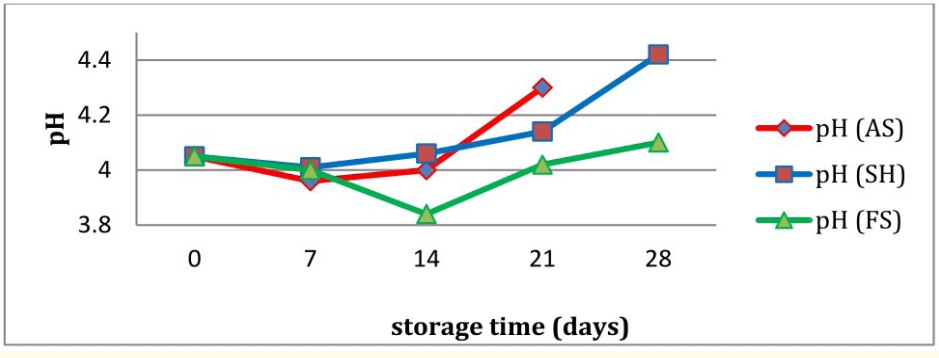

Figure 6: *pH for tomatoes stored under (AS), (SH), (FS).*

Crude Protein

The overall crude protein content decreased with increasing storage time for tomatoes stored under the three storage environments. There was no significant difference ($P > 0.05$) in the percentage crude protein for tomatoes stored under the different storage environments. Percentage crude protein for ambient, storage house and fridge storage ranged from 0.8 to 1.2, 0.7 to 1.2 and 0.7 to 1.2 respectively (Figure 7). However, for the studied duration, crude protein content remained constant under the studied conditions. P Idah [42] evaluated the effects of storage period on some nutritional properties of tomatoes stored in the pot-in-pot evaporative cooler for 21 days. In these conditions, a decrease in percentage crude protein with increasing storage period was observed. The difference observed in the current studies may be due to the difference in variety and environmental conditions as observed by Cheema and Karmarkar [43].

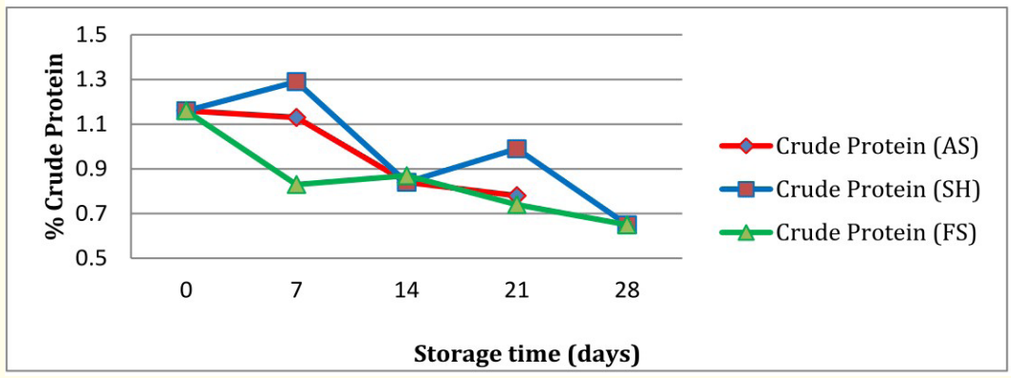

Figure 7: *Percentage crude protein for tomatoes stored under (AS), (SH), (FS).*

Ash content

The results of the ash content assessed for tomatoes stored in all storage environments remained fairly constant, regardless of the storage environment. The percentage ash content for environments (AS), (SH) and (FS) ranged from 0.47 - 0.51%, 0.48 - 0.51% and 0.46 - 0.59%, respectively. However, for the first seven storage days, the percentage ash content for (AS) and (FS) environments was reduced by 2% and 8%, respectively but that for the (SH) generally remained constant (Figure 8). No significant ($P > 0.05$) difference in the percentage ash was observed for tomatoes stored in all the environments. The results obtained in the current study were close to those reported by P Idah [42] which ranged between 1.49% and 0.46%.

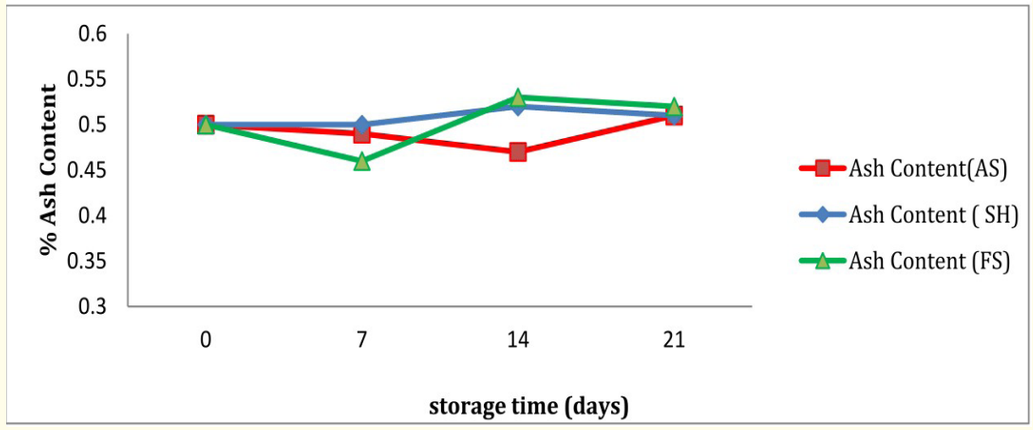

Figure 8: *Percentage ash content for tomatoes stored under (AS), (SH), (FS).*

Color

Table 3 shows how the tomato color changed with increasing storage period. The color of the tomatoes stored under the three storage environments changed significantly from green to yellow-green to red-orange during storage. Changes in color occurred after seven days of storage, indicating increased red coloration. Change in color was more pronounced in tomatoes stored under (AS) conditions compared to (SH) and (FS) environments (Figure 9). In the case of tomato ripening, different colors are present simultaneously since chlorophyll is degraded from green to colorless compounds at the same time that carotenoids are synthesized from colorless precursor (phytoene) to carotene (pale yellow), lycopene (red), b-carotene (orange), and xanthophylls and hydroxylated carotenoids (yellow) [44,45]. In the view of prolonging shelf life, it is desirable that the color changes take place as slowly as possible. Color development in tomato is sensitive to temperature; a better plastid conversion is achieved when temperature is above 12˚C and below 30˚C [40,46,47]. On the other hand, at low temperature (below 12˚C), chlorophyll is not easily degraded and lycopene accumulation does not take place. These results are in agreement with the current studies.

Storage time (days)	(AS)	(SH)	(FS)
0	Yellow-green+2.5	Yellow-green+2.5	Yellow-green+2.5
7	Red-orange+6.0	Red-orange+5.0	Red-orange+4.7
14	Red-orange+5.8	Red-orange+6.2	yellow-orange+3.8
21	Red-orange+7.4	Red-orange+6.9	Red-orange+6.1
28	Not applicable	Red-orange+7.0	Red-orange+5.3

Table 3: *Color changes of the stored tomatoes under ambient environment, storage facility and fridge.*

Figure 9: *Pictorial view of the color progression of the stored tomatoes.*

Conclusion and Relevancy of the Study

The results from this study, in addition to affirming that at the micro-level, societal shaping of technology is indispensable to successful diffusion, support the following conclusions:

1. The storage house stored tomatoes for extra more 10 days compared to the ambient storage for tomato Padma harvested at green mature stage.

2. Furthermore, tomatoes stored in the storage facility retained their nutritional composition close to the fridge samples.

With a storage house storing tomatoes for 10 extra days while maintaining the vegetable quality, the authors are confident that if any design modifications on the storage house are made to maintain a relatively lower temperature and higher relative humidity, the facility can be a better alternative especially in reducing postharvest losses and improve storage facilities not only in Uganda but in a number of sub-Saharan countries with similar climates as far as rural communities are concerned.

Conflict of Interests

The authors have not declared any conflict of interests.

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Bibliography

1. Nunes MCN. "Impact of environmental conditions on fruit and vegetable quality". *Stewart Postharvest Review* 4.4 (2008): 1-14.

2. Olosunde WA. "Performance Evaluation of Absorbent Materials in the Evaporative Cooling System for the Storage of Fruits and Vegetable". M. Sc thesis, Department Of Agricultural Engineering, University of Ibadan, Ibadan (2006).

3. Rick CM. "Rabbiteye blueberry storage life and fruit quality in controlled atmospheres and air storage". *Journal of American Society for Horticultural Science* 113.5 (2008): 723-728.

4. Okolie NP and Sanni T. "Effect of Postharvest treatments on Quality of whole Tomatoes". *African Journal of Food Science* 6.3 (2012): 70-76.

5. Oke M., *et al*. "The effects of genetic transformation of tomato with antisense phospholipase DNA on the quality characteristics of fruits and their processed products". *Food Biotechnology* 17.3 (2003): 163-182.

6. Concellon., *et al*. "Effect of low temperature storage on physical and physiological characteristics of eggplant fruit (Solanum melongena L.)". *LWT - Food Science and Technology* 40.3 (2007): 389-396.

7. Muhammad., *et al*. "Quality characteristics of tomatoes (lycopersicon esculentum) stored in various wrapping materials". *African Journal of Food Science and Technology* 3.5 (2012): 123-128.

8. Lee., *et al*. "Preharvest and postharvest factors influencing vitamin C content of horticultural crops". *Postharvest Biology and Technology* 20.3 (2000): 207-220.

9. Moya., *et al*. "Ripening of mountain papaya (Vasconcelleapubescens) and ethylene dependence of some ripening events". *Postharvest Biology and Technology* 34.2 (2004): 211-218.

10. Dostal HC and Leopold AC. "Gibberellin delays ripening of tomatoes". *Science* 158.3808 (1967): 1579-1580.

11. Britton., *et al*. "Overview of carotenoid biosynthesis". *Carotenoids* 3 (1998): 13-147.

12. Burns., *et al*. "Identification and quantification of carotenoids, tocopherols and chlorophylls in commonly consumed fruits and vegetables". *Phytochemistry* 62.6 (2003): 939-947.

13. Marangoni., *et al*. "Membrane effects in postharvest physiology". *Postharvest Biology and Technology* 7.3 (1996): 193-217.

14. Brown., *et al*. "Chlorophyll breakdown". In: Scheer, H. (Ed.), Chlorophylls, Boca Raton, FL (1991): 465-489.

15. Perez., *et al*. "Effect of storage temperature on the shelf life of Hass avocado (Perseaamericana)". *Food Science and Technology International* 10.2 (2003): 7377.

16. Yost., *et al*. 1990 (still missing).

17. Znidarcic.. *et al*. "Influence of postharvest temperatures on physicochemical quality of tomatoes". *Journal of Food, Agriculture and Environment* 8.1 (2010): 21-25.

18. AOAC. Official methods of analysis. Association of Official analysis chemistry (1999).

19. Binstend., *et al*. "Tomato paste and other tomato products". Food trade press (1973).

20. Bigelow. *et al*. "Tomato products: Research laboratory bulletin 21-1" (1950).

21. Smith., *et al*. "Extraction of total available carbohydrates from grass and legume tissue". *Plant Physiology* 39.6 (1964): 960-962.

22. AOAC. Official methods of analysis. Association of Official analysis chemistry (1984).

23. Rodriguez-Amaya., *et al*. "HarvestPlus Handbook for Carotenoid Analysis". Published by CIAT (International Center for Tropical Agriculture) (2004).

24. Ponc., *et al*. "Effect of refrigerated storage (12.5°C) on tomato (Solanum lycopersicum) fruit flavor: A biochemical and sensory analysis". *Postharvest Biology and Technology* 111 (2016): 6-14.

25. Kumar., *et al*. "Non-refrigerated storage of tomatoes-effect of HDPE film rapping". *Journal of Food Science and Technology* 36 (1999): 438-440.

26. Javanmardi J and Kubota C. "Variation of lycopene, antioxidant activity, total soluble solids and weight loss of tomato during postharvest storage". *Postharvest Biology and Technology* 41.2 (2006): 151-155.

27. Carli., *et al*. "Dissection of genetic and environmental factors involved in tomato organoleptic quality". *BMC Plant Biology* 11 (2011): 58.

28. Kader., *et al*. "Effects of super atmospheric oxygen levels on postharvest physiology and quality of fresh fruits and vegetables". *Postharvest Biology Technology* 20.1 (2000): 1-13.

29. Sadler GD and Murphy PA. "pH and Titratable acidity". In: Nielsen S (Ed.), Food Analysis, Aspen Publishers, Inc., Gaithersburg 2 (1998): 101-116.

30. Walker., *et al*. "Carbon translocation in tomato-effects of fruit temperature on carbon metabolism and rate of translocation". *Annals of Botany* 41.4 (1977): 825-832.

31. Gautier., *et al*. "How does tomato quality (sugar, acid, and nutritional quality) vary with ripening stage, temperature, and irradiance". *Journal of Agricultural and Food Chemistry* 56.4 (2008): 1241-1250.

32. Wills., *et al*. "Use of 1-MCP to extend the time to ripen of green tomatoes and postharvest life of ripe tomatoes". *Postharvest Biology and Technology* 26.1 (2002): 85-90.

33. Dorais., *et al*. "Tomato (Solanum lycopersicum) health components: from the seed to the consumer". *Phytochemistry Reviews* 7 (2008): 231-250.

34. Fagundes., *et al*. "Effect of active modified atmosphere and cold storage on the postharvest quality of cherry tomatoes". *Postharvest Biology and Technology* 109 (2015): 73-81.

35. Ana Vinha., *et al*. "Influence of the Storage Conditions on the Physicochemical Properties, Antioxidant Activity and Microbial Flora of Different Tomato (Lycopersicon esculentum L.) Cultivars". *Journal of Agricultural Science* 5.2 (2013): 118-129.

36. Olliver. "Occurrence in foods". In: The Vitamins, WH Sebrell and RS Harris, eds., Academic Press, New York 1 (1967): 359-367.

37. Friedman GD., *et al*. "Drugs and colon cancer". *Pharmacoepidemiology and Drug Safety* 7.2 (1998): 99-106.

38. Giovanelli., *et al*. "Variation in antioxidant components of tomato during vine and post-harvest ripening". *Journal of the Science of Food and Agriculture* 79.12 (1999): 1583-1588.

39. Gómez PA and Camelo AFL. "Calidad postcosecha de tomates almacenados en atmósferas controladas". *Horticultura Brasileira* 20.1 (2002): 38-43.

40. Babitha., *et al*. "Effect of storage conditions on the postharvest quality of tomato". *Journal of Agricultural Sciences* 1.4 (2010): 409-441.

41. Batu A. "Determination of acceptable firmness and color values of tomatoes". *Journal of Food Engineering* 61.3 (2004): 471-475.

42. P Idah., *et al*. "Effects of Storage Period on Some Nutritional Properties of Orange and Tomato". *AU Journal of Technology* 13.3 (2010): 181-185.

43. Cheema., *et al*. "Cold storage of fruits and vegetables". Indian Council of Agricultural Research, Misc Bulletin No 23 (1939).

44. Giovannoni J. "Molecular biology of fruit maturation and ripening". *Annual Review of Plant Physiology and Plant Molecular Biology* 52 (2001): 725-749.

45. Giuliano., *et al*. "Regulation of carotenoid biosynthesis during tomato development". *Plant Cell* 5.4 (1993): 379-387.

46. Cantwell., *et al*. "Impact of storage conditions on grape tomato quality". 6th ISHS Postharvest Symposium, International Society for Horticultural Science, Antalya, Turkey (2009).

47. Dumas., *et al*. "Effects of environmental factors and agricultural techniques on antioxidant content of tomatoes". *Journal of the Science of Food and Agriculture* 83.5 (2003): 369-382.

Volume 13 Issue 3 March 2018