Responses of fresh-cut products of four mango cultivars under two different storage conditions

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Revised: 10 March 2017 / Accepted: 21 March 2017 / Published online: 6 April 2017
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Abstract Due to availability of minimally processed products, the consumption of fresh produce has increased over recent years. The present study has been undertaken with the objective of screening of four mango cultivars ('Kesar', 'Rajapuri', 'Totapuri' and 'Ladvo') for evaluating the consequences of minimal processing on their quality attributes under storage at two different temperatures (5 ± 1 °C, 95% RH and 10 ± 1 °C, 87% RH) up to 12 days. The result of the study revealed significant impacts of low temperature storage on the quality parameters of fresh-cut mango cultivars. The evaluated bioactive compounds such as total phenolics, vitamin C and carotenoids were better retained in the samples stored at 5 °C as compared with that of 10 °C. Moreover, the storage of fresh-cut mango cultivars at 5 °C showed lower water loss and microbial contamination. Sensory analyses revealed that the storage of fresh-cut mango cultivars at 10 °C influenced overall acceptability due to changes in their visual perception, though taste, odor and firmness were less affected. This study revealed a significant variation in the storability of fresh-cut mango cultivars with respect to the storage temperature. Among currently studied four cultivars of mango, slices of 'Totapuri' showed comparatively the least change in color, firmness and sensory

properties during storage at 5 and 10 °C and it can be a potential cultivar for fresh-cut processing.

Keywords Bioactive · Fresh-cut · Storage · Mango · Shelf-life · Temperature

Introduction

Mango (*Mangifera indica* L.) is one of the most important fruits in terms of production, marketing and consumption throughout tropical and subtropical countries. The fruit is large, fleshy drupe with edible mesocarp and the size and shape vary considerably depending upon the cultivar. In the international market, its popularity is due to excellent flavor, color, taste and high in several bioactive compounds such as total phenolics, carotenoids, ascorbic acid and dietary fibres (Arauz 2000). Mango fruit possess potentiality for its introduction as new fresh-cut product. The fresh-cut fruits and vegetables have been demanded by the modern consumers mainly due to their attractive, convenient and rich in functional contents with health improving attributes. On the contrary, their faster deteriorative nature compare to the intact commodity, ultimately reduce the self-stability of final product. The purposes of fresh-cut fruits and vegetables production are to provide low priced, safe, nutritious and convenient fresh processed items to consumers. However, fresh-cut processors and industrialist are facing problem with the selection of mango cultivars, quality at harvest, incorrect ripening stages, shape and size, treatments, packaging and marketing. Therefore, the handling, storage and distribution of fresh-cut produce are not an easy task and simultaneously it requires a thorough understanding of fresh cut produce physiology under different storage regime.

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Cultivar selection is the most important consideration in fresh-cut processing because cultivars can vary significantly in characteristics such as flesh texture, skin color, and browning potential (Amiot et al. 1995). A perusal of survey of literature reveals that quality attributes such as flavor, functional compounds and storage behavior differ among different mango cultivars (Sellamuthu et al. 2013; Kim et al. 2007). Generally, cultivars with reduced key enzymes activity e.g., browning, softening, volatile generation, are desired for minimal processing (Romig 1995), because enzymatic activities varies with the genotypes. On the other hand, temperature management during storage and shipping is a critical factor that affects fruit quality at destinations, and generally 8–13 °C (depending on cultivar and duration) and 85–90% RH are recommended storage conditions for mangoes during distribution (Ahmad et al. 2007). However, when the mango fruit is exposed to temperatures lower than 10 °C, the chilling injury (CI) takes place as a result of malfunction or disruption of cellular wall and membrane functions that affects the transfer or flow of cellular fluids in and out of the cell, resulting in irregular metabolites (amino acids, sugars and mineral salts) (Wills et al. 1981). Considerable amount of evidences regarding the degree of chilling sensitivity of mango varieties under low temperature storage have been established (Hardenburg et al. 1986). Nevertheless, the responses of slices prepared from various mango cultivars mainly in terms of changes in nutritional quality as well as sensory properties during their storage under refrigeration are needed to be elucidated. The low temperature storage is highly recommended for the storage of fresh-cut produce as it can slows down ethylene sensitivity, the metabolic activities, reduces microbial growth and enhances the shelf-life. However, the shelf-life of fresh-cut mangoes varies with the storage temperature and cultivars. For instance, Poubol and Izumi (2005) reported that the shelf-life of fresh-cut ‘Carabao’ mango was 4–6 days at 5 °C and 3–4 days at 13 °C, whereas fresh-cut ‘Nam Dokmai’ mango had storage life of 2 days and less than 1 day at 5 and 13 °C, respectively. Similarly, the shelf-life of fresh-cut ‘Kent’ mango was extended up to 5–6 days at 5 °C and 3–4 days at 12 °C, but firmness loss and decline in ascorbic acid in slices stored at 5 °C might be a sign of chilling injury (Dea et al. 2010). Therefore, an intense care is needed to be taken while selecting storage temperature for fresh-cut produce.

Thus, it has become the fundamental necessity to understand the impact of storage temperatures on the kinetics of quality attributes for the selected cultivars of mango or any other fruit destined for minimal processing in order to modulate appropriate storage condition so as to extend the shelf-life with maintain quality.

Materials and methods

Fruit material

The fruits of mango cultivars viz., ‘Kesar’, ‘Ladvo’, ‘Rajapuri’ and ‘Totapuri’ were freshly harvested in the month of May 2013 at their commercial maturity stage from an orchard located in the vicinity of Karamsad village of Anand, Gujarat. After harvest, the fruits were transported to laboratory within 2 h and sorted based on the uniformity of shape, size, color, and free from any injuries.

Minimal processing

The initial washing of fruits with tap water was followed by surface disinfection with 200 ppm sodium hypochlorite solution (pH 6.5 adjusted with 2.0 M citric acid) for 5 min, rinsed with distilled water and air-dried at room temperature for 15–20 min. The fruits were peeled manually with the sharp stainless steel peeler and cut from the sides of the seed and then each half cut was further sliced longitudinally into 4–6 fingerlets with approx. 1–1.5 cm thickness. The slices obtained from mango cultivars were kept horizontally in food grade sterilized clamshell with 250 g fingerlets in each container and the quality analyses was carried out at the beginning and after 4, 8, and 12 days of storage period at 5 ± 1 °C, 95% RH and 10 ± 1 °C, 87% RH.

Evaluation of quality

Color

During storage, mango slices were evaluated for their color change, following the method of Papadakis et al. (2000) using digital camera (FinePix S2950, FUJIFILM, Japan) and Adobe Photoshop CS 8.0 software (Adobe System, Inc. San Jose, CA, USA). The measurement of lightness (L^*), green to red (a^*) and blue to yellow (b^*) values were taken by pointing the cursor at different areas on digital image of each mango cultivar. The a^* and b^* components were converted into hue angle (h°) and chroma (C) according to the formula (1) and (2), respectively.

$$\text{Hue angle } (h^\circ) = \tan^{-1} b^*/a^* \quad (1)$$

$$\text{Chroma} = \sqrt{a^{*2} + b^{*2}} \quad (2)$$

Browning index

Browning index was measured as per the method described by Saxena et al. (2012) according to which 0.5 g sample

was extracted in 5 mL of ethanol (67%) for 1 h. The extract was filtered through Whatmann No. 1 filter paper and the browning index in terms of optical density of the filtrate was recorded at 420 nm (A_{420}) with 67% ethanol as blank.

Firmness

The firmness of fruit samples was measured with fruit pressure tester (FT-327, FACCHINI srl, Alfonsine, Italy) by placing the fruit sample on a flat surface and by applying force with an 11 mm flat-bottomed probe and allowed to penetrate up to 5 mm into the flesh and the force required to penetrate the probe into fruit tissue is expressed in terms of Newton (N).

Weight loss percentage (WLP)

Mango slices (50 g) from each replicate was placed into previously tarred petri dish and dried at 70 °C for 48 h. After drying, the petri dish was put in a desiccator to cool to room temperature. The weight was recorded before and after drying by using an analytical balance (Shimadzu BW 380 H, Tokyo, Japan). Weight loss was calculated according to the formula 3:

$$\text{Weight loss (\%)} = 100 - [100 \times \text{DM (\%)}_{\text{Day 0}} \div \text{DM (\%)}_{\text{Day N}}] \quad (3)$$

DM (%) Day 0 and DM (%) Day N stand for dry matter on day 0 and dry matter on day N, respectively.

Total soluble sugars

The estimation of total soluble sugars was performed according to the method cited by Bico et al. (2009). One gram mango tissue was homogenized in mortar and pestle with 10 mL 80% (v/v) ethanol and kept in a water bath (80–85 °C) for 30 min. After cooling, the homogenate was filtered twice through two layers of muslin cloth. The extract evaporated to dryness over water bath and resulting residue was dissolved in 40 mL of distilled water. A 0.2 mL aliquot of the resulting solution was reacted with 0.5 mL phenol solution (5%, w/v) and 2.5 mL concentrated sulphuric acid (H_2SO_4). The absorbance was measured at 490 nm after 20 min by spectrophotometry (Mini Spec SL 207, Elico) against a reagent blank. The concentration of total soluble sugars was expressed in gram glucose per kilogram fresh weight.

Vitamin C

Estimation of ascorbic acid was performed as per the method of Roe and Oesterling (1944). Briefly, 2 g of mango tissue was homogenized in 20 mL of 5% metaphosphoric acid and glacial acetic acid mixture and centrifuged for 10 min at 5000 rpm. A known volume of aliquot was incubated in the mixture of 2% 2, 4 dinitro-phenyl hydrazine (DNPH) and 10 μL of 10% thiourea for 3 h at 37 °C. After the period of incubation, 5 mL of 85% H_2SO_4 was added to dissolve orange-red osazone crystals and optical density was measured against blank at 540 nm. The concentration of ascorbic acid was calculated as per the standard curve prepared using L-ascorbic acid and expressed in gram ascorbic acid per kilogram fresh weight.

Total carotenoids

Total carotenoids content was measured using the method described by Tomes (1963). Five gram fruit tissue was homogenized in pre-cooled mortar with 50 mL hexane and acetone (60:40) mixture. The upper organic layer was transfer into a capped tube on ice. Re-extracted the remaining aqueous layer with 10 mL of the same solvent repeatedly and transferred the organic layer to the same tube until the aqueous layer became colorless. The quantification was carried out by spectrophotometry at 450 nm. Total carotenoids concentration was calculated according to the formula 4 and expressed as milligrams per kilogram fresh weight.

$$\text{Carotenoid} = 4 \times \text{Absorbance at } 450\text{nm} \quad (4)$$

Total phenolic content (TPC)

Total phenolic content was determined by following Folin–Ciocalteu's method described by Lim et al. (2006). One gram fruit tissue was extracted with 10 mL of methanol and the resultant homogenate was centrifuged at 10,000 rpm for 15 min at 4 °C. A volume of 0.3 mL of extract of each sample was mixed with 1.5 mL of FCR (which was diluted 10X with distilled water) and 1.2 mL of sodium carbonate (7.5%, w/v) in a test tube. The tube was then vortexed and incubated in dark for 30 min at room temperature. The optical density (OD) was read at 765 nm and the amount of TPC was expressed as grams gallic acid equivalents (GAE) per kilogram fresh weight.

Browning-related enzymes

Extraction and assay of polyphenol oxidase (PPO) and peroxidase (POX) activity

Mango tissue (2 g) was homogenized in 25 mL of 0.1 mol L⁻¹ sodium phosphate buffer (pH 6.5). The homogenate was centrifuged for 30 min at 15,000 rpm for PPO and 18,000 rpm for POX at 4 °C. The PPO was assayed according to the method cited by Zhu and Zhan (2010). The supernatant (0.1 mL) was incubated with 2.5 mL of catechol (0.5 mol L⁻¹ dissolved in the extraction buffer) and change in optical density at 420 nm was recorded at the interval of 30 s up to 3 min. PPO activity was expressed in Units per min per milligram protein (Unit min⁻¹ mg⁻¹ protein). One unit of PPO activity was defined as a change of 0.001 in absorbance under standard assay conditions.

The activity of POX was assayed as per the method described by Mazumdar and Majumder (2003). The substrate ortho-dianisidine and hydrogen peroxide was reacted with 0.1 mL enzyme extract at 30 °C, followed by addition of H₂SO₄ after 5 min of incubation to stop the reaction and optical density was measured at 430 nm. The specific activity of POX was expressed as Unit min⁻¹ mg⁻¹ protein considering one unit of POX as an increase in absorbance by 1.0 under standard conditions.

Extraction and assay of phenylalanine ammonia lyase (PAL) activity

The assay of PAL activity was carried out according to the method described by Malik and Singh (1980). One gram mango tissue was extracted in 0.1 mol L⁻¹ sodium borate buffer (pH 8.8) and the homogenate was centrifuged at 14,000 rpm for 20 min at 4 °C. The reaction mixture consisted 0.2 mL L-phenylalanine (0.1 mol L⁻¹), 3.2 mL of sodium borate buffer (0.1 mol L⁻¹, pH 8.8), and 0.2 mL enzyme extract were incubated at 37 °C for 2 h. PAL activity was measured by spectrophotometry at 290 nm and was expressed as Unit min⁻¹ mg⁻¹ protein where one unit is defined as micromole cinnamic acid released per hour.

Total protein content

The total protein content in the crude enzyme extract was estimated as per the method of Lowry et al. (1954) using bovine serum albumin as a standard.

Sensory evaluation

Sensory evaluation of fresh-cut mango cultivars was performed to determine the overall acceptability by assessing

color, taste, odor and texture during 12 days of storage. Samples of fresh-cut mango cultivars were randomly presented to the fourteen non-trained panelists consisting of students and researchers and they rated the quality attributes on the basis of a nine-point hedonic scale: 9 = excellent; 7 = good; 5—fair; 3—poor and 1—unusable. A score of 6 was considered the limit of market acceptability.

Microbial analysis

Serial dilutions of samples were prepared by washing vigorously 10 g tissue with 90 mL of 1 g L⁻¹ sterile buffered peptone water in sterilized round bottom tubes at room temperature and inoculated over plate count agar (PCA) at 35 °C for 48 h and potato dextrose agar (PDA) supplemented with 0.05 g L⁻¹ chloramphenicol at 21 °C for 5–7 days by the spread plate method (ICMSF 1978). After incubation, the number of colonies was counted and expressed as log colony forming units per gram fresh weight (log CFU g⁻¹ FW).

Statistical analysis

The experiment design was four (cultivars) × two (storage temperature) × four (storage time) factorial in a completely randomized design with three replications. Statistical analysis was performed using SPSS software (version 19.0, IBM Crops, White Plains, NY, USA). Data from all analyses were expressed as mean ± standard deviation. Analysis of Variance (ANOVA) was performed using General Linear Model, followed by Least Significant Difference (LSD) post hoc test to separate means of significant main effect and interaction at the $p < 0.05$.

Results and discussion

Color change

The change in color is an important factor in the consumer acceptance of the fresh-cut fruit. The change in lightness (L^*), hue angle (h°) chroma (C) values of fresh-cut mango cultivars as influenced by storage temperatures during 12 days of analysis is displayed in Fig. 1. The initial L^* and h° values measured for four mango cultivars ranged from 62 to 66 and 78 to 86, respectively (Fig. 1a, b). With the extent of storage time, the decrement in L^* and h° of fresh-cut mango cultivars was significant at $p < 0.001$ and $p < 0.01$, respectively (Table 2). This decrease in h° accompanied with the loss of lightness was probably due to enhanced enzymatic reactions leading to cut surface darkening. However, there was insignificant difference for

Fig. 1 Changes in **a** lightness (L^*), **b** Hue angle (h°), **c** chroma (C), **d** browning index (BI), **e** firmness and **f** weight loss percentage (WLP) in fresh-cut mango cultivars during their 12 days of storage period at 5 and 10 °C

L^* and h° in the selected mango cultivars due to the effect of storage temperatures (Table 2). Among the four cultivars, the slices of ‘Totapuri’ maintained higher L^* value throughout their storage at 5 °C. Previous study conducted by Plotto et al. (2004) documented a decrease in L^* and h° in fresh-cut ‘Tommy Atkins’ mango during

storage was related to the increased intensity of browning and change of flesh color from light yellow to orange/red, respectively. González-Aguilar et al. (2008) also reported a decline in L^* values in flesh of three mango cultivars (Ataulfo, Kent and Keitt) during 21 days of storage at 5 °C.

Fig. 1 continued

Regarding the changes in chroma, all samples of fresh-cut mango cultivars showed consistent declining trend throughout the storage period at both temperatures. As summarized in Table 2, F-values were significantly ($p < 0.001$) higher for chroma than L^* and h° due to the effect of cultivars, temperatures and storage time and their interactions which indicated that there was significant ($p < 0.001$) difference in chroma of fresh-cut mango cultivars during storage period of 12 days at 5 and 10 °C. As shown in Fig. 1c, slices of ‘Ladvo’ showed the highest decline in chroma approx. by two- and three-fold at the end of storage at 5 °C and 10 °C respectively, followed by ‘Kesar’ and ‘Rajapuri’. This significant reduction in h° and C of fresh-cut mango cultivars during storage suggested the reduction in color intensity which might be the consequences of the degradation due to elevated metabolic activity in wounded tissue (Salinas-Hernández et al. 2015). Among the selected mango cultivars, ‘Totapuri’ slices exhibited the least reduction in chroma at both the storage temperatures.

Browning index (BI)

In general, the consistent rise in browning index was observed in all the four fresh-cut mango cultivars during 12 days of storage period at both 5 °C and 10 °C. As shown in Table 2, there was significant ($p < 0.001$) effect of storage temperatures and time on BI of fresh-cut mango cultivars. While considering the effect of storage temperatures on changing pattern of BI throughout the storage period as presented in Fig. 1d, the slices of ‘Kesar’, ‘Ladvo’, and ‘Totapuri’ exhibited insignificant variation, but in case of fresh-cut ‘Rajapuri’, BI value was approx. by twofold greater at 10 °C than that observed at 5 °C. At the end of storage time, ‘Kesar’ slices showed the highest value of BI at 5 °C, whereas, ‘Ladvo’ presented the least BI value. At 10 °C, slices of ‘Rajapuri’ attained maximum BI value and lowest by ‘Ladvo’. These differences in BI values of mango cultivars during storage under 5 and 10 °C was most likely due to the variation in their physiological and biochemical properties at the time of harvest. The results obtained in the present study were in agreement with the findings of González-Aguilar et al. (2008), who reported that fresh-cut ‘Kent’, ‘Keitt’, and ‘Ataulfo’ exhibited significant difference in their browning potential during 12 days of storage at 5 °C. This was an advantage of the ‘Ladvo’, and ‘Totapuri’ cultivar compared with ‘Kesar’ and ‘Rajapuri’ mango used for minimal processing.

Firmness

Firmness is one of the most critical quality attributes influencing consumer appeal and marketing of fresh fruit,

which consequently decreased fruit shelf life and market value. Figure 1e shows changes in firmness of slices of mango cultivars. The average value of firmness of fresh mango cultivars was 23 N. It was documented that ‘Tommy Atkins’ and ‘Kent’ mangoes having firmness ranging from 13 to 27 N maintained better quality and extended shelf-life as a fresh-cut product (Rattanapanone et al. 2001). Storage temperatures and time had significant ($p < 0.001$) influence on the firmness of mango cultivars slices (Table 2). Due to the effect of storage temperatures, the firmness loss in fresh-cut mango cultivars was significantly ($p < 0.05$) higher at 10 °C than that observed at 5 °C during 12 days of storage (Fig. 1e). At the end of storage, the firmness value ranged from 9–19 N at 5 °C, and from 5 to 15 N at 10 °C. There was significantly ($p < 0.05$) greater firmness values maintained for slices of ‘Totapuri’ as compared to that of remaining three mango cultivars. This difference was existed probably due to the varied physiological behavior among mango cultivars (Allong et al. 2000).

Weight loss percentage (WLP)

The exposures of interior tissue after cutting enhance water evaporation rate and affect the overall quality through rapid water loss causes shriveling or withering of tissue. The storage temperatures and time had significant ($p < 0.001$) influence on weight loss of fresh-cut mango cultivars (Table 2). WLP increased significantly during storage with greater rise occurred for fresh-cut mango cultivars stored at 10 °C than those held at 5 °C (Fig. 1f). It was noted the highest ($35 \pm 0.49\%$) for cv. ‘Kesar’ and the least ($18 \pm 0.23\%$) for cv. ‘Rajapuri’ during 12 days of storage period at 10 °C. This variation of WLP among different fresh-cut mango cultivars may be dependent on their physiology, biochemistry and/or morphology (Hodges and Toivonen 2008). Moreover, in the present study, the relative humidity at 5 and 10 °C were 95 and 87% RH, respectively, which could be the possible reason for greater WLP at 10 °C as compared to that at 5 °C.

Total soluble sugars (TS)

Total soluble sugars of fresh-cut mango cultivars were significantly ($p < 0.001$) affected by the storage temperatures and time and the rate of change differed among the studied cultivars (Table 2). Initially, TS content was highest ($130.27 \pm 4.94 \text{ g kg}^{-1}$) in slices of ‘Totapuri’ and least ($98.32 \pm 9.28 \text{ g kg}^{-1}$) in ‘Ladvo’ (Table 1). On 4th day of storage, TS content enhanced approx. by 56 and 50% in slices of ‘Rajapuri’ and ‘Kesar’, while its increment occurred approx. by 40 and 21% in ‘Ladvo’ and ‘Totapuri’ at 5 °C. However, a significant reduction in TS content

Table 1 Changes in total soluble sugars (TS), vitamin C and total carotenoids in fresh-cut mango cultivars during their 12 days of storage period at 5 and 10 °C

Mango cultivars	Storage period (Days)			
	0	4	8	12
Total sugars (g kg ⁻¹)				
At 5 °C				
Kesar	114.35 ± 1.80 ^d	230.57 ± 5.41 ^a	210.15 ± 4.75 ^b	127.87 ± 8.84 ^c
Ladvo	98.32 ± 9.28 ^d	166.00 ± 3.01 ^b	184.02 ± 1.37 ^a	135.74 ± 4.97 ^a
Rajapuri	103.00 ± 2.49 ^d	232.85 ± 2.73 ^a	146.91 ± 5.05 ^a	124.68 ± 3.62 ^c
Totapuri	130.27 ± 4.94 ^c	165.82 ± 2.86 ^a	150.21 ± 6.83 ^b	112.19 ± 6.11 ^d
At 10 °C				
Kesar	114.35 ± 1.80 ^d	165.77 ± 7.18 ^a	130.75 ± 1.82 ^c	157.48 ± 4.37 ^b
Ladvo	98.32 ± 9.28 ^d	169.55 ± 7.48 ^b	101.26 ± 6.90 ^c	172.91 ± 24.56 ^a
Rajapuri	103.00 ± 2.49 ^d	194.43 ± 9.94 ^a	135.74 ± 7.28 ^c	157.72 ± 4.33 ^b
Totapuri	130.27 ± 4.94 ^b	192.43 ± 4.53 ^a	123.42 ± 6.54 ^c	118.44 ± 4.96 ^d
Vitamin C (g kg ⁻¹) × 10 ⁻²				
At 5 °C				
Kesar	48.96 ± 0.60 ^d	65.97 ± 10.05 ^b	57.18 ± 0.80 ^c	87.15 ± 5.46 ^a
Ladvo	60.53 ± 5.02 ^d	101.05 ± 1.59 ^a	91.20 ± 6.50 ^b	90.39 ± 4.24 ^c
Rajapuri	56.94 ± 2.28 ^c	106.37 ± 7.81 ^a	93.40 ± 2.71 ^b	93.87 ± 5.98 ^b
Totapuri	55.79 ± 4.02 ^d	91.20 ± 2.03 ^a	59.26 ± 3.21 ^c	67.82 ± 1.78 ^b
At 10 °C				
Kesar	48.96 ± 0.60 ^d	162.15 ± 1.25 ^a	100.81 ± 4.58 ^c	107.29 ± 22.58 ^b
Ladvo	60.53 ± 5.02 ^d	119.44 ± 1.25 ^c	151.50 ± 11.12 ^a	145.95 ± 18.59 ^b
Rajapuri	56.94 ± 2.28 ^d	106.13 ± 1.40 ^b	96.29 ± 18.45 ^c	120.37 ± 17.15 ^a
Totapuri	55.79 ± 4.024 ^d	93.98 ± 6.65 ^a	59.26 ± 0.87 ^b	83.79 ± 10.45 ^b
Total carotenoids (mg kg ⁻¹)				
At 5 °C				
Kesar	3.75 ± 0.08 ^b	3.61 ± 0.02 ^b	6.24 ± 0.04 ^a	2.99 ± 0.08 ^c
Ladvo	3.07 ± 0.08 ^c	3.11 ± 0.02 ^c	5.88 ± 0.04 ^a	3.76 ± 0.08 ^b
Rajapuri	5.71 ± 0.02 ^c	7.19 ± 0.10 ^b	7.48 ± 0.11 ^b	12.45 ± 0.02 ^a
Totapuri	6.71 ± 0.02 ^d	7.63 ± 0.14 ^c	12.19 ± 0.12 ^b	15.32 ± 0.04 ^a
At 10 °C				
Kesar	3.75 ± 0.08 ^{bc}	3.25 ± 0.06 ^c	4.80 ± 0.12 ^a	4.31 ± 0.18 ^b
Ladvo	3.07 ± 0.02 ^{bc}	2.91 ± 0.02 ^c	5.89 ± 0.06 ^a	3.63 ± 0.06 ^b
Rajapuri	5.71 ± 0.02 ^d	6.17 ± 0.06 ^c	14.99 ± 0.05 ^a	13.21 ± 0.15 ^b
Totapuri	6.71 ± 0.02 ^c	6.69 ± 0.02 ^c	11.11 ± 0.15 ^a	7.93 ± 0.02 ^b

Means within the row represented by different superscript letters are significantly different at $p < 0.05$ using LSD. The values represented (a–d) in the results indicated the range from higher to lower rank

took place on 8th day and reached to their initial amount in 12 day of storage time. Similarly, the changing trend of TS in fresh-cut mango cultivars stored at 10 °C showed increased amount on 4th day and subsequently on 8th day it declined. However, eventually it increased which may be due to enhanced water loss at 10 °C. Generally, the sugar content increases after harvesting but it decreases with increase of the storage period due to its utilization during respiration as an energy source. In this study, a significant increment in the sugar content was observed during storage of fresh-cut mango cultivars at temperatures of 5 °C and 10 °C, which may be attributed to the accumulation of free

sugars from the hydrolysis of starch by the action of amylase (Lima et al. 2001) and further reduction indicates its consumption with the storage period till the end of analysis.

Changes in ascorbic acid (AA)

Vitamin C is nutritionally an important nutrient and highly susceptible to decompose during storage. It was reported that temperature, pH, oxygen, concentration of secondary metabolites, presence of metals (iron, copper) influence the vitamin C content of final product. The initial AA content

Table 2 ANOVA table for the physico-chemical attributes of fresh-cut mango cultivars

Source of variation	df	F-value						
		Lightness	Hue angle	Chroma	BI	Firmness	WLP	TS
Cultivars	3	8.72***	7.81***	420.52***	344.47***	70.54***	8.16***	28.95***
Temperature	1	2.56 ns	0.78 ns	26.85***	351.70***	468.88***	23.99***	52.87***
Time	3	93.44***	4.89**	20.43***	1986.53***	493.67***	132.27***	510.83***
Cultivars × temperature	3	13.60***	3.13*	61.21***	56.17***	4.07**	2.16 ns	20.80***
Cultivars × time	9	8.30***	3.61***	7.44***	211.08***	22.58***	2.47*	35.65***
Temperature × time	3	8.43***	1.29 ns	32.93***	71.04***	71.61***	6.56***	125.46***
Cultivars × temperature × time	9	7.14***	2.51**	26.32***	98.57***	3.64***	0.94 ns	25.4***

Source of variation	df	F-value						
		AA	Carotenoids	TP	PPO	POX	PAL	Overall acceptability
Cultivars	3	61.04***	21155.25***	122.69***	2.82*	2.90*	43.88***	10.88***
Temperature	1	159.29***	79.55***	245.99***	73.88***	1.63 ns	2.16 ns	1407.98***
Time	3	174.42***	8808.01***	24.15***	13.01***	66.02***	34.62***	6794.94***
Cultivars × temperature	3	28.21***	1699.51***	24.05***	4.00*	0.67 ns	1.33 ns	4.74**
Cultivars × time	9	12.27***	1386.82***	13.80***	3.19*	3.53***	16.39***	6.09***
Temperature × time	3	17.84***	717.09***	51.44***	15.52***	2.43 ns	4.06*	251.39***
Cultivars × temperature × time	9	14.36***	1116.54***	7.24***	3.03*	2.59*	7.05***	4.51***

ns, *, **, *** non-significant or significant at $p < 0.05$, 0.01, 0.001, respectively

was the highest in fresh-cut ‘Ladvo’ mangoes ($60.53 \pm 5.02 \times 10^{-2} \text{ g kg}^{-1}$) and the least was observed in fresh-cut ‘Kesar’ ($48.96 \pm 0.60 \times 10^{-2} \text{ g kg}^{-1}$) (Table 1). There were significant ($p < 0.001$) variations in AA content among fresh-cut mango cultivars due to the effect of storage duration and temperatures (Table 2). Previously, Gil et al. (2006) has been reported the AA content of fresh-cut mangoes in the range from 75 to 115 mg/100 g FW. This study revealed the overall rise in AA content of fresh-cut mango cultivars during storage at both the temperatures. This increment of AA in mango slices kept at 10 °C was comparatively higher than those stored at 5 °C. ‘Kesar’, ‘Rajapuri’ and ‘Totapuri’ slices were reported with abrupt rise in AA concentration on 4th day of storage, which thereafter declined on 8th days and finally increased towards the end of storage, while ‘Ladvo’ was observed with consistent increment in its AA content up to 8th day and then it declined at the end of storage period held at 10 °C. According to Nunes et al. (1998), the increase of AA concentration on a fresh weight basis at higher temperature may be due to water loss during storage rather than to actual increase in AA content. Similar kind of fluctuating trend of AA content was reported for the slices of ‘Kesar’ and ‘Totapuri’ kept at 5 °C, but the extent of increment was comparatively lesser than that observed at 10 °C. Nevertheless, AA content increased on 4th day in fresh-cut ‘Ladvo’ and ‘Rajapuri’ and subsequently

diminishing pattern was adopted towards the end of storage period at 5 °C. Tovar et al. (2001) reported that the AA concentration in fresh-cut mango slices stored at 5 °C or 13 °C increased, but reduction noted after certain time probably due to reactions with reactive oxygen species induced by chilling stress (Tatsumi et al. 2006).

Change in carotenoids

The accumulation of carotenoids in fruits occurs during their ripening and postharvest storage which is responsible for yellow and orange color of mango. Klein (1987) demonstrated that the cell disruption cause the degradation of carotenoids due to their exposure to oxygen or light. The effect of selected storage temperatures on the profile of carotenoids of fresh-cut mango cultivars during their storage period for 12 days is presented in Table 1. Carotenoids of fresh-cut mango cultivars was significantly ($p < 0.001$) affected by the storage temperatures and time (Table 2). At the beginning, the amount of carotenoids was highest for ‘Totapuri’ ($6.71 \pm 0.02 \text{ g kg}^{-1}$) and least for ‘Ladvo’ ($3.07 \pm 0.02 \text{ g kg}^{-1}$). During storage at 5 °C, it consistently elevated approx. by more than two fold in slices of ‘Rajapuri’ and ‘Totapuri’ till the end of storage, while in slices of ‘Kesar’ and ‘Ladvo’ its accumulation was observed up to 8 days of storage and then reduced at the end of storage time. Similar changing trend of carotenoids

concentration was observed for slices of mango cultivars held at 10 °C. Though it was found with consistent rise in carotenoids concentration in slices of ‘Rajapuri’ and ‘Totapuri’ but the rate of accumulation was comparatively slower at 5 °C than that depicted at 10 °C. The total carotenoids content in fresh-cut mango cultivars was found in agreement with those reported by Litz (1997).

Changes in total phenolics (TP) content

Phenolic compounds show unique health-promoting effects and at one hand act as antioxidants and on the other hand as substrate for polyphenol oxidase or peroxidase.

It has been reported that TP content of whole mango fruit increased during storage that ranged between 0.83 and 6.84 g/kg (Hossain et al. 2014). TP in fresh-cut mango cultivars varied from 2.82 to 7.23 g/kg during 12 days of storage period. The storage duration and temperatures had a significant ($p < 0.05$) effect on TP content of fresh-cut mango cultivars (Table 2). At 5 °C, in response to minimal processing of mango cultivars, TP content got accumulated faster and reached to their maximum values at the end of storage in all cultivars, except ‘Totapuri’ (Fig. 2a). However, it underwent significant reduction during initial 4 days of storage at 10 °C, but thereafter the changing behavior was varied depending upon the cultivars. The overall results indicated that fresh-cut mango cultivars kept at 5 °C possess higher amount of TP over the storage period as compared to slices stored at 10 °C. Among four cultivars, ‘Totapuri’ slices exhibited least change in TP profile throughout their storage at both the temperatures. However, the higher TP content in fresh-cut mango cultivars as compared to previously reported by Robles-Sánchez et al. (2009) in fresh-cut ‘Ataulfo’ might be due to the different physiological stage of fruit selected in these studies.

Changes in browning-related enzymes

Wounding stress due to cutting process induces the activation of PPO and POX, enzymes involve in the oxidation of phenolic compounds into quinones which further polymerize to melanin and lead to surface browning and PAL, the first enzyme in the phenylpropanoid pathway responsible for phenolic synthesis (Degl’Innocenti et al. 2005).

Polyphenol oxidase (PPO) activity

Since PPO activity in mango is cultivar-dependent and therefore the variation in the level of polyphenol oxidase activity during fruit storage has been considered important for the prediction of susceptibility to browning (Sellamuthu et al. 2013). The change in PPO activity was significant at

the level of $p < 0.001$ due to the effect of storage temperatures and time and the variation among the fresh-cut mango cultivars was significant at the level of $p < 0.05$ (Table 2). At 5 °C, the selected fresh-cut mango cultivars exhibited significant ($p < 0.05$) diminishing trend of PPO activity and reached to their least level at the end of storage time (Fig. 2b). However the sliced mango cultivars stored at 10 °C lead to significant activation of PPO during initial 4 days of storage except in ‘Rajapuri’. But on 8th day of storage, it decreased in all the four mango cultivars and again increased at the end of storage. At 12th day of storage, it enhanced approx. by 61% and 20% in slices of ‘Kesar’ and ‘Rajapuri’, respectively, while it declined by 10% and 12% in slices made from ‘Ladvo’ and ‘Totapuri’ as compared to that noted initially, indicating the role of PPO activity in the browning occurrence during storage. These significant ($p < 0.05$) variations in PPO activity in selected mango cultivars under storage at two different temperatures suggest the importance of selection of storage temperature and cultivars. Similar changing pattern of PPO activity was demonstrated by Robles-Sánchez et al. (2009) in fresh-cut ‘Ataulfo’ mango during 15 days of storage at 5 °C.

Peroxidase (POX) activity

There was significant ($p < 0.05$) difference in POX activity among fresh-cut mango cultivars and it was found to be significantly ($p < 0.001$) influenced by the storage duration, but there was insignificant variation in the changing trend of POX activity at 5 °C and 10 °C. As represented in Fig. 2c, it was determined that during 8 days of storage, POX activity exhibited approx. 89, 81, 78 and 77% reduction in fresh-cut ‘Kesar’, ‘Ladvo’, ‘Rajapuri’ and ‘Totapuri’, respectively at 5 °C, while the reduction noted at 10 °C was ~64 and 74% in fresh-cut ‘Kesar’ and ‘Ladvo’, respectively during same time. In case of fresh-cut ‘Rajapuri’, the maximum decline (~67%) of POX activity was observed on 4th day of storage and thereafter increased significantly up to 12 days of storage period. Among the four selected mango cultivars, Totapuri showed consistently decreasing trend throughout the storage period with ~52% reduction in its POX activity by the end of storage.

Phenylalanine ammonia lyase (PAL) activity

The data regarding the change in PAL activity is presented in Fig. 2d, revealed that initially PAL activity was highest (4.97 Units min⁻¹ mg⁻¹ protein) in fresh-cut ‘Ladvo’, while fresh-cut ‘Kesar’ had least PAL activity (3.2 Units min⁻¹ mg⁻¹ protein). The storage temperatures did not significantly affected PAL activity of fresh-cut mango

Fig. 2 Changes in **a** total phenolics (TP), **b** polyphenol oxidase (PPO), **c** peroxidase (POX) and **d** phenylalanine ammonia lyase (PAL) activity in fresh-cut mango cultivars during their 12 days of storage period at 5 and 10 °C

cultivars, but there was significant ($p < 0.001$) variation existed in PAL activity among selected mango cultivars during 12 days of storage period. PAL activity of fresh-cut

‘Ladvo’, and ‘Rajapuri’ showed declining trend with the increase of storage period at both the selected temperatures. ‘Totapuri’ exhibited consistently increasing pattern

Fig. 2 continued

up to 8 days of storage and thereafter declined at the end of storage, whereas ‘Kesar’ had fluctuated pattern in PAL activity throughout the storage at both the temperatures.

Sensory evaluation

Based on the evaluation of appearance, taste and aroma, the overall acceptability of fresh-cut mango cultivars was significantly ($p < 0.001$) influenced by storage duration and temperatures, which was found to be significantly ($p < 0.001$) varied among mango cultivars (Table 2). At 10 °C, the loss of freshness took place to the higher extent than that at 5 °C after 4 days of storage period and browning was prominent on the areas where the peel was removed which may be attributed to increased dryness of surface tissue (Table 3). Therefore, the appearance of

fresh-cut mango cultivars stored at 10 °C was severely affected as a result of surface discoloration, withering and microbial contamination at the end of storage. The external quality of fresh-cut mango cultivars was better maintained at 5 °C up to 8 days of storage, but ‘Rajapuri’, ‘Ladvo’ and ‘Kesar’ slices showed the changes in their textural quality like softening after 8 days of storage and reduce the products overall acceptability by 12 days of storage. Symptoms such as change in texture, decrease in color, water soaking increases, peel or skin darkening, browning, increase PPO and PAL activity are indicators of chilling injury (CI) (Hodges et al. 2001). According to the previously published work by Dea et al. (2010), the reduction in firmness in both whole and fresh-cut mango at low temperature (5 °C) may be attributable to the occurrence of chilling injury.

Table 3 Changes in overall acceptability in fresh-cut mango cultivars during their 12 days of storage period at 5 °C and 10 °C

Mango cultivars	Storage period (Days)			
	0	4	8	12
At 5 °C				
Kesar	9.0 ± 0.0 ^a	8.07 ± 0.12 ^b	6.97 ± 0.15 ^c	3.43 ± 0.21 ^d
Ladvo	9.0 ± 0.0 ^a	8.23 ± 0.21 ^b	6.60 ± 0.36 ^c	3.33 ± 0.21 ^d
Rajapuri	9.0 ± 0.0 ^a	8.33 ± 0.12 ^a	6.57 ± 0.21 ^b	2.60 ± 0.36 ^c
Totapuri	9.0 ± 0.0 ^a	8.33 ± 0.15 ^a	7.23 ± 0.25 ^b	3.70 ± 0.20 ^c
At 10 °C				
Kesar	9.0 ± 0.0 ^a	6.97 ± 0.15 ^b	4.40 ± 0.20 ^c	1.17 ± 0.15 ^d
Ladvo	9.0 ± 0.0 ^a	7.27 ± 0.25 ^b	4.33 ± 0.25 ^c	1.30 ± 0.10 ^d
Rajapuri	9.0 ± 0.0 ^a	7.50 ± 0.10 ^b	4.23 ± 0.25 ^c	1.17 ± 0.21 ^d
Totapuri	9.0 ± 0.0 ^a	7.87 ± 0.12 ^b	4.40 ± 0.17 ^c	1.10 ± 0.10 ^d

Means within the row represented by different superscript letters are significantly different at $p < 0.05$ using LSD. The values represented (a–d) in the results indicated the range from higher to lower rank

Microbial contamination

Storage temperature is a very important factor in controlling microbial growth. Although storage under refrigeration temperatures deters the growth of many organisms, some can grow at these conditions (Nguyen-The and Carlin 1994). Regarding the results of microbial contamination, total mesophilic bacteria and yeasts and molds on cut mango cultivars were observed more at 10 °C, which have shortened the shelf-life of fresh-cut mango cultivars from 8 days at 5 °C to 4 days at 10 °C (Table 4). Similar results were reported by Allong et al. (2001) who demonstrated the positive effects of lower temperatures (5 °C instead of 10 °C) storage on fresh-cut 'Julie' and 'Graham' mangoes, including the level of microbial contamination. Lowering the temperature from 10 to 5 °C extended the marketable period, which illustrates the importance of low temperatures for handling fresh-cut produce.

Table 4 Changes in total mesophilic bacterial and yeasts and molds count in fresh-cut mango cultivars during 6 and 12 d of storage period at 5 °C ± 1 °C and 10 °C ± 1 °C

Mango cultivars	Storage period (Days)		
	0	6	12
Total mesophilic bacterial count (log CFU g ⁻¹)			
At 5 °C			
Kesar	0.0	2.42 ± 0.10	3.64 ± 0.04
Ladvo	0.0	2.48 ± 0.00	3.52 ± 0.05
Rajapuri	0.0	2.82 ± 0.04	3.95 ± 0.04
Totapuri	0.0	2.10 ± 0.17	3.29 ± 0.12
At 10 °C			
Kesar	0.0	3.82 ± 0.05	tntc ^a
Ladvo	0.0	4.06 ± 0.04	tntc
Rajapuri	0.0	3.53 ± 0.12	tntc
Totapuri	0.0	2.85 ± 0.15	tntc
Yeasts and molds (log CFU g ⁻¹)			
At 5 °C			
Kesar	0.0	3.15 ± 0.08	tntc
Ladvo	0.0	3.60 ± 0.09	4.05 ± 0.03
Rajapuri	0.0	3.36 ± 0.04	tntc
Totapuri	0.0	3.47 ± 0.11	3.72 ± 0.03
At 10 °C			
Kesar	0.0	3.79 ± 0.04	tntc
Ladvo	0.0	3.4 ± 0.05	tntc
Rajapuri	0.0	3.92 ± 0.04	tntc
Totapuri	0.0	2.88 ± 0.09	tntc

^a tntc stands for too numerous too count

Conclusion

Screening of four mango cultivars was carried out to determine performance of their fresh-cut product under storage at two different low temperatures. In conclusion, the behavior of selected cultivars varied widely during storage period and studied quality attributes were significantly influenced at both 5 °C and 10 °C. Low temperature storage significantly affected the nutritional quality and sensory traits of fresh-cut mango cultivars. The sensory attributes of slices of 'Kesar' 'Rajapuri' and 'Ladvo' were highly affected due to appearance of chilling injury symptoms. The overall results revealed that 'Totapuri' slices had least changes in vitamin C, total phenolic content and antioxidant activity and retained better color and firmness as compared to the rest of the mango cultivars and achieving 8 and 4 days of shelf-life at 5 and 10 °C, respectively. Thus, cv. Totapuri can be considered for its minimal processing.

Acknowledgements The authors are thankful to the Head, P.G. Department of Biosciences, Sardar Patel University, Gujarat, India for providing necessary facilities for carrying out this work.

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