Comparison of Three Shipping Packages in Reducing Postharvest Losses of Mandarin (*Citrus reticulate* Blanco) Fruits along the Value Chain

Majubwa, R.O.[1], S.A. Sargent[2], T.J. Msogoya[1], J.X. Chaparro[2], M.A. Ritenour[3], D.J. Huber[2], and C.A. Sims[4]

[1]Department of Crop Science and Horticulture, Sokoine University of Agriculture, P.O. Box 3005, Morogoro, Tanzania
[2]Horticultural Sciences Dept., Univ. of Florida/IFAS, P.O. Box 110690, Gainesville, FL 32611
[3]Indian River Research and Education Center, Univ. of Florida/IFAS, 2199 S. Rock Road, Fort Pierce, FL 34945
[4]Food Science and Human Nutrition Dept., Univ. of Florida/IFAS, Gainesville, FL 32611

*Corresponding author e-mail: omaryrama@sua.ac.tz

Abstract

A study was conducted to compare the effect of three shipping packages; traditional bamboo baskets (BAMB), bulk on truck (BULK) and stackable plastic crates (SPC) and the effect of fruit position in the package (bottom, middle, and top) on postharvest loss of mandarin (Citrus reticulate Blanco.) fruits along the value chain. A 3x3 factorial experimental design in a completely randomized design (CRD) was used to set up the trial. Harvested mandarin fruits were sorted and the uniform undamaged fruits packed in SPCs, BAMB, and BULK packages. Fruits were transported for 161km from Kikundi village in the Morogoro district through Chalinze to Sokoine University of Agriculture (SUA). On arrival at SUA, fruits were held under simulated wholesale (3 days) and retail conditions until when at least 50% of the fruits were rated unmarketable. During the study, fruits were evaluated for external and internal fruit quality including; proportion of decays, weight loss, pulp temperature, soluble solids content (SSC), titratable acidity (TA), SSC/TA, and Ascorbic acid. Results show a significant interaction between (i) shipping-packages and fruit position with respect to fruit pulp temperature and cumulative decay and (ii) storage time in terms of juice volume, SSC, TA, SSC/TA, and ascorbic acid. For fruit in SPC, decays was higher on fruits at top than at the middle and bottom of the package. SPC reduced fruit decay by 7.9% or 5.1% than those packed in BAMB or BULK, respectively. Mandarin fruits in SPC and BAMB particularly at the middle and bottom of SPC and BULK experienced lower pulp temperature than those at the top of packages. Fruit internal quality; soluble solids content (SSC), titratable acidity (TA), and ascorbic acid (ASC) changed only with storage duration. The study recommends use of SPC for reducing fruit decays, and for slowing fruit pulp temperature rise during shipping. Further study is recommended to establish the cost benefit of SPC over BAMB and BULK packaging as a means to enhance its adoption.

Keywords: Shipping packages, Citrus fruits, Mandarin fruit packaging, Fruit position in the package, Postharvest storage technologies

Introduction

Mandarin (*Citrus reticulate* Blanco) fruits ranks the third in production volumes after sweet oranges (*Citrus cinensis* Mil.) and lemons (*Citrus limon*) and limes (*Citrus aurantiifolia*) fruits produced in East Africa and in the country (FAOSTAT, 2019). In Tanzania the major citrus fruits (including mandarin) growing areas are Tanga, Coastal and Morogoro regions, with 35,640 ha, 11,123 ha and 4,582 ha of the total national production area, respectively (NBS, 2013). Most of the citrus fruits from the regions are consumed locally in major cities and towns (Izamuhaye, 2008; Lynch, 1999) located 50 to 700 km away within the country and some exported to neighboring countries including Kenya (Izamuhaye, 2008). Fruit transportation is mainly conducted through bulk on truck, in a mixed load of sweet oranges and mandarins in the same truck (Lynch *et al.,* 1999; Msogoya and Kimaro, 2012; Tsa 2012).

Considerable postharvest loss in fruit quality and salable quantity has been reported along the mango (43.8%) and sweet oranges (48.3%) value chains (Tsa. 2012; Msogoya and Kimaro. 2012). Of the 48.3% losses in oranges, 17.9% occur at retail, 15.4% in wholesale trading, 12.0 % at the middlemen trading and 3.0% at farmer level. The main causes of postharvest losses in sweet oranges along the value chain in the order of magnitude were reported to be; microbial decay, mechanical damages, shriveling, and fruit flies (Tsa. 2012).

Due to its thin and brittle peel characteristics, mandarin fruits are much delicate than other citrus fruits (Brown, 2006), hence the postharvest losses experienced along the value chain are likely to be higher than those reported in sweet oranges. In India however, postharvest loss of mandarin fruits along the value chain from harvest to distribution was reported to be 46% (Bhattarai *et al,* 2003). Citrus fruits including mandarins have oil glands on the peel flavedo that when damaged during handling tend to release phytotoxic peel oil compounds causing brown/dark burning appearance on the fruit rind (Zhang *et al.,* 2011; Montero *et al.,* 2012). Damaged areas on the fruit peel also serves as entry points for decay microorganisms causing fruit deterioration during subsequent handling stages.

Unfortunately, despite the delicate nature of mandarin fruits among other citrus fruits, in Tanzania little is known about the effect of shipping packages on the quantity and quality loss of the fruit along the value chain. The main objective of this study is therefore to compare the effectiveness of traditional shipping packages; bamboo baskets (BAMB) and bulk on truck (BULK) with an improved package "stackable plastic crates" (SPC) on maintaining fruit quality and reducing postharvest loss of mandarin fruits along value chain (farm to retail marketing/ handling). This simulated study specifically evaluated change in external and internal fruit quality including; proportion of decays, weight loss, juice volume, pulp temperature, soluble solids content (SSC), titratable acidity (TA), SSC/TA, and Ascorbic acid for the different packages and fruit position (top, middle, and bottom) in the package during handling from harvest to storage/ marketing.

Materials and Methods

Mandarin Fruit Source

In the 2014/ 2015 seasons, mandarin fruits of local unknown cultivar were harvested from an orchard at Kikundi village, Kibungo ward in Morogoro district. Fruits were harvested from randomly selected trees using the Drop-Catch method. One picker climbed into the tree, picked fruits and dropped them down for another person to catch. Harvested fruits from random trees were combined, sorted, and the uniform, undamaged fruits packaged in SPCs, BAMB or BULK for shipping simulation trial in the same way wholesale traders, and farmers do pack their fruits during shipping. Three packaging for shipping methods; SPCs of 250 to 300 fruits capacity, BAMB of 500 to 800 fruits carrying capacity, and heaping of unpacked fruits on the floor of a 3.5 tones open top truck (BULK) were used during a simulation trial. In the trial, SPCs were used as a new introduced packaging practice.

Experimental Design

The simulated shipping experiment was set as a 3x3 factorial experiment in a completely randomized block design (CRBD) with shipping package at three levels; SPC, BAMB, and BULK and fruit position in the packages at three levels; top, middle, and bottom. Each of the treatment combinations was replicated three times. The number of packages per packaging method was considered as replications. Under each packaging method, three layers of fruit positions were marked as; top, middle, and bottom. Package location on the truck served as blocks, whereas a set of each packaging method was placed at the front, middle, and rear part of the truck to avoid variations due to load position on the truck (Fig 1). For simulation of wholesale and retail handling conditions (before sale) on arrival at SUA, fruits in the SPC, BAMB, and BULK shipping packages were retained for

Figure 1: Arrangement field packaging methods; (A) Bamboo baskets "BAMB", (B) Bulk on truck "BULK" and (C) Stackable plastic crates "SPC" on the truck during the simulated shipping trial of mandarin fruit.

three days at outdoor with full sun exposure during the day and covering during the night. After the three days of wholesale simulation, fruits were unloaded from each package and placed on benches for display until at least 50% of the fruits per treatment combination rated unmarketable.

Fruit packaging

BAMB

The bamboo baskets of 500 to 800 fruits carrying capacity each were first lined with fresh grasses on the inner side and the three layers of fruits (bottom, middle, and top) each separated with a layer of grasses loaded into each package. Each layer had over 100 marked fruits of which ten fruits at each layer were numbered for tracing during data collection. Additional layer of fresh grasses was placed at the top and tied up with sisal ropes. The BAM packages were then loaded on the truck one onto the other with package tops covered with grasses facing to each other.

BULK

BULK packaging involved placing a layer of fruits on fresh grass cushioning materials of about 10 cm thick spread on the truck floor, followed by another layer of cushioning materials before adding the second and third layers of fruits. Bulk packed fruits were separated in three categories; front, middle and rear part of the truck with each group containing 900 fruits. Each group was divided further into three equal sub groups, considered as replications. In each replication, at least 100 fruits were maintained on the top, middle and lower layer of fruits, respectively separated by grass cushioning materials.

SPC

Plastic crates of 40 cm (width) by 58.5 cm (length), by 23.0 cm (depth) and carrying capacity of 250 to 300 fruits were used. A 2.5 cm layer of foam was placed at the bottom of the crate before packing the first layer of fruits and above the second and third layers of fruits. In each crate fruits were filled to allow stacking of one crate onto the other without compressing the fruits. No linings were added on the sides of the package during loading of the fruits to permit natural ventilation. Loaded SPC were packed onto the truck in three layers high. To avoid fruit leaping from SPC, an empty fourth crate was tied on top and secured using sisal ropes (Fig. 1). At least 100 fruits were maintained on the top, middle and lower layer of fruits in each SPC.

Simulation of Shipping and Storage Conditions

Most citrus fruits produced in Tanzania are consumed locally in big towns (Izamuhaye, 2008) including city centers within the region or nearby areas located at least 150 km from the production areas. Access to the production areas involves use of rough/ungraded and tarmac roads. Based on that, after packaging and loading, fruits were transported from Kikundi village at Matombo division in Morogoro district to Sokoine University of Agriculture (SUA) through Chalinze in the Pwani region. The produce was shipped for 1 hour on 18 km of ungraded, none-tarmac road and the remaining 143 km for 2 hours and 37 minutes on the tarmac road to cover a total distance of 161 km in 3 hours and 37 minutes. The tarmac road had 2-4 humps at about every 20 km distance. Similar to what most traders do during transportation of citrus fruits, the shipping simulation was conducted on a clear day starting at 18:30 hours to 22:07 hours, and the truck body/bed was partially covered to allow some air circulation. The ambient temperature range during transportation was be 29.5°C.

On arrival (Day 0) at SUA Horticulture Postharvest Laboratory, fruits were unloaded while maintaining treatment grouping and replications. Fruits under BULK were unloaded following the same heaping arrangement on a spread polypropene sheet and held outside at simulate wholesale traders handling conditions. Fruits in BAMB and SPC were retained in the packages and also placed on the sheet. All treatments were left open during the day and covered with polypropene sheet during the night simulating commercial wholesale conditions for three days (average period that wholesale traders hold their fruits during selling). On day 3 of wholesale simulation all packages were opened and fruit losses quantified. Undamaged fruits from all packages were then transferred inside to the horticulture postharvest laboratory to simulate retail traders handling. Similar treatment grouping were maintained but all on laboratory bench displays. Under the simulated retail handling conditions fruits were retained until when at least 50% rated unmarketable due to either decay and or shriveling. The mean temperature and relative humidity (RH) at retail simulated conditions (laboratory room) were at 24.7 °C, 79.9% RH.

Analysis of Losses

During the study, both internal and external/ physical fruit quality postharvest losses were evaluated across treatment combinations.

Physical/External Fruit Quality

Percent Fruit Decay

Assessment of fruit visual quality was done on Day 3 of wholesale simulation and every three days during retail storage simulation to identify and record fruits found with signs of decay. Then percentage cumulative fruit decay was calculated following equation 1.

$$Decayed\ fruits(\%) = \frac{Number\ of\ decayed\ fruits}{Total\ number\ of\ sampled\ fruits} \times 100 \quad (1)$$

Physiological Weight Loss

Fruit physiological weight was determined according to Huidrom *et al.* (2016) using a digital kitchen scale (Ozeri, ZK 14-S) and percentage physiological weight loss (PWL) established based on equation 2. Ten fruits from each packaging method and position replication were numbered and used for tracking of weight change during successive handling from day 0 of storage.

$$PWL(\%) = \frac{Initial\ weight(g) - Final\ weight(g)}{Initial\ weight(g)} \times 100 \quad (2)$$

Internal Fruit Qualities

Six (6) fruits randomly picked from each packaging method position (top, mid, bottom) per replication were sampled. Evaluations were conducted on Day 0 of wholesale simulation, Day 3 of storage (initial day of retail simulation), and every three days of storage during handling at retail simulated condition until 50% of the fruits in at least one of the treatment is rated unmarketable. Five internal fruit qualities; pulp temperature, juice volume (v/w%), soluble solids content (oBrix), titratable acidity (% citric acid), and ascorbic acid content (mg/100g) were evaluated.

Fruit Pulp Temperature

Fruit pulp temperature was measured using a long probe digital thermometer (TA804-PROBE, Lexington, KY USA) inserted to the middle of the fruit core through the pistil end. The probe was twisted to an angle towards the segments and maintained for one minute. Temperature readings (°C) were record separately for each of the sampled fruits.

Juice Volume

Fruits weight was measured using a digital kitchen scale (Ozeri, ZK 14-S), then each fruits was cut and the juice squeezed using a hand held juice squeezer. The juice from each fruit was filtered using a tea strainer into a plastic measuring cylinder and juice volume recorded. Percent juice volume was then calculated based on equation 3.

$$Percentage\ Juice\ Volume(v/\mathrm{w}\%) = \frac{Juice\ volume(ml)}{Whole\ fruit\ weight(g)} \times 100 \quad (3)$$

Soluble Solid Content (SSC) and Titratable acidity (TA)

Fruit juice of six fruits per treatment was composited to make three samples (of two fruits each) and used for evaluation of SSC and TA. Fruit SSC was determined according to Huidrom *et al.* (2016) where 1m l of mandarin fruit juice samples were pipetted onto a handheld digital refractometer (Antago PAL-1, Japan) and readings in degree Brix recorded. Fruit TA was determined according to Rajwana *et al.* (2010) by pipetting 5 ml of the juice into 50 ml of distilled water and titrated against 0.1N NaOH to 8.2 pH using an automatic potentiometric titrator (HI 901, Hanna Instrument, USA). Percentage of the dominant acid (citric acid) was then calculated based on equation 4.

$$Titratable\ acidity(\%) = \frac{0.1N\ NaoH\ used \times 0.064}{Volume\ of\ sample\ used} \times 100 \quad (4)$$

Where; N = normality

Fruit Total Ascorbic Acid Content

Ascorbic acid (Vitamin C) content was determined according to Seki (1990) based on the oxidation reduction reaction principle. Two milliliters of the composite juice used for SSC were diluted to 50 ml with 10 % TCA solution and filtered using a Whatman filter papers No. 1. Ten milliliters of the filtrate was slowly titrated against a standard solution of 2,6 - Dichlorophenolindophenol and sodium salt until a pink colour marking the titration end-point attained. A blank solution of 10 % TCA solution was titrated against the standard solution (2,6-Dichlorophenolindophenol). The volumes of indophenol solution used to oxidize the ascorbic acid in the fruit juice sample extract and blank solution were recorded. The vitamin C content was then calculated using equation 5.

$$Fruit\ Vitamin\ C\ content(mg/100gm) = \frac{(A - B * \mathrm{C} * \mathrm{V} * 100}{D * S} \quad (5)$$

Whereby:

A = volume (ml) of the Indophenol solution used for the sample

B = volume (ml) of the Indophenol solution used for the blank

C = mass (mg) of ascorbic acid equivalent to 1.0 mL indophenols solution

S = mass (g) of sample taken for analysis

V = total volume (ml) of extract

D = volume (ml) of sample filtrate taken for analysis

Statistical Analysis

Fruit pulp temperature, physiological weight loss, cumulative fruit decays, SSC, TTA, SSC/TTA, and content of fruit ascorbic acid were evaluated. Analysis of variance of data (ANOVA) was conducted using PROC GLM (SAS institute Inc., Version 9.3, Cary, NC, USA) based on a randomized complete block design. Post comparison Tukey's test at $p<0.05$ was conducted to separate the means for all evaluated parameters.

Results

Following the shipping simulation and storage experiment, fruits in most of the treatments evaluated took a maximum 12 days for ≥ 50% to be rated unmarketable. The results presented here, reflects the evaluation conducted during the period.

Shipping Packages and Fruit Position in the Package

Fruit decay following shipping simulation varied significantly ($p<0.01$) with both package type and fruit position in a package (Appendix 1, Table 1). Fruit packed in SPC particularly at the middle of package had the lowest decays (18.1%) compared to those packed at the same position in BAMB (37.7%) and BULK (32.5%) (Table 1). SPC reduced the percent of fruit decay by 7.9% and 5.1% more than the BAMB and BULK packaging methods, respectively. Similarly, SPC demonstrated lower decay (22.5%) on fruits located at the bottom of the package than fruits at same position in BULK (29.8%). SPC reduced decay of fruits located at the bottom of the package by 5.7% and 7.3% more over BAMB and BULK packaging, respectively. However, within the SPC package, fruits located at the middle (18.1%) and bottom (22.5%) experienced less decay than those at the top of the package (33%).

Table 1: Interaction effect of packaging method and fruit position in the package on cumulative fruit decay during storage at ambient condition after shipping simulation (12 days storage)

	Cumulative Fruit Decay (%)		
Fruit Position in the Package	**Stackable Plastic Crate (SPC)**	**Bamboo Basket (BAMB)**	**Bulk on Truck (BULK)**
Top	32.98 aA	31.31 aA	26.47 aA
Middle	18.13 bB	37.69 aA	32.54 aA
Bottom	22.45 bB	28.18 aBA	29.76 aA

Percentage cumulative fruit decay means within a column followed by the same low letter or by the same capital letter within a row do not differ significantly according to Tukey's test ($p<0.05$).

Table 2: Effect of fruit storage time on cumulative fruit decay and weight loss during storage at ambient condition following shipping with SPC, BAMB, and BULK field packages

Fruit Storage Time	Cumulative Fruit Decay (%)	Change in cumulative fruit decay (%)	Cumulative Weight Loss (%)	Change in weight loss (%)
Day 3	13.47	13.47 a	0.923	0.92 b
Day 6	27.15	13.68 a	4.77	3.85 a
Day 9	35.10	7.95 b	8.70	3.93 a
Day 12	39.61	4.51 b	11.12	2.42 b

Percentage cumulative fruit decay and cumulative weight loss means within a column followed by the same letter do not differ significantly according to Tukey HS test ($p<0.05$)

Storage Time

Fruit physiological weight loss ($p<0.0001$) and decay ($p<0.001$) varied significantly with storage time (Appendix 1, Table 2). Weight loss due to water loss was higher on Day 6 (3.9%) and Day 9 (3.9%) of storage than on Day 3 (0.9%) and Day 12 (2.4%). On the contrary, fruit decay was higher on Day 3 (13.5%) and Day 6 (13.7%) than on Day 9 (8%) and Day 12 (4.5%) of storage.

The fruit pulp temperature following the shipping simulation experiment varied significantly ($p<0.001$) with both package type and fruit position in a package (Table 3). Generally, fruits in BAMB retained the lowest fruit pulp temperature (23.7 °C) compared to SPC (25.1 °C) and BULK (29.7 °C) packages for the fruits located at the top of the packages. On the other hand SPC (23.5 °C) and BAMB (23.5 °C) packages were able to retain lower fruit pulp temperature than BULK (25.4 °C) packaging for the fruits located at the middle of the package. Interestingly, pulp temperature on fruits under BULK package decreased with depth from top to the bottom of the package, being highest at top (29.7 °C) and least at the bottom (23.7 °C). Whereas for SPC, pulp temperature was equally lower on fruits at the middle (23.5 °C) and bottom (23.9 °C) than at top (25.1 °C) of the package.

Percent of fruit juice volume (v/w%) during storage following shipping varied significantly (P<0.05) with both packaging method and storage duration (Appendix 1, Fig.2). Both SPC and BAM had similar trend of change in juice volume, being high on day 3 and Day 12 of storage, while BULK maintained an increasing trend that peaked on day 9 (39.5%) of storage. On Day 3 of storage (end of wholesale simulation), BAMB package demonstrated higher juice volume than BULK whereas on Day 9 BULK (39.6%) had higher juice volume than SPC (34.7%). However, on day 12 (Day 9 at retail storage) fruits from BAMB packaging had higher juice volume than both BULK and SPC.

Both fruit SSC, TA, SSC/TA ratio, and ASC varied significantly (p<0.0001) with storage

Table 3: Interaction effect of packaging method and fruit position in the package on fruit pulp temperature at wholesale storage conditions (day 3) after shipping simulation

	Pulp temperature (°C)		
Fruit Position in the Package z	**Stackable plastic crate (SPC)**	**Bamboo basket (BAMB)**	**Bulk on truck (BULK)**
Top	25.1 aB	23.7 aC	29.7 aA
Middle	23.5 bB	23.5 aB	25.4 bA
Bottom	23.9 bA	23.2 aA	23.7 cA

Fruit pulp temperature means within a column followed by the same low letter or by the same capital letter within a row do not differ significantly according to Tukey's test (p<0.05)

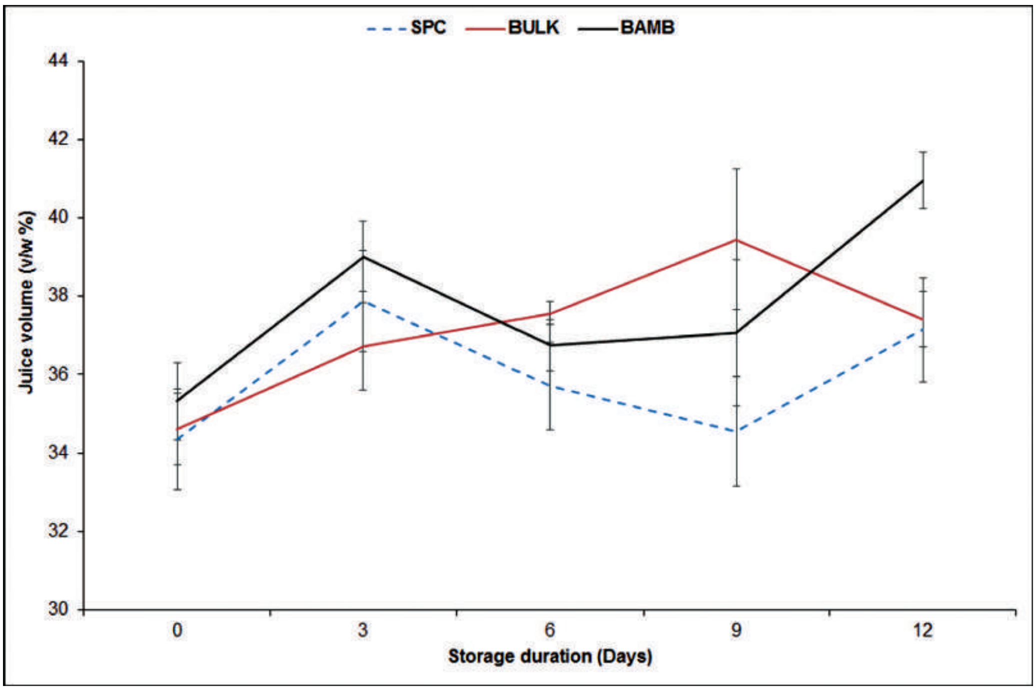

Figure 2: Effect of packaging methods; SPC, BAMB, and BULK on percentage juice volume following 12 days storage at ambient conditions

duration (Appendix 2, Fig. 3). However, SSC was significantly higher on Day 12 (10.3 oBrix) than on the proceeding days of storage (Fig. 3a). Similarly the SSC/TA ratio started to increase significantly from Day 6 through Day 12 (Days 3 through 9 of retail storage) (Fig. 3c). On the contrary TA was high on Day 0 than on Day 6 (day 3 of retail handling) and the least on Day 9 through Day 12 (day 9 of retail handling) (Fig. 3b). Ascorbic acid (ASC) was significantly higher during the three days of wholesale simulation than on Day 9 and Day 12 after harvest (Day 6 and 9 of retail storage).

Discussion

Fruit decay has been the major concern for wholesale and retail traders. The low decays in SPC compared to BAMB and BULK packaging observed in this study could be related to low contamination from cushioning materials. Both BAMB and BULK packaging used grasses as cushion materials which increases chances for produce contamination. On the other hand, fruit located at the top of the package can experience covert mechanical damage caused by fruit–fruit contact, and fruit to package impact or abrasion making fruits susceptible to attack by decay pathogens. Mechanical damages and high pulp temperature could be the reasons for the higher fruit decay observed on fruits located at the top of SPC than middle and bottom of the package. Damages provide entry points, while high temperature favour growth and multiplication of decay pathogen on produce (Barkai-Golan, 2001; Martinez-Romero *et al.,* 2004; Ladaniya, 2008; Kader and Yahia, 2011). Plastic crates are easily cleanable and have smooth inner surface, which reduce the chance for mechanical damage on fruit surface (Abejón *et al.,* 2020). Both BAM and BULK used grass cushioning materials which are likely to serve as source of decay pathogens. Bamboo baskets (BAMB) also have rough inner surfaces potential for causing surface abrasion and puncture on fruits (Ladaniya, 2008).

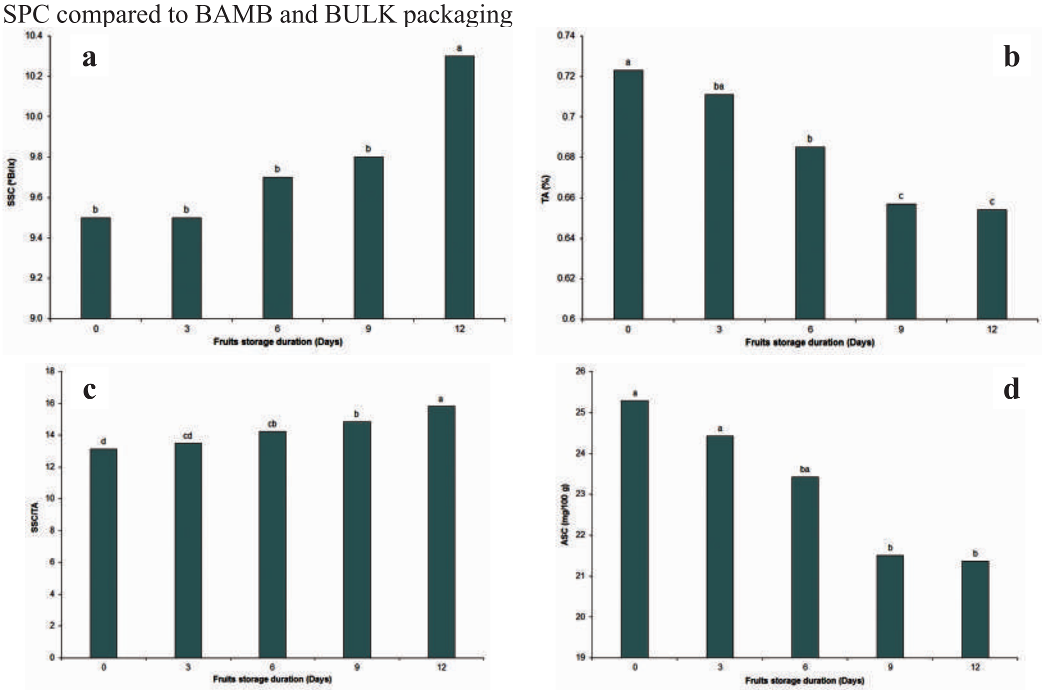

Figure 3: Effect of fruit storage time on SSC (a), TA (b), SSC/TA (c), and ASC (d) following shipping simulation with SPC, BAMB, and BULK packaging

On the other hand, the higher cumulative decay observed on fruits located at the middle of BULK and BAMB packages than at the middle of the SPC package may have been attributed to the prevailing high temperature (28.5 °C) and RH (89%) and poor ventilation in the packages compared to 27 °C and 85% in SPC. The dried banana leaves and raw grasses were used as cushioning but was likely to reduce air circulation in the packages. Soil borne decay pathogen like *Geotrichum candidum* (Sour rot) is known to live and grow on fermented grasses (Ladaniya, 2008). The middle and bottom part of BULK package was likely to provide favourable conditions for growth of decay pathogen than SPC. SPC package have vents on the side, which give better produce ventilation, also contain fewer fruits and more shallow depth that reduced compression damage and eliminated contact with any grass or soil materials.

In this study, wholesale handling conditions were found to exposed fruits to higher temperatures leading to variations in fruit pulp temperature among packages and between fruit position within the package. Produce handling conditions at wholesale exposes fruits at top packages, particularly under BULK packaging to direct sun exposure. That was the also the reason for the observed higher pulp temperature on fruits at the top than middle and bottom of the SPC package. Similar findings have been reported by Thompson *et al.* (2011) indicating high temperature on cherry fruits at top of the boxes than middle and bottom positions. This study also associate the dry banana leaves cushioning materials used as lining in the BAMB package with the relatively low pulp temperature and high RH recorded throughout the BAMB package positions.

Fruit cumulative decay increased with storage duration, however the observed higher decay on Day 3 (end of wholesale) suggest existence of covert fruit fly infestation, mechanical damage and or latent infection which may have been occurred in the field (harvesting) and during shipping. Whereas the higher increase in decay from Day 3 to Day 6 (day 3 of retail handling) than on day 9 and day 12 was likely attributed to latent infections and recontamination from sorted decayed fruits. The higher temperature and relatively low RH experienced at wholesale (23 to 29.7 °C, RH of 74 to 84.5%) and retail (24.6 °C, RH of 79.9%) simulated conditions was likely associated with the promotion of growth and development of decay pathogens such as *Penicillium digitatum* and *Geotrichum candidum* Link. (*Geotrichum citri-aurantii*) which grow well and rapid at an ambient temperatures of 25 to 30 °C and 28 to 30 °C, respectively (Smilanick *et al.,* 2006; Ladaniya, 2008). Such higher temperatures were also likely to encourage growth of *Diplodia natalensis* (Diplodia stem end rot) (Ismail *et al.,* 2004). Presence of any wound on fruit surface due to mechanical damage would also enhance attack by fungal pathogens (Ismail *et al.,* 2004; Ladaniya, 2008). The higher temperatures observed at wholesale handling in the packages during this study were likely associated with stimulating latent infections during simulated wholesale and handling conditions.

Physiological weight loss due to water loss increased with storage time, however the observed higher change in weight loss on day 6 and day 9 (day 3 and day 6 of retail storage) than on day 3 of wholesale storage was partly attributed to high storage temperature (24.6 °C) and low relative humidity (79.9%) recorded at retail simulated conditions. These results suggest that, maintaining fruit in their shipping container during wholesale handling reduced water loss more than when exposed on display during retail marketing conditions. Ladaniya (2008) has reported similar findings.

The higher juice volume (v/w%) observed on BULK than SPC packaging on day 9 and on BAMB than on both BULK and SPC in day 12 was partly related to water loss from the fruit peel that may have been varied slightly among fruits in the different packages. Water loss from the peel at constant juice volume, increased the percent of juice volume of individual fruits. The slightly less weight loss observed in this study on fruits previously packaged in SPC than BULK on day 9 and BAMB on day 12 could be the reason for the observed trends in juice content among packages over storage time.

Regardless of the packaging methods under practice, fruit SSC, TA, ratio of SSC/TA, and total ascorbic acid content varied considerably with storage time. The increase in SSC on day 12 (day 9 retail storage) was likely associated with the higher water loss (11.2%) under retail handling conditions. Burdon *et al.* (2007) also reported a slight non-significant increase in SSC following exposure of ‘Satsuma’ mandarin to 30 °C and 65% RH for 3 days. Similarly, a significant increase in SCC during storage has been reported in 'Hamlin' orange, 'Robinson' tangerines and 'Palestine' lime following four weeks of storage at 15 °C, 95% RH (Echeverria and Ismail, 1987).

The decrease in TA starting on day 6 (day 3 retail storage) observed in this study associated with metabolism of organic acids particularly citric acid (Hairai and Ueno, 1977; Marcilla *et al.,* 2006) accelerated by high temperature and low RH exposure during retail handling simulation (24.6 °C, 79.9% RH). Similarly, Burdon *et al.* (2007) reported a significant decrease in TA following exposure of Satsuma mandarin to high temperature and low RH (30 °C, 65% RH) for 3 to 5 days. On the other hand, a similar decrease in TTA in mandarin fruits during storage time has been reported in other studies (Echeverria and Ismail, 1987; Shellie *et al.,* 1993; Pérez *et al.,* 2005). The increase in soluble solids content and decrease in titratable acidity increased the SSC/TTA ratio. Similar findings have been reported in earlier studies (Echeverria and Ismail, 1987; Pérez *et al.,* 2005; Burdon *et al.,* 2007; Tietel *et al.,* 2010).

On the other hand, the observed decrease in ascorbic acid in this study starting on Day 9 (day 6 retail storage) was likely associated with retail storage conditions, particularly high temperature (24.6 °C). Ascorbic acid has been reported to be thermally instable, being very susceptible to degradation at high storage temperatures (Pérez *et al.,* 2005; Burdurlu *et al.* 2006). No changes in SSC, TTA, SSC/TTA or ascorbic acid content were attributed to the packaging methods used in this study. However, storage temperature and citrus senescence during storage have been reported to alter both flavor (SSC and TTA) and nutritional quality particularly ascorbic acid content (Miller, 1946; Biolatto *et al.,* 2005). Storage of citrus fruits at 5 to 8 °C, has been reported to minimize the loss in nutritional quality mainly ascorbic acid content (Grierson and Miller, 2006).

Conclusions

The study assessed the performance of three field-packaging methods; BAM, SPC and BULK and the position of fruit in the packages (top, middle, and bottom) on physical fruit quality (decay, weight loss) and internal/ nutritional quality (juice volume, SSC, TA, SSC/ TA, and Ascorbic acid). During the study, SPC reduced fruit decay, and fruit pulp temperature particularly for the fruits at the middle and bottom of the package. In addition, it was observed that, retention of mandarin fruits in the shipping package (SPC and BAMB) help to reduce weight loss, maintain high juice volume, and minimize fruit heating. Among packages, BAMB was effective in minimizing fruit pulp temperature for fruits located at all positions in the package, however the insulation materials used; dry banana leaves and raw grasses are likely to reduce ventilation, retain high RH, and also serves as source of latent infection for later fruit decays. Packaging methods had no effect on internal fruit qualities. Internal fruit quality varied only with storage duration, with most of the fruit becoming unmarketable on the 9th day of retail handling. Fruit SSC, and SSC/TA increased and TA and Ascorbic acid decreased with storage duration. The increase in SSC and decrease of TA, and Ascorbic acid observed in this study associated with the increase in water loss during storage period. This study also associate the decline in ascorbic acid and titratble acidity and the increase in SSC and SSC/TTA ratio with the high storage temperature experienced at wholesale and retail levels.

Therefore, the study recommends use of SPC over BAMB and BULK methods as the best option to reduce fruit decays, fruit pulp temperature rise and hence reduce produce loss. The study also recommends retention of fruits in shipping container with few on display to reduce water loss during retail handling. However, it is still important to ensure proper shading of the fruits during wholesale and retail conditions as it may enhance respiration and growth of decay microorganisms. Use of banana leaves as insulation materials in BAMB is advocated to reduce fruit heating during handling, however study are required to ascertain its freeness from latent infections. In addition proper management of the crop in the field is required to ensure effective control of pest and disease along the fruit handling chain particularly to reduce latent infections that could grow during storage.

Further studies are recommended to establish the cost benefit of using plastic crates (SPC) over BAMB and BULK packaging as a means for advocating its adoption. Further studies are also required to evaluate the quality and use of existing insulating materials including banana leaves in reducing fruit pulp temperatures.

Acknowledgement

The author acknowledge that, this work was made possible by the generous support of the American people through the United States Agency for International Development (USAID) that funded the Innovative Agricultural Research Initiative project (iAGRI) (Award No. CA-621-A-00-11-00009-00). Nevertheless, opinions expressed herein are those of the authors and do not necessarily reflect the views of the U.S. Agency for International Development or the United States Government.

References

Abejón, R., Bala, A., Vazquez-Rowe, I., Aldaco, R., and Fullana-i-Palmer, P. (2020). When plastic packaging should be preferred: Life cycle analysis of packages for fruit and vegetable distribution in the Spanish peninsular market. Resources, Conservation and Recycling, 155, 104666.

Barkai-Golan, R. (2001). Postharvest Diseases of Fruits and Vegetables; Development and Control. Elsevier Science B.V, Netherlands. 418 pp.

Biolatto, A., V. Salitto, R.J.C. Cantet, and N. A. Pensel. (2005). Influence of different postharvest treatments on nutritional quality of grapefruits. Food Science and Technology 38: 131–134.

Brown, G.K. (2006). Harvesting Techniques. In: Fresh Citrus Fruits, 2nd ed (Edited by Wardowsky,W.F., Miller, W.M., Hall, D.J., and Grierson, G). Florida Science Source Inc., Longboat Key, FL. 223–249pp.

Burdon, J., N. Lallu, S. Osman, D. Billing, H. Boldingh. (2007). Postharvest conditioning of Satsuma mandarins for reduction of acidity and skin puffiness. Postharvest Biol. and Technol 43: 102 -114.

Burdurlu, H.S., N. Koca, and F. Karadeniz. (2006). Degradation of vitamin C in citrus juice concentrates during storage. *Journal of Food Engineering,* 74: 211–216.

Grierson, W. and W.M. Miller. (2006). Storage of citrus. In: Fresh Citrus Fruits, 2nd ed (Edited by Wardowsky, W.F., Miller, W.M., Hall, D.J., Grierson, and G) Florida Science Source Inc., Longboat Key, FL. 547–581pp.

Izamuhaye, J.C. (2008). Explorative study on citrus farming systems: a case of Tanga Region-Tanzania. Vanhall Larenstein, Wageningen University. Netherlands. 70pp.

Kader. A., and E.M. Yahia (2011). Postharvest biology of tropical and subtropical fruits In: Postharvest biology and technology of tropical and subtropical fruits Vol 1 (Edited by Yahia, E.M) Woodhead Publishing Limited, Philadelphia, USA. 79-110pp.

Ladaniya, M. S. (2008). Citrus fruit, biology, technology, and evaluation (First edition). Elsevier Inc., London, UK. 558pp.

Lynch, K. (1999). Commercial horticulture in rural Tanzania an analysis of key influences. Geoforum 301: 171-183.

Marcilla, A., Zarzo, M., and Del-Río, M.A. (2006). Effect of storage temperature on the flavour of citrus fruit. *Spanish Journal of Agricultural Research,* 4(4): 336-344.

Martinez-Romero, D., Serrano, M., Carbonell, A., Castillo, S., Riquelme, F., and Valero, D. (2004). Mechanical damage during fruit post-harvest handling: technical and physiological implications In: Production practices and quality assessment of food crops, Springer, Dordrecht 233-252pp.

Miller, E.V. (1946). Citrus fruits in storage. The botanical review 7: 393 – 423.

Montero, C.R.S., L.L. Schwarz, L.C. dos Santos, R.P. dos Santos, and R.J. Bender. (2012). Oleocellosis incidence in citrus fruit in response to mechanical injuries. Scientia Horticulturae 134: 227–231.

National Bureau of Statistics and Office of Chief Government Statistician Zanzibar. (2012). National Sample census of Agriculture Small Holder Agriculture 2007/2008 Vol 2, Crop Sector – National Report, Tanzania. 539pp.

Pérez, A. N., Luaces, P., Oliva, J., Rios, J. J., and Sanz, C. (2005). Changes in vitamin C and flavor compounds of mandarin juice due to curing of fruits. *J. Food Chem* 91: 19 – 24.

Seki, T. (1990). Laboratory Manual for Food Analysis. Technical cooperative project of Jomokenyatta University College of Agriculture and Technology, Kenya. 68pp.

Shellie, K.C., Firko, J., and Mangan, R.L. (1993). Phytotoxic response of Dancy tangerine to high-temperature, moist, forced-air treatment for fruit fly disinfestation. *Journal of the American Society for Horticultural Science,* 118: 481–485.

Smilanick, J. L., G.E. Brown, and J.W. Eckert. (2006). Postharvest citrus diseases and their control. In: Fresh Citrus Fruits, 2nd Edt (Eds Wardowsky,W.F., Miller, W.M., Hall, D.J., Grierson, G), Florida Science Source Inc., Longboat Key, FL, 339-395pp.

Thompson, J.F, E.J. Mitcham, and F. G. Mutchell (2011). Preparation for fresh market. In: Postharvest Technology of Horticultural Crops 3rd edition (Eds Kader. A.A) University of California Davis Agriculture and Natural Resources. California. 67-79pp

Tsa, F.H. 2012. A case study of orange from Matombo division to Morogoro urban markets, Tanzania. University of Copenhagen, Copenhagen, Denmark. 97pp.

Zheng, Y., S. He, S. Yi, Z. Zhou, S. Mao, X. Zhao, and L. Deng. (2010). Characteristics and oleocellosis sensitivity of citrus fruits. Scientia Horticultura, 123: 312–317.

Appendices

Appendix 1: Analysis of variance for the effect of field packaging methods, fruit passion in the package and storage time on fruit quality following 12 days storage at ambient condition

Treatments	Cumulative Fruit Decay (%)	Cumulative Weight Loss (%)	Fruit Pulp Temperature (°C)	Juice Volume (v/w %)
Storage Duration (SD)	***	****	-	ns
Packaging Method (PM)	**	ns	****	**
Fruit Position in Package (FP)	ns	-	****	ns
SD X PM	ns	ns	-	*
SD X FP	ns	-	-	ns
PM X FP	**	-	***	ns
SD X PM X FP	ns	-	-	ns

*ns, *, **, ***, or **** refers to non-significant, significant at p< 0.05, p< 0.01; p< 0.001, or p<0.0001, respectively.*

Appendix 2: Analysis of variance of field packaging methods, fruit passion in the package and storage time on selected fruit quality following nine days storage at ambient condition

Treatment	SSC (°Brix)	TA (% citric acid)	SSC/TA (ratio)	Ascorbic Acid (mg $100g^{-1}$)
Storage Time (ST)	****	****	****	****
Packaging Method (SM)	ns	ns	ns	ns
Fruit Position in Package (FP)	ns	ns	ns	ns
Interactions				
ST X SM	ns	ns	ns	ns
ST X FP	ns	ns	ns	ns
SM X FP	ns	ns	ns	ns
ST X SM X FP	ns	ns	ns	ns

*ns, or ****, non-significant, or significant at p<0.0001, respectively*