JOURNAL OF HORTICULTURE AND POSTHARVEST RESEARCH
2022, VOL. 5(3), 269-284

Journal of Horticulture and Postharvest Research

Journal homepage: www.jhpr.birjand.ac.ir

University of Birjand

Quality retention of selected exotic fruits: Balata (*Manilkara bidentata*), Spanish Tamarind (*Vangueria edulis*) and fresh-cut West Indian Lime (*Citrus aurantifolia*)

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ARTICLE INFO

Original Article

Article history:
Received 17 March 2022
Revised 29 April 2022
Accepted 8 June 2022
Available online 3 September 2022

Keywords:
Chilling injury
Exotics
Modified atmosphere packaging
Storage
Total soluble solids

DOI: 10.22077/jhpr.2022.5146.1269
P-ISSN: 2588-4883
E-ISSN: 2588-6169

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ABSTRACT

Purpose: Exotic fruits could fulfill global requirements of health-conscious consumers, providing efficient postharvest management protocols are implemented to assure safety and quality. **Research Methods:** Compositional changes of ripe balata fruits (*Manilkara bidentata*), were investigated when seal-packaged in low density polyethylene (LDPE) for 7 days at 6-7˚C and 28-30˚C. Mature Spanish tamarind (*Vangueria edulis*) fruits were stored at 20˚C and 30˚C and ripening changes analyzed after 3 days. Quarter-sliced mature-green (M1) and ripe-yellow (M2) West Indian lime (*Citrus aurantifolia*) were seal-packaged in LDPE at 4-5˚C, 7-8˚C and 28-30˚C and evaluated over seven consecutive days. **Findings:** Balata seal-packaged in LDPE for 7 days at 6-7˚C and at 28-30˚C, accounted for lower fresh weight losses, higher total soluble solids (TSS), pH, TSS:TTA, vitamin C, better skin-gloss appearance and more acceptable flavor than control fruits over the same period. Ripe Spanish tamarind stored at 20˚C and 30˚C and 75-85% relative humidity had a yellowish-brown skin and pulp color, TSS (3.0-3.1%), TTA (2.24g/100g - 2.48g/100g), TSS:TTA (1:1.3), pH (3.4) and vitamin C (1.84 mg/100g). West Indian lime M2 quarter-slices at 7-8˚C secured superior quality ratings due to the absence of chilling injury symptoms, cut-edge browning and fermentative aroma compared to similar treatments after 4 days at 4-5˚C. At 28-30˚C, M1 and M2 became unmarketable in less than two days. **Research Limitations:** More cultivars required. **Originality/value:** The unique postharvest quality characteristics of exotic fruits could be successfully managed to fulfill the basic requirements of health-conscious consumers and to exploit existing and potential niche markets.

INTRODUCTION

Biodiversity has enabled tropical and sub-tropical countries to be sanctified with an extensive range of exotic fruits and vegetables (Medina-Torres et al., 2021). The majority of these fruits are edible and have gained popularity owing to their unique taste, nutraceutical values, sensory qualities, and mouthfeel. Exploiting their potential can fulfill the basic requirements of health-conscious consumers and help local communities to acquire self-sufficiency to exacerbate their economic security (Bhat & Paliyath, 2016). This study highlights three popular exotic tropical fruits, with regard to their postharvest quality attributes during storage.

The interest and demand for exotic fruits have grown rapidly in European and American markets. Exotic fruits have a strong appeal to consumers, not only for the ethnic communities, for whom exotics may in fact be a part of their everyday diet, but also for the indigenous population. Some exotic fruit traders expect sales to double by the end of the decade, and the market appears to be receptive to the wide range of exotic fruits that are constantly being offered. An interest in the further expansion of this lucrative market is shared by exporters in the various developing countries as well as by many of the importers, wholesalers and retailers who make up the foreign exotic fruit trade.

Balata (*Manilkara bidentata*), Spanish tamarind (*Vangueria edulis*) and West Indian lime (*Citrus aurantifolia*) are three popular exotics produced in the tropical and sub-tropical climates which could result in economic benefits including more foreign exchange earnings, increased employment and greater use of agricultural resources and infrastructure. However, the high perishability of these exotic fruits have challenges as their marketability do not have sufficient shelf life to survive the distribution system, and therefore require effective storage protocols to assure safety and quality (Ghidelli & Perez-Gago, 2017).

For producers and exporters, it is important to have an attractive and marketable selection of high-quality fruits. However, in order for the Caribbean region to succeed in both the fresh fruit trade and in the fruit processing industry, regionally or extra-regionally, compliance to stringent quality requirements, consistent volume and optimum postharvest handling techniques is imperative. Adherence to these requirements are inevitable for development of effective and efficient postharvest technological packages for these exotic fruits otherwise availability will remain restricted to the natural periods of gluts and scarcities as they exist at present. Furthermore, exotic fruits are characterized by moderate to high respiration rates, rapid loss of soluble sugars, undesirable textural changes and loss of cellular integrity which in turn are manifested in loss of sweetness, flavor, unpalatable textures and unattractive colors. These quality attributes must be managed to facilitate the longer duration associated with shipments to foreign markets.

Balata also called ausubo, are exotic globose berries, about 2.5-3cm in diameter with a yellow-orange skin color, usually contain a single shiny black seed, surrounded by an edible light-brown grainy textured pulp which is sweet, succulent, juicy and refreshing. Occasionally, two seeds per fruit are found (Little & Wadsworth, 1964; Marshall, 1939). Balata is a member of the Sapotaceae family native to Puerto Rico and widely distributed throughout the West Indies, Mexico, Panama, Northern South America, including the Guianas and Venezuela, Peru and Northern Brazil (Chudnoff, 1984; Longwood, 1961). Balata fruits are borne from trees growing to 30-45m in height. In Trinidad and Tobago balata trees flower at the beginning of the dry season, January to February and the fruit ripens by April and May (Marshall, 1939).

While commercially significant as a timber tree due to its diverse use in the tropics for railway sleepers, bridges, heavy construction, furniture, turnery, flooring, violin bows, billiard cues due to its strength, high wear resistance and durability there is a paucity of information on the shelf life, nutritional composition and organoleptic properties of balata fruits (Bridgemohan & Isaac, 2017). Accordingly, the need to prolong the shelf-life and optimize fruit quality is warranted in view of the brief seasonality of production, dilemmas in harvesting fruits due to tree heights, variable fruit maturity and ripening patterns and overall lack of information of their postharvest behavior under various storage regimes.

Spanish tamarind (*Vangueria edulis*) is another lesser-known known tropical exotic fruit belonging to the Rubiaceae family (Britton & Nelson, 1926; Mayori, 2018). This profusely branched, deciduous multi-stemmed shrub, native to Madagascar, rarely exceed 6m in height. The bark is smooth grey to dark grey. Leaves are opposite elliptic-ovate or rotundate with conspicuous greenish-white veins. During growth and development, fruits maintain their globular shape. Fruits have a smooth, tough, shiny green skin color when immature, changing to yellowish-brown when ripe and have 4-5 woody seeds up to 1.6cm long. The ripe fruit pulp is edible and has a chocolate-like color with a distinctive acidic taste (Bridgemohan & Isaac, 2017). Utilization of this exotic fruit is also compromised due to a paucity of information on postharvest quality management procedures.

West Indian lime is an exotic fruit used worldwide in cuisine and belongs to the Rutaceae family (Penjor et al., 2014). In the hospitality industry throughout the Caribbean fresh-cut sections of West Indian limes are popularly used as a food additive to impart citric flavor and odor in novel foods. However, occurrences of cut-edge browning and excessive juice leakage often result in high postharvest losses during commercial preparation and retail display during refrigerated storage. When cells are ruptured by cutting or slicing during minimal processing, wound-induced physiological and biochemical reactions are initiated that shorten storage life (Cantwell & Suslow, 2002; Singla et al., 2020; Moradinezhad, 2021; Awad et al., 2021). Fresh-cut limes, either quartered or cross-sectioned wedges cannot be classified as a ready-to-eat item as other fresh-cut products such as watermelons, pineapples or papayas, yet they are required in consistent and incredible quantities in the food industry where cut sections are incorporated in several menus at restaurants, bars, hotels, hospitals, fruit salads, fish and meat entrees as flavor enhancers, toppings, appetizers and garnishes. Notwithstanding the wealth of information on post-cutting maintenance of quality of a diverse range of fresh-cut fruits and vegetables of tropical and temperate origins, there are fewer published studies of a similar nature on fresh-cut limes (Artés-Hernández et al., 2007).

The objectives of these experiments varied according to the type of exotic fruit selected. For balata, the aim was in determining the effects on quality attributes of ripe fruits when seal-packaged in low density polyethylene (LDPE) during storage. Investigations on Spanish tamarind focused on the effects of temperature and storage duration on physio-chemical attributes. Fresh-cut West Indian limes were examined to determine the effects of modified atmosphere packaging and fruit maturity on the maintenance of quality attributes.

MATERIALS AND METHODS

Experiment 1

Mature tree-ripe balata fruits were purchased at a retail market in North Trinidad, placed in a single-ply cardboard box as a single layer and transported to the laboratory in the Department of Food Production at the University of the West Indies within one hour of purchase. Fruits were sorted for freedom from defects, and selected fruit washed with tap water for the removal of extraneous materials followed with a postharvest dip for 5 minutes in 300 µg ml^{-1} sodium hypochlorite solution to control surface pathogens. Thereafter, sanitized fruits were left in a holding room for 15-20 minutes at 20-22°C and 80-85% relative humidity until surface moisture had evaporated.

Heaps of five (5) fruits were placed in paper bags (PB, control) and in sealed low density polyethylene bags (LDPE) respectively and stored at 6-7˚C and 28-30˚C and at 85-90% R.H. up to seven days. There were ten (10) replicates for each package treatment. Pre-storage measurements were taken on twenty-five fruits apart from those allocated to the two package treatments to determine actual fruit fresh weight as well as weights of fruit skin, seed and flesh. Data were also taken on percentage fresh weight losses after 7 days at 6-7˚C. Fruits were weighed by a precision digital balance (Accuris, Benchmark Scientific, USA). The results were calculated as the percentage of the total weight loss between the initial and final weight (Moradinezhad, 2021). The methodology for each of the following parameters was evaluated and described hereunder (A.O.A.C,1975; Graham et al. 2004).

Skin and flesh colors were determined with a Minolta Chroma meter (Model CR-200, Minolta Corp, Ramsey, N.J.), calibrated with a white standard (Minolta calibration plate CR-A43). The fruit chromaticity was expressed as L* a***,** b* coordinates (CIE, 1976). The “L” color component represented the lightness of color and it was greater for lighter colors. The “a” values were negative for green and positive for red while the “b” values were negative for blue and positive for yellow.

pH was determined with an Orion Research digital pH meter (EA 920, Orion Research Inc. Boston, MA) which was first standardized with two buffer solutions of pH 7.41 and 4.01. The extract was obtained by macerating 25g of pulp with 100 ml de-ionized water for one minute in a Waring Commercial laboratory blender (Model 34 BL97, Waring Products Corp, Hartford, CT). Total soluble solids concentration (TSS) was determined on the juice expressed from a vertical fruit section using a hand-held Leica refractometer with a measuring range of 0-50˚ Brix (Model #10431, Leica Inc. Buffalo, N.Y.). Total titratable acidity (TTA) content was determined on a sample extract comprising of 25g of pulp macerated in 100ml of de-ionized water for one minute in a Waring Commercial laboratory blender (Model 34 BL97, Waring Products Corp, Hartford, CT). The extract was then centrifuged using a Chermle centrifuge (Model Z 360 K, National Labnet Co. Woodbridge, N.J.) and the acidity measured by titration with phenolphthalein as an indicator, using standard 0.1M NaOH. Ascorbic acid or vitamin C contents were also determined on a sample extract comprising of 25g of pulp macerated in 100 ml of 0.4 % oxalic acid for one minute in a Waring Commercial laboratory blender (Model 34 BL97, Waring Products Corp, Hartford, CT). The extract was then centrifuged using a Chermle centrifuge (Model Z 360 K, National Labnet Co. Woodbridge, N.J.) and the ascorbic acid content measured by titration against 0.01N potassium iodate (Kefford, 1957).

The experiment consisted of a completely randomized design with a factorial arrangement of variables. Each treatment was replicated ten (10) times with each replicate consisting of five fruits. Data were subjected to Analysis of Variance, using Minitab statistical software (Minitab Release 13.1) and the levels of significance determined by the F-test. Comparison of the means using the least significant difference (LSD) method was done at the 5% level, where applicable.

Experiment 2

Physical quality attributes of Spanish tamarind as listed in Table 2 were evaluated over a three-year period using seventy-five mature fruits randomly selected in each year. Simultaneously, physio-chemical measurements listed in Tables 2 and 3 were taken in each year on 126 fruits. A completely randomized design was used made up of 3 replicates with each replicate consisting of 21 fruits and then subjected to ripening in separate storage rooms for 3 days at 20˚C and 30˚C where the relative humidity was 75-85%. Data were subjected to Analysis of Variance, using Minitab statistical software (Minitab Release 13.1) and the levels of significance determined by the F-test. Comparison of the means using the least significant difference (LSD) method was done at the 5% level, where applicable. The methodology used for the all measurements were done according to previous studies described by Mohammed (1990) and Mohammed and Brecht (2002).

Experiment 3

West Indian limes (*Citrus aurantifolia*) were harvested at the mature-green stage (M1) and at the uniform ripe-yellow stage (M2) from an orchard in Central Trinidad and transported to the Food Biology laboratory, in the Department of Food Production, The University of the West Indies, within two hours of harvest. Fruits were processed in a room where the limes were sanitized with a wet loose-woven gauze-like cotton cloth before cutting into similar portions with a sharp stainless steel knife into quarter wedges. All cut wedges were washed with chlorinated water (100µLL^{-1} NaClO) at 18-20°C for 3-4 minutes and rinsed for one (1) minute in tap water. The excess surface water remaining on the fresh-cut sections was absorbed with paper towels.

Fruit wedges (quarters) at both stages of maturity (M1 and M2) were seal-packaged up to eight (8) quarters per bag in low density polyethylene bags (LDPE) and stored at 4-5°C, 7-8°C and 28-30°C and evaluated for marketable quality, chilling injury, cut-edge browning, fermentative aroma, pH, total soluble solids (TSS), total titratable acidity (TTA), TSS:TTA, and vitamin C content. Data were taken daily up to seven (7) days on all of the above parameters except for fermentative aroma which was taken on days 0, 4 and 7 respectively. The methods used to measure the chemical quality parameters were similar to that described in experiments 1 and 2.

The methodology for the other parameters is hereby described. Firmness was determined with a Kochler digital penetrometer (Model # K 19550, Koehler Instrument Company, Bohemia, N.Y.) using a K20500 brass probe with a hardened stainless steel tip which was used to measure penetration depth. Chilling injury (CI) based on external damage was scored on each fruit using a subjective scale: 1 = no damage, 2 = slight damage, 3 = medium damage, 4 = severe damage, 5 = very severe damage. The CI index was calculated according to the formula (1) used by Pesis et al. (1994).

$$CI = \sum_{0}^{5} \frac{IL * FL}{T} \qquad (1)$$

CI stands for the CI Index, *IL* stands for the injury level, *FL* is the number of fruits at this level, and *T* is the total number of fruits.

Marketable quality was rated on each fruit using the following subjective scale 1= very poor quality, 2= poor quality, 3= moderate quality, 4= good quality and 5= excellent. The number of fruit with a rating of 3 and above was used to calculate percentage marketable fruit. Fermentative aroma and cut-edge browning were each evaluated on a hedonic scale from 1-4, with 1=none, 2= slight, 3=moderate and 4=severe (Cantwell & Suslow, 2002; Singla et al., 2020).

The experiment consisted of a completely randomized design with a factorial arrangement of variables. Each treatment consisted of three replicates with each replicate consisting of eight (8) fruit quarters or wedges. Data were subjected to Analysis of Variance, using Minitab statistical software (Minitab Release 3.1) and levels of significance determined by the F-test. Mean values were subjected to the least significant difference test (LSD) at p≤0.05 according to Montgomery (2004).

RESULTS AND DISCUSSION

Experiment 1

Ripe balata fruits (Plate 1) stored in LDPE packages at 6-7°C were firmer, had less fresh weight losses with an overall superior quality and shelf life after 7 days compared to fruits stored in paper bags (PB) (Table 1). However, fruit stored in similar packages at 28-30°C had an abbreviated shelf life after 2 days, with fruits in LDPE succumbing to a distinctive off-taste versus fruits kept in PB, probably related to a greater dissipation of accumulated volatiles in the latter than the former packages (Rux et al., 2017).

Evidence from the pre-storage data signified the edible percentage of balata fruit to be 43.0% (Fig. 1). Thus the inedible skin and seed accounted for more than half (57%) of the overall fruit weight. The inedible percentage of balata fruits is more than tamarind, passion fruit, quince and watermelons by 17%, 14%, 18% and 9% respectively and 3% less than rambutan (Ruiz-Torralba et al., 2018). The ratio of edible to inedible fruit percentages are important factors in consumerism of fresh fruits and their potential applications in fresh-cut and processing industries (Sheu et al., 2020). Investigations on the nutraceutical and bioactive compounds of the inedible components of fruits and their potential development into value-added food and non-food products are critical and urgently required. This is in accordance with the current global campaign to reduce food waste as one of the strategies which the Food and Agricultural Organization (FAO) has implemented to achieve its specific target in the Sustainable Development Goals (SDGs), designed to guarantee food security for the rapidly growing global population (Sheu et al., 2020; FAO, 2015).

Despite having a thin, glossy, firm yet flexible skin texture, percentage fresh weight losses of fruits in PB after 7 days at 6-7°C was 6.2 %. Even so, visible evidence of shriveling was only slight. The modified atmosphere within the sealed LDPE bags created a saturated micro environment accounting for only 0.13% fresh weight losses compared to control fruit which was 6.2%. These findings supported previous studies of other commodities reported by Ben-Yehoshua et al., (1983), Mohammed and Wickham (1993), Tinebra et al. (2021) and Roopnarine and Mohammed (2021).

The bright yellow-orange color on the fruit skin recorded at harvest was transformed to a faded orange-brown color after 7 days in both package treatments at 6-7°C. However, the intensity of the color change that was more obvious for fruits in PB than LDPE bags was confirmed by the readings obtained for "L" values (Table 1). The "b" skin color averaged 21.1 for LDPE sealed fruits compared to 18.9 averaged for fruit in PB bags. This provided further evidence to support the differences in the intensity of skin color associated with fruits in both package treatments with seal-packaged LDPE fruits maintaining better retention of a fresh-like skin color appearance.

Pre-storage fruit flesh color was at a lighter brown color with "L" readings averaging 53.2 as opposed to fruits stored one week later which recorded 46.5 under refrigerated conditions. MAP did not influence appreciable changes in flesh fruit color after 7 days at 6-7°C in view of the "a" and "b" readings. A similar trend for "L" values taken at day 0 and day 7 respectively was also noted (Table 1).

Mature-ripe balata fruits had a unique sweet, juicy taste accompanied with high TSS ranging from 23.2-24.8 and low TTA of 0.04. Similar scales for TSS and TTA were reported for custard apple (*Annona squamosa* L.) and mammy apple (*Pouteria sapota*) (Nascimento et al., 2008). Paull and Duarte (2011), reported TSS as critical in the determination of fruit quality and consumer acceptability. Sugars and acids are closely related to taste and indicative of the degree of fruit maturity (Cavalante et al., 2012). Packaging of balata fruits, regardless of MAP or PB did not alter TSS or TTA respectively after 7 days at 6-7°C, perhaps, due to the influence of the refrigerated temperature on the reduction of respiration. However, the data on the TSS:TTA ratio proved otherwise (Table 1). Accordingly, the pre-storage TTS:TTA value 0 at day 0 was significantly higher compared to either package after 7 days at 6-7°C with fruits in MAP being more effective in doing so than those in PB. This indicated that the modified atmospheres slowed down the senescence process and the subsequent loss of fruit quality more effectively than control fruits in PB consistent with previous investigations reported by Cavalante et al., (2012). Nonetheless, the high levels of TSS, vitamin C and pH combined with low TTA (Table 1) confirmed that balata fruits are enriched with natural distinctive flavor, taste and nutritious quality attributes.

Table 1. Physico-chemical quality attributes of balata fruits stored in low density polyethylene bags (LDPE) and paper bags (PB) at 6-7°C over 7 days

	Storage temperature @ 6-7°C		Storage temperature @ 6-7°C	
Parameters	Paper bags (control)		LDPE bags (MAP)	
	Day 0	Day 7	Day 0	Day 7
Skin color				
L	^{y} 51.7c	32.6a	51.7c	36.1b
a	9.9a	21.1b	9.9a	23.3b
b	36.3c	18.9a	36.3c	21.6b
Flesh Color				
L	53.2b	47.5a	53.2b	45.5b
a	2.3 b	1.7 a	2.3b	1.7a
b	27.1b	15.4a	27.1b	13.4a
% Fr. Wt. Losses_	0.00a	6.20b	0.00a	0.13a
pH	5.20a	6.15b	5.20a	6.22b
TSS	24.8a	23.2a	24.8a	24.0a
TTA g/100 flesh	0.04a	0.04a	0.04a	0.04a
TSS:TTA	620c	580a	620c	600b
Vit. C mg/100 flesh	35.81a	34.75a	35.81a	35.10a

^{y}Mean separation in each column for each treatment by LSD$_{(0.05)}$; means not suffixed by the same letter are statistically different at the 5% level.

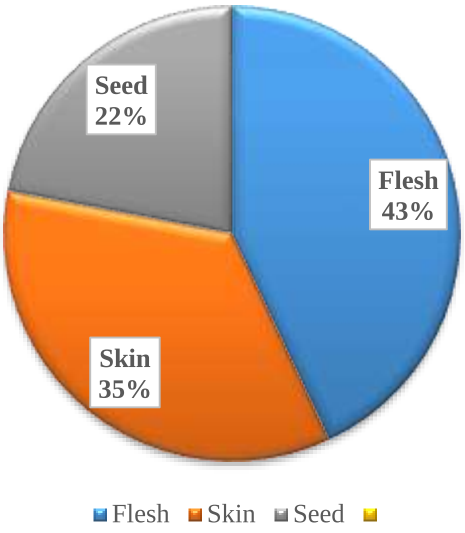

Fig. 1. Fresh weight percentages of flesh, skin and seed of tree-ripe balata fruits.

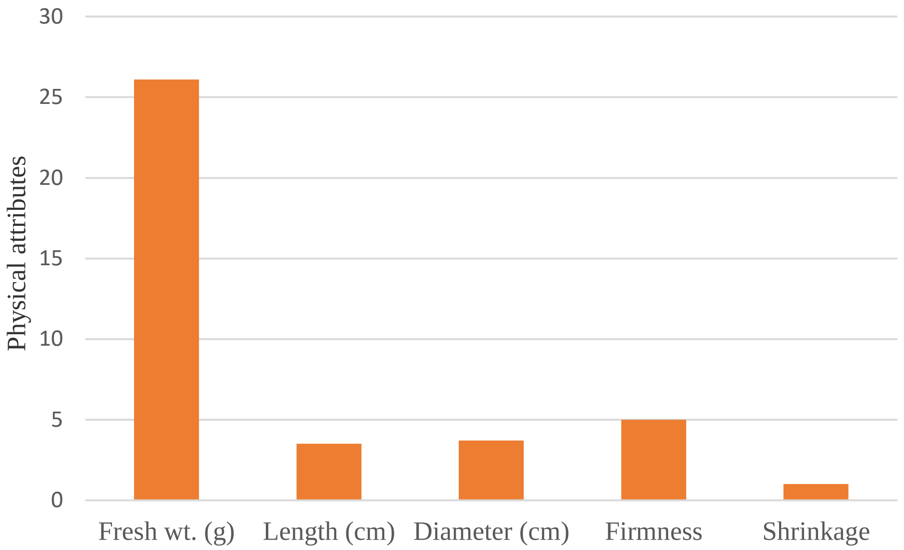

Fig. 2. Physical attributes of mature-green Spanish tamarind fruits. ˣFirmness rating 1-5: 1 = very soft; 2 = slightly soft; 3 = slightly firm; 4 = firm; 5 = very firm. ʸShrinkage rating 1-5: 1 = no shrinkage; 2 = slight shrinkage; 3 = moderate shrinkage; 4 = severe; 5 = extreme.

Table 2. Color of mature-green Spanish tamarind fruit

Parameter	L	a	b
Skin color	ʸ58.54a	-15.52a	36.28a
Flesh color	72.50b	-2.65b	25.60b
LSD$_{(0.05)}$	8.4	3.0	8.8

ʸMean separation in each column for each treatment by LSD $_{(0.05)}$; means not suffixed by the same letter are statistically different at the 5% level.

Experiment 2

Quality characteristics of Spanish tamarind fruits harvested at the physiologically mature stage had an average fresh weight of 26.1g, with fruit dimensions being 3.5cm x 3.7cm, similar to that reported by Gmelin (2002) (Fig. 2). Fruits were dense and firm with no visible evidence of shriveling (Fig. 2). The bright glossy green skin color had ‘L, a, b’ values of 58.54, -15.52 and 36.28, while the flesh color had a lighter green color with ‘L’ being 72.50 and ‘a’ and ‘b’ values being -2.65 and 25.60 respectively (Table 2).

Fresh weight losses of fruits at 20ºC were 39.9% compared to ripened fruits at 30˚C which amounted to 42.8% (Table 3). Such high levels of moisture loss for fruits stored at either temperature resulted in extensive shrinkage. Fruit skin and pulp had a spongy texture notwithstanding, the tough-like nature of the skin. Accompanying this was a loss in fruit appearance and a significant reduction in fruit firmness (Plate 2).

Fruit edibility was dependent on whether the pulp was eaten together with the skin. Both skin and pulp amounted to 9.8g for fruits ripened at 20˚C and 9.0g for fruits ripened at 30˚C, due to more transpiration at the higher compared to the lower temperature (Table 3). Nevertheless, percentage edibility for fruits ripened at 20˚C was almost similar to those ripened at 30˚C, that is, 70.5% for the former and 68.8% for the latter. However, if only the pulp was eaten then the percentage edibility declined further by 16.27% and 16.31% for fruits ripened at 20˚C and 30˚C respectively.

The inedible hard ligneous seeds, averaging 4-5 per fruit represented almost 29.6% of the entire fruit weight. Ripe fruits had a brown color that was almost the same for the skin and the pulp with only minor differences of the effects of temperature used for ripening (Table 3).

Visible evidence of fruit senescence was associated with sporadic white inclusions of fungal growth which seldom penetrated the skin to affect the edible pulp.

The universally acquired taste and flavor of the Spanish tamarind fruit pulp, reminiscent to that of the arboreal fruit of *Tamarindus indica* L. which belongs to family Leguminosae, are well known throughout the Caribbean and among the ethnic population in Metropolitan countries. The chemical composition of both fruits is similar with respect to pH, TSS, TTA, TSS:TTA and vitamin C (Table 3). The major difference in popularity is related to advances made with *Tamarindus indica* in the development of value-added products. Due to its pleasant acidic taste and rich aroma, the pulp is widely used for domestic and industrial purposes. The pulp is used for seasoning, to flavor confections, curries and sauces as well as a substitute for chemical acidulates in the preparation of certain beverages (Muzaffar & Kumar, 2017; Mahajani, 2020). *Tamarindus indica* pulp is also processed into number of products including tamarind juice, concentrates, powder, pickles and paste as well as for some medical uses and is regarded as a digestive, carminative, laxative, expectorant and blood tonic (Haynes et al., 2006; Devi & Boruah, 2020; Chimsah et al., 2020). The need for similar investigations on the Spanish tamarind is therefore warranted and this is currently being undertaken by the authors. Vitamin C content was remarkably low, averaging 1.84 mg/100g (Table 3) but nevertheless similar to some fruits such as loquat, bilberry and fig. However, there are still some research gaps regarding correlating the nutritional and phytochemical properties with its food value and medicinal applications (Mayori, 2018).

Table 3. Physical and chemical quality characteristics of Spanish tamarind fruits ripened at 20°C and 30°C

Quality attributes	Spanish tamarind fruits ripened at		
	20°C	30°C	$LSD_{(0.05)}$
Whole fruit weight (g)	[y]13.9a	12.9a	1.5
Skin weight (g)	2.4a	2.1b	0.4
Pulp weight (g)	7.4a	6.9b	0.4
Seed weight (g)	4.1a	3.9a	0.6
Seed number/fruit	4-5a	4-5a	0.3
Fruit firmness[w]	5.0a	4.8b	0.1
Fruit length (cm)	3.2a	3.2a	0.3
Fruit diameter (cm)	3.1a	3.2a	0.2
Shrinkage[x]	4.6b	5.0a	0.3
Fresh weight loss (%)	39.9b	42.8a	1.3
Total Soluble Solids (TSS)	3.0a	3.1a	0.3
Total Titratable Acidity (TTA) g/100g	2.24a	2.40a	0.4
TSS:TTA	1:1.3a	1:1.3a	0.5
pH	3.4a	3.4a	0.2
Vitamin C mg/100g	1.84a	1.53a	0.5

[w] Firmness rating 1-5: 1 = very soft; 2 = slightly soft; 3 = slightly firm; 4 = firm; 5 = very firm.

[x] Shrinkage rating 1-5: 1 = no shrinkage; 2 = slight shrinkage; 3 = moderate shrinkage; 4 = severe; 5 = extreme

[y] Mean separation in each column for each treatment by $LSD_{(0.05)}$; means not suffixed by the same letter are statistically different at the 5% level.

Experiment 3

Marketable quality and shelf-life of fresh-cut quarter-sliced limes were influenced by storage temperature, storage duration and fruit maturity (Plate 3). Accordingly, quarter sections of ripe-yellow (M2) limes stored at 7-8°C secured the highest marketable quality rating (Fig. 3), had no evidence of cut-edge browning (Fig. 4), chilling injury (Fig. 5) or fermentative aroma (Fig. 6) after seven (7) days. However, mature-green (M1) slices held at the same temperature attained the salable limit three (3) days earlier than M2 slices (Fig. 3). Despite the absence of a fermentative aroma, initial evidence of cut-edge browning of M1 slices at 7-8°C occurred much earlier (day 2) than the occurrence of visible symptoms of chilling injury (day 5) (Figs. 4, 5, 6). Mature-green (M1) quarter slices were therefore more sensitive to chilling injury damage than ripe-yellow (M2) quarter slices. Thus chilling injury symptoms, characterized with randomly scattered pits eventually coalesced to form leathery, brown, sunken areas on the rind became obvious at day 1 for M1 quarter slices stored at 4-5°C. Similar CI symptoms were delayed on M2 slices for additional 6 days (Fig. 5). Evidence of cut-edge browning and chilling injury symptoms (Figs. 4, 5) progressed slower for M2 quarter wedges compared to their M1 counterparts during storage at 4-5°C, whilst the opposite occurred for the detection of fermentative aroma ratings (Fig. 6). The inverse relationship between high marketable quality, reduced cut-edge browning and minimal chilling injury for M2 versus M1 quarter lime slices was not obtained for fermentative aroma.

Occurrences of cut-edge browning seemed to be related to differences in sensitivity to chilling injury exasperated by greater cell membrane impairment of M1 slices compared to M2 slices. Perhaps, advancement of earlier initiation of disrupted cell membrane integrity of M1 versus M2 slices probably resulted in more lipid peroxidation of the former than the latter. It may well be that the decrease in phenolic compounds which usually accompanies maturation and ripening accounted for less release of these compounds during the process of slicing of the M2 over the M1 lime fruits, thereby limiting the action of polyphenol oxidase (PPO) (Saltveit and Choi, 2007). However, to date, no quantitative method is available to accurately measure the occurrence of cut-edge browning of fresh-cut limes during exposure to low temperature storage. To the best of our knowledge, this study is the first to identify quantitative parameters of measuring CI-related browning of fresh-cut West Indian limes. However, recent investigations suggested that lysophospholipids as the most probable primary wound signal involved in the formation of browning substances (García et al., 2017; Saltveit, 2018). Earlier reports by Kulkarnia and Aradhya (2005) and Artés-Hernández et al., (2007) supported claims of decreased phenolic compounds with maturation and ripening of other fruits including banana, guava and pomegranate.

There were minor changes in total soluble solids over time and temperature. Minor increases in pH and slight decreases in total titratable acidity were observed up to day 2 for M2 quarter slices stored at 4-5°C and for M1 slices stored at 7-8°C (Table 5). Overall, changes in TSS, TTA, pH and TSS:TTA were not appreciable over time and changes at these low temperatures did not follow any particular pattern. Variable changes in chemical parameters were also observed by Artés-Hernández et al. (2007) which they attributed to loss of electrolytes based on smaller size fruit cuts having larger cut surface areas.

As expected, the riper (M2) fruit quarter slices accounted for more vitamin C content compared to the mature-green M1 quarters (Table 5), but the losses in vitamin C content as a result of cutting were greater in M2 compared to M1 fruit samples (Table 4). At 4-5°C there was a 24.4% cent loss in vitamin C after the initial two days of storage (Gil et al., 2006; Ajibola, 2009). For M2 fruit quarters the percentage loss in vitamin C amounted to 33.6% while sections stored at 7-8°C where chilling injury symptoms were absent during the first two days of storage (Fig. 5), as opposed to cut-edge browning (Fig. 4), the percentage decrease in vitamin C content from day 0 to day 1 and 2 was almost three-folds higher for M2 over M1 quarter wedges (Table 5). Further studies are presently being conducted on these chemical parameters.

Table 4. Skin and pulp color of Spanish tamarind ripened at 20°C and 30°C

Temperature °C	Skin color			Flesh color		
	L	a	b	L	a	b
20	^{y}49.1b	8.58a	32.35a	49.9b	8.50a	32.10a
30	50.1a	8.55a	32.30a	51.1a	8.51a	32.35a
LSD$_{(0.05)}$	0.5	0.4	0.7	0.5	0.4	0.7

^{y}Mean separation in each column for each treatment by LSD$_{(0.05)}$; means not suffixed by the same letter are statistically different at the 5% level.

Table 5. Effect of fruit maturity and modified atmosphere packaging upon pH, TSS, TTA, TSS:TTA, and vitamin C content of fresh-cut lime

Chemical quality	Temp. °C	Maturity stage	Storage period (days)								Statistics
			0 day	1 day	2 days	3 days	4 days	5 days	6 days	7 days	Sig. P≤0.05
pH	4-5	M$_1$	2.58	2.51	2.78	2.79	2.84	2.80	2.80	2.80	LSD$_{0.05}$ = 0.03
		M$_2$	2.36	2.44	2.82	2.84	2.84	2.85	2.93	2.64	
	7-8	M$_1$	2.58	2.35	2.74	2.74	2.68	2.70	2.71	2.69	
		M$_2$	2.36	2.37	2.71	2.71	2.78	2.68	2.79	2.85	
TSS(%)	4-5	M$_1$	7.50	9.00	8.33	8.17	8.50	8.83	8.50	8.33	LSD$_{0.05}$ = 0.71
		M$_2$	7.80	9.00	8.67	8.17	8.50	8.33	8.33	7.67	
	7-8	M$_1$	7.50	7.00	7.50	7.33	7.17	7.83	7.17	7.83	
		M$_2$	7.80	8.00	7.50	7.17	7.67	7.67	7.00	8.33	
TTA	4-5	M$_1$	3.64	3.12	3.67	3.28	2.94	3.38	2.89	3.38	LSD$_{0.05}$ = 0.08
		M$_2$	4.03	3.59	2.63	3.25	2.81	3.12	2.55	3.17	
	7-8	M$_1$	3.64	4.29	3.61	3.33	2.86	3.20	3.43	2.63	
		M$_2$	4.03	3.25	3.70	3.04	2.86	3.85	2.68	2.47	
TSS:TTA	4-5	M$_1$	2.06	2.89	2.27	2.49	2.89	2.61	2.94	2.46	LSD$_{0.05}$ = 0.22
		M$_2$	6.93	2.51	3.29	2.51	3.03	2.67	3.27	2.42	
	7-8	M$_1$	2.06	1.63	2.08	2.20	2.51	2.45	2.09	2.97	
		M$_2$	1.93	2.47	2.03	2.36	2.68	1.99	2.61	3.57	
Vitamin C	4-5	M$_1$	18.90	14.28	14.28	15.85	15.52	15.67	16.00	14.27	LSD$_{0.05}$ = 2.59
		M$_2$	25.30	16.80	15.95	16.22	16.21	16.40	17.00	13.41	
	7-8	M$_1$	18.90	17.64	18.75	17.56	17.55	18.00	17.10	16.61	
		M$_2$	25.30	16.80	19.32	19.33	18.23	18.40	18.44	18.30	

^{y}Mean separation in each column for each treatment by LSD $_{(0.05)}$; means not suffixed by the same letter are statistically different at the 5% level.

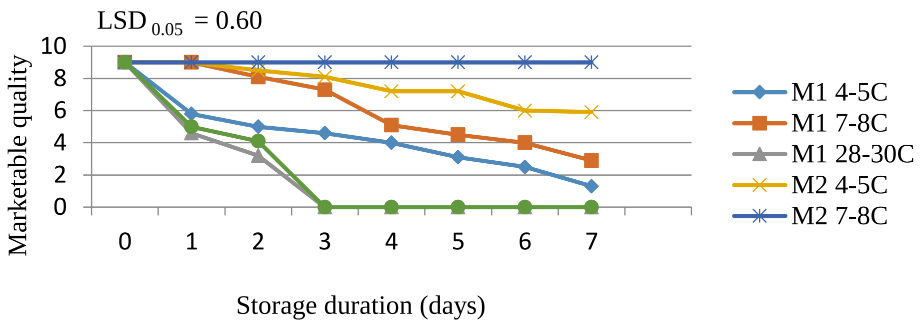

Fig. 3 Effect of fruit maturity and modified atmosphere packaging upon marketable quality of fresh-cut limes.

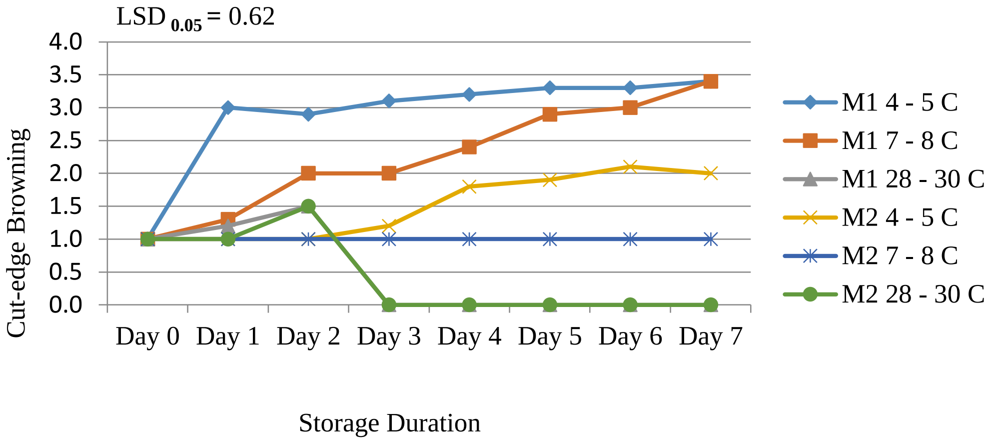

Fig. 4. Effect of fruit maturity and modified atmosphere packaging upon cut-edge browning of fresh-cut limes.

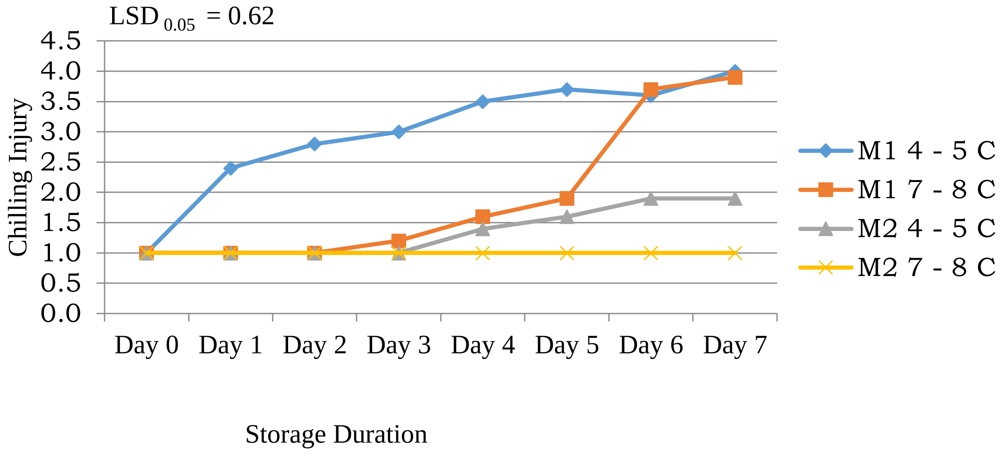

Fig. 5. Effect of fruit maturity and modified atmosphere packaging upon chilling injury of fresh-cut limes.

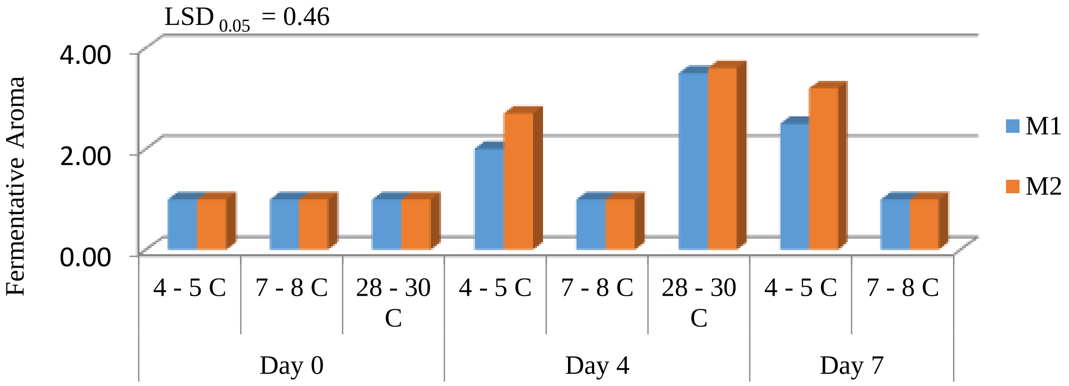

Fig. 6. Effect of fruit maturation and modified atmosphere packaging upon development of fermentative aroma of fresh-cut limes.

Plate 1. Balata fruit with and without seed.

Plate 2. Internal and external quality of Spanish tamarind.

Plate 3. Fresh-cut lime wedges after 7 days at 7-8ºC.

CONCLUSION

The three exotic fruits investigated exhibited unique quality profiles as influenced by storage temperature, storage duration, packaging and stage of maturation upon harvesting. Balata fruits stored in sealed in LDPE bags at 6-7°C accounted for a shelf life of 7 days versus 2 days when stored at 28-30°C. Physiologically matured Spanish tamarind fruits displayed similar quality attributes on the same day of harvest. Storage of fruits after 3 days at 30°C hastened the ripening process earlier than their counterparts held at 20°C but physio-chemical differences were minimal. Ripe–yellow West Indian limes (M2) quarter-slices seal-packaged in LDPE bags and stored at 7-8°C secured superior quality ratings due to the absence of chilling injury symptoms, cut-edge browning and a fermentative aroma which was observed for similar slice treatments even after 4 days at 4-5°C. M1 and M2 slices were unmarketable in less than two days at 28-30°C. Further research is warranted on the mode of action of other postharvest treatments to enhance the shelf life of these exotic fruits in order to establish international niche markets.

Conflict of interest

The authors have no conflict of interest to report.

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