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Variation in physico-chemical, organoleptic and microbial qualities of intermediate moisture pineapple (*Ananas comosus* (L.) Merr.) slices during storage

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Abstract

Pineapple is a commercial tropical fruit ranking sixth in global fruit production. Seasonal market gluts result in huge postharvest losses in all pineapple-growing nations. To reduce postharvest losses of fruits, viable, cost-effective and market-oriented value-added products are needed urgently. The present study was carried out to determine the suitability of two commercial varieties, Kew and Mauritius, for the development of intermediate moisture (IM) fruits and to evaluate product quality during storage. Pineapple slices were steam blanched for 2 min, followed by immersion in osmotic solution containing sucrose and sorbitol (fruit: solution ratio of 1:4), in combination with 0.5% ascorbic acid and 0.25% potassium metabisulfite, for 6 h and were subsequently dehydrated in a tray drier at 50 °C until the moisture content of the product attained equilibrium. The initial moisture contents of IM Kew and Mauritius pineapple slices were 26.53 and 21.65 g/100 g, respectively, while the water activity ranged between 0.671 and 0.666. The L* and b* values showed a decreasing trend, while a* value increased throughout storage, irrespective of variety and storage conditions. The initial TSS of IM pineapple from both varieties was 72 ^{0} Brix, which declined during storage. Though titratable acidity of the product decreased during storage, the decline was insignificant. The total carotenoids of the product from Mauritius was significantly higher (0.809 mg 100 g^{-1}) compared to the one from Kew (0.215 mg 100 g^{-1}). Total phenolics contents in IM slices showed an increasing trend during storage, irrespective of varieties and storage conditions. IM pineapple slices from the variety Mauritius had significantly higher flavonoids (40.50 mg) than the product from Kew (30.0 mg 100 g^{-1}). DPPH radical scavenging activity was highest (3.0 μl ml^{-1}) in IM slices from the variety Mauritius as compared to those from Kew (5.0 μl ml^{-1}). IM pineapple from Mauritius recorded higher organoleptic scores throughout storage. Fungi were not detected in any of the samples throughout the storage period while the population of bacteria and yeast was negligible.

Keywords: Intermediate moisture (IM), Pineapple, Physico-chemical, Organoleptic, Microbial

Introduction

Pineapple is a commercial fruit of the tropics and in many tropical countries it is cultivated round the year. Pineapple is known for the presence of proteolytic enzyme, bromelin in its pulp. Besides, the fruit is also a good source of carotenoids, vitamin C, vitamins B1 and B2. The fruit is ranked sixth in terms of global production. The major producers are Brazil, Philippines, Costa Rica and Thailand. India is ranked seventh with a production of 1.79 million tonnes, having a productivity of 16.83 t per hectare (NHB 2020), which is about 8% of global share in production. The fruit is mainly grown in the North-Eastern and Southern States of the nation.

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The south Indian State of Kerala is one of the leading pineapple producing regions, owing to its predominantly warm, humid tropical climate. The variety 'Mauritius' occupies more than 90% of the area under cultivation. The varieties 'Kew' and 'MD-2' are also grown on a limited scale. Since pineapple is grown round the year in the State, bumper production leading to market gluts is a recurring phenomenon. This result in heavy post harvest losses and many a time, farmers resort to distress sales and thus being deprived of remunerative price for their produce. Therefore, interventions in the form of novel and market oriented processed products of pineapple are need of the hour, which would enable farmers and entrepreneurs to utilize the crop effectively after harvest and thus help in the reduction of post harvest losses to a great extent.

Intermediate Moisture Fruits (IMF) have a water activity ranging between 0.65–0.90 and moisture content of 15–40 g/100 g, which is a result of a slight thermal treatment, pH reduction, as well as the addition of humectants and preservatives, all placed in the context of hurdle technology for the preservation of food (FAO 2003). Compared to conventionally dehydrated fruits and vegetables, intermediate moisture products are superior in terms of colour, flavour and texture, which make them more appealing to consumers. Shelf-stable intermediate moisture (IM) carrot shreds were developed based on 'hurdle technology' (HT), which included the combination of factors like drying by two methods- Infrared drying (IR)/ Tray drying (TD) to reduce water activity [a_w] to 0.6, pretreatments and packaging (Chaturvedi et al. 2013). Intermediate moisture (IM) papaya cubes were developed using a novel combination technology including osmotic dehydration, blanching and infrared drying. These cubes were further hygienized by exposing to gamma radiation dose of 2 kGy. The final processed product could be stored up to 60 days at ambient temperature, whereas, the unprocessed freshly cut samples spoiled within 2 days. (Mishra et al. 2015). Pineapple being a perishable fruit, the present study was conducted to develop intermediate moisture (IM) fruit slices and to evaluate the physic-chemical, organoleptic and microbial quality of the product, keeping in mind the huge post harvest losses occurring in the fruit in developing countries with tropical climate.

Materials and methods

Preparation of intermediate moisture pineapple slices

Pineapple varieties 'Mauritius' and 'Kew' were selected for the study. The fruits were wiped with a clean, wet cloth to remove the adhering dirt and dust on the rind. The fruits were then peeled using a sharp stainless steel knife, after removal of the crown. Peeled fruits were washed in fresh tap water and subsequently, eyes on the surface of the peeled fruit were removed. The hard core of the fruit was removed using a stainless steel pineapple corer. These fruits were then sliced into rings of 2.0 cm thickness, followed by steam blanching for 2 min. The blanched slices were subsequently cooled in fresh tap water for 10 min, followed by immersion in osmotic solution containing sucrose and sorbitol in 1: 1 ratio (fruit: solution ratio of 1: 4), in combination with 0.5% ascorbic acid and 0.25% potassium metabisulphite, for 6 h. This treatment was found ideal for production of intermediate moisture pineapple from a previous experiment by the same researchers, involving six different osmotic agents viz. sucrose, sucrose+sorbitol, sucrose+ sodium chloride, glucose syrup, palm sugar and honey. Evaluation of pineapple varieties and osmotic agents in the development of intermediate moisture fruit revealed that the combination of sucrose and sorbitol in 1: 1 ratio, along with 0.5% ascorbic acid and 0.25% potassium metabisulfite resulted in better physic-chemical properties and higher organoleptic scores. Therefore, this treatment combination was selected as the ideal pre-treatment for developing intermediate moisture slices from pineapple. The fruit slices were then drained off the osmotic solution followed by adsorption of excess solution with a bloating paper, and were subsequently dehydrated at 50 °C in a tray dryer developed by the National Institute for Interdisciplinary Science and Technology (CSIR), Kerala. The moisture content was constantly monitored until the product attained equilibrium between its moisture content and the drying air humidity, wherein the weight became constant. The intermediate moisture fruit slices thus developed were packed in polyethylene laminated aluminium pouches, followed by storage under ambient (32 ± 2 °C, 85–90% RH) and refrigerated (5 ± 1 °C, 85% RH). Qualitative changes in the product were evaluated at monthly intervals for a period of 3 months.

Physico-chemical, organoleptic and microbial quality characteristics

The moisture content of fresh and IM fruit samples was determined by an infra-red moisture analyser (Hallmark Mechatronics, Model-Sartorius, MA 150C, Germany). Water activity of fresh and IM pineapple was measured by filling the sample cup to about half of its capacity and values were obtained directly from a digital output (Aqua lab, Model- Pre 40,412, Decagon Devices, USA). Colour values were determined by reflectance measurement, with a Minolta CM-3600D spectrophotometer (Konica Minolta Sensing, Inc., Osaka Japan). D_{65} lamp was used as reference light source (Hajare et al., 2006). The colour values L,* a* and b* were analysed using JAYPAK 4808 software (Quality Control System, Version1.2). Total soluble solids (TSS) were assessed with a digital refractometer (ATAGO, PAL 1 & 2, Japan). Determination total carotenoids was done as per the method of Ranganna (1997). Extraction of total carotenoids was done with acetone and petroleum ether, using a separating funnel with 3% acetone in petroleum ether as blank. Anhydrous sodium sulphate was added during extraction to absorb excess water. The optical density values were measured at 452 nm (UV-Visible 1800 spectrophotometer, Shimadzu, Kyoto, Japan). Total flavonoids were determined as per the method suggested by Chang et al. (2002). Ethanol extract of the sample was mixed with 1.5 mL of methanol, 0.1 mL of 10% aluminium chloride, 0.1 mL of 1 M potassium acetate and 2.8 mL of distilled water, kept at room temperature for 30 min. Absorbance of the reaction mixture was measured at 415 nm. Estimation of total phenolics contents was carried out with Folin-Ciocalteau reagent (Asami et al. 2003). 5 mL of sample extract solution in 80% ethanol (1 mL) was added with 0.3 mL of Folin-Ciocalteau reagent. After 6 min, 10 mL of 7% sodium carbonate solution was added and mixed well, left for 2 h. A blue coloured complex was formed when phenols reacted with phosphomolybdic acid in alkaline medium. The absorbance readings were taken at 740 nm on a UV-visible spectrophotometer (UV-Visible 1800 spectrophotometer, Shimadzu, Kyoto, Japan). The quantification of total phenolics contents was done using a calibration curve prepared with a gallic acid standard. The results were expressed as g gallic acid equivalent (GAE) per 100 g of sample. The free radical scavenging activity of samples was determined based on the DPPH method (Braca et al. 2001). The sample extract was added with 1.3 mL DPPH solution diluted in methanol and the absorbance was measured at 517 nm. The radical scavenging percentage was calculated by the formula, per cent inhibition = (Control-Sample)/ Control) × 100. The sample concentration providing 50% inhibition (Inhibitory concentration- IC_{50}) was calculated from formula given above. Gallic acid was used as standard.

Intermediate moisture pineapple was evaluated by 25 non-trained panelists for appearance, colour, flavour, taste, aroma, texture and overall acceptability on a nine point hedonic scale (Lawless and Heymann 2003). Kruskal-Wallis test was done to determine the significant difference between treatments. Microbial load in the product was determined as per the procedure suggested by Agarwal and Hasija (1986). The experiment was repeated twice and five replicates were taken for testing each quality parameter. The data was expressed on the basis of Mean and Standard Deviation (SD). A two-way analysis of variance (ANOVA) was conducted using Completely Randomised Design (CRD) to arrive at the influence of varieties and storage conditions on the shelf life and physico-chemical, organoleptic and microbial quality of intermediate moisture slices.

Results and discussion

Changes in physic-chemical, organoleptic and microbial properties of intermediate moisture pineapple slices were evaluated at monthly intervals for 3 months, as explained below.

Moisture content

Shelf life of food is negatively correlated to its moisture content. Higher moisture content in foods favours microbial growth, leading to faster spoilage. Intermediate moisture fruits are considered to have a moisture content in the range of 15 to 40 g/ 100 g. Initial moisture contents of intermediate moisture pineapple from the varieties Kew and Mauritius were 26.53 and 21.65 g/ 100 g, respectively (Table 1). A declining trend in moisture content of the product was observed throughout the storage period in both the varieties, irrespective of the storage condition. However, IM slices held at low temperature retained higher moisture content than those under ambient conditions. IM slices from the variety Kew had higher moisture than the samples from Mauritius. After 3 months of storage, IM slices from the varieties Kew and Mauritius retained 23.03 and 19.81 g/ 100 g moisture, while those held under refrigerated storage had 24.82 and 20.96 g/100 g, respectively. Loss of moisture during storage may be due to evaporation of water in the form of vapour from the product and this accounts for higher moisture loss in the product stored under ambient conditions. Similar findings were reported by Panwar et al. (2013) in intermediate moisture *aonla* fruit segments. Decline in moisture content of intermediate moisture papaya developed by hurdle technology was also reported by Shrivastava and Gowda (2016). However, the finding contradicts the one reported by Atri et al. (2016) who reported an increasing trend in moisture content of intermediate moisture papaya products. Influence of variety and storage temperature had significant effect on moisture content in intermediate moisture pineapple slices in the present study. Enclosure of IM pineapple slices in polyethylene laminated aluminium pouches may have retarded loss of moisture through evaporation from the product.

Water activity

Spoilage of food is greatly influenced by its water activity. Water activity is the vapour pressure of water in the food sample to that of pure water. A lower a_w value is an indication of longer shelf life of foods. IM pineapple slices did not vary significantly in their water activity values. The initial a_w values of the product from Kew and Mauritius were 0.671 and 0.666, respectively (Table 1). Water activity values did not show any significant trend during storage in both the varieties. However, samples stored under ambient conditions had higher water activity compared to the refrigerated product. Water activity of the product after 3 months of ambient storage was 0.659 and 0.769, while those under

Table 1 Moisture (g/100 g), water activity (a_w), colour values (L*, a*, b*) of intermediate moisture pineapple slices during storage

MOISTURE (g/100 g)					WATER ACTIVITY (a_w)				L* value				a* value				b* value			
Storage	KEW		MAURITIUS		KEW		MAURITIUS		KEW		MAURITIUS		KEW		MAURITIUS		KEW		MAURITIUS	
	A*	L*	A*	L*	A*	L*	A*	L*	A*	L*	A*	L*	A*	L*	A*	L*	A*	L*	A*	L*
INITIAL	26.56	26.56	21.67	21.67	0.671	0.671	0.666	0.666	47.42	47.42	43.12	43.12	3.84	3.84	3.89	3.89	24.34	24.34	17.26	17.26
1MAS	25.06	25.56	21.16	21.54	0.670	0.640	0.650	0.780	44.72	45.65	40.85	41.43	4.36	3.81	2.92	3.92	23.99	24.16	16.19	17.18
2MAS	24.89	25.12	20.88	21.28	0.760	0.690	0.680	0.650	41.69	44.55	36.48	40.55	4.36	3.81	2.99	4.01	23.99	24.34	14.26	17.02
3MAS	23.06	24.84	19.84	20.98	0.659	0.654	0.769	0.655	36.38	41.67	29.74	36.80	6.29	3.53	3.05	4.11	16.45	19.80	12.14	15.30
SE (± d)	0.014				0.001				0.014				0.013				0.014			
SE (± m)	0.01				0.001				0.01				0.01				0.01			
CD (0.05) (A X B XC)	0.03				0.003				0.03				0.029				0.03			

*A** Ambient, *L** Low temperature

refrigerated conditions had 0.654 and 0.655 in the varieties Kew and Mauritius, respectively. Significant effect on water activity was noticed in intermediate moisture pineapple slices due to the varietal characteristics, combined with storage temperature. The findings reveal that water activity of IM pineapple slices are not linked to the moisture content of the product. Similar findings were reported in osmo-dried cantaloupe by Naknaen et al. (2016) which had a_w values in the range of 0.60 to 0.65, who also reported that products with similar moisture content could have different water activity. Water activity ranging from 0.4 to 0.7 was recorded in intermediate moisture muskmelon chunks by Ahmad Din et al. (2019).

Colour measurement

Measurement of colour values would give an indication of the extent of browning or darkening of the product. Moreover, colour of any food item has a direct bearing on consumer preference. L* (lightness), a* (redness) and b* (yellowness) values are measured in foods in order to understand the deterioration in quality of the product. In case of IM pineapple, higher L* and b* values with a corresponding lower a* value indicates better colour retention in the product. IM slices from Kew had higher L* and b* values compared to the product from Mauritius, whereas a* value was higher in the product from Mauritius. Colour values varied significantly as a result of interaction between varietal characteristics and storage temperature. Colour characteristics of IM slices for L*, a* and b* from the variety Kew were 47.42, 3.84 and 24.34, respectively whereas the values were 43.12, 3.89 and 17.26 in the product from Mauritius (Table 1). This difference in colour values in the initially developed product could be due to the difference in the pulp colour of the variety, wherein the variety Kew had lighter yellow colour while it was deeper in Mauritius. The L* and b* values showed a decreasing trend while the a* value increased throughout storage, irrespective of varieties and storage conditions. The increase in a* value might be due to the concentration of carotenoids and flavonoids in the fruit tissue as a result of water loss during osmosis, followed by dehydration. Further, the Maillarad reaction that occurs between reducing sugars and amino groups during dehydration may have resulted in browning of the product, which may have contributed to increase in a* value. However, combination of sucrose and sorbitol as osmotic agents, incorporated with antioxidants ascorbic acid and potassium metabisulphite, might have reduced the intensity of browning. This finding is in conformity with the one reported by Naknaen et al. (2016) in osmo-dried cantaloupe wherein the use of sorbitol in osmotic solution could reduce brown colour with higher L* value and lower a* value in the product, compared to the control sample. Similar findings were also reported by Chauhan et al. (2011) in osmotically dehydrated apple slices.

Total soluble solids

TSS of fresh as well as processed fruits have an important role in consumer acceptability. More than 80% of TSS is constituted by sugars, along with water soluble vitamins, minerals and organic acids forming the rest of the constituents. Higher TSS is directly related to sweetness in fruit products which is preferred by majority of consumers. The initial TSS of IM pineapple slices developed from both Kew and Mauritius was 72.0 ^{0}Brix. (Table 2). Sorbitol, being lower in molecular weight than sucrose, its use along with sucrose may have resulted in solid gain in IM slices. Similar findings were reported by Naknaen et al. (2016) in osmo-dried cantaloupe. Higher sugar concentration (60 ^{0} B) and dehydration temperature (60°C) resulted in increased water loss from the produce and solid gain in osmosed guava slices (Sagar and Kumar 2010). TSS of IM pineapple showed a slight decline during storage, which was not significant. TSS content of IM pineapple between varieties was not significant. However, the interactive effect of pineapple varieties and storage temperature had

Table 2 TSS (^{0}Brix), Acidity (g/100 g) and microbial quality of intermediate moisture pineapple slices during storage

TSS (^{0}Brix)					ACIDITY (g/100 g)				BACTERIA(10^{-5} cfu/g)[a]				FUNGI(10^{-3} cfu/g)[a]				YEAST(10^{-4} cfu/g)[a]			
Storage	KEW		MAURITIUS		KEW		MAURITIUS		KEW		MAURITIUS		KEW		MAURITIUS		KEW		MAURITIUS	
	A*	L*	A*	L*	A*	L*	A*	L*	A*	L*	A*	L*	A*	L*	A*	L*	A*	L*	A*	L*
INITIAL	72.00	72.00	72.00	72.00	1.600	1.600	1.600	1.600	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1MAS	71.20	71.00	71.10	72.00	1.580	1.600	1.180	1.200	ND	ND	1	ND	ND	ND	ND	ND	11	ND	ND	ND
2MAS	71.00	71.00	71.05	71.50	1.110	1.150	1.000	1.130	1	1	ND	1	ND	ND	ND	ND	13	ND	ND	ND
3MAS	70.00	70.80	71.00	71.50	0.896	1.025	1.020	1.100	2.5	3	2	2	ND	ND	ND	ND	15	2.6	ND	ND
SE (± d)	0.132				0.157				0.923				0.000				4.038			
SE (± m)	0.094				0.111				0.653				0.000				2.855			
CD (0.05) (A X B XC)	0.281				NS				NS				NS				NS			

[a]values are logarithmic transformed values
*A** Ambient, *L** Low temperature
ND Not detected

significant effect on TSS content of intermediate moisture slices during storage. TSS of samples under refrigerated storage was higher than the product held under ambient conditions. This may be due to lower rates of biochemical reactions under refrigerated storage. The finding is in conformity with the one reported by Atri et al. (2016) wherein a fall in TSS of intermediate moisture papaya products during storage was observed.

Titratable acidity

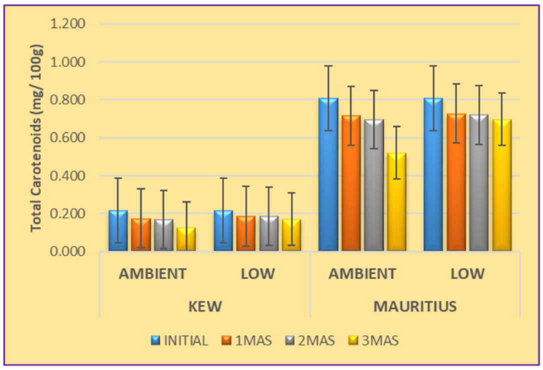
Citric acid is the major organic acid in most of the fruits and in pineapple, it is the predominant one. Acidity in fresh and processed products has a key role in determining consumer acceptance. Higher acidity is often disliked by consumers whereas an adequate blend of acids and sugars are liked by majority of consumers. Acid content, along with sugars are key factors responsible for the unique, fruity flavour of fruit based products. Titratable acidity of IM pineapple slices from Kew and Mauritius were 1.60 and 1.20 g/100 g, respectively. Titratable acidity of IM pineapple slices declined steadily throughout storage (Table 2). The decline in acidity of intermediate moisture pineapple slices was insignificant with respect to both varieties as well as storage conditions. Decline in acidity of osmotically dried and candied papaya over a period of 6 months storage was reported by Atri et al. (2016). Samples held in refrigerated storage had higher titratable acidity compared to the slices under ambient conditions. Higher acidity in refrigerated samples may be due to retarded biochemical reactions at lower temperature. After 3 months of refrigerated storage, IM pineapple slices from the varieties Kew and Mauritius were 1.025 g and 1.00 g/100 g, respectively while it was 0.89 g and 1.02 g/100 g under ambient conditions. However, the finding of the present study contradicts the results reported by Chaturvedi et al. (2013) who reported a rise in total acidity of intermediate moisture carrot shreds.

Total carotenoids

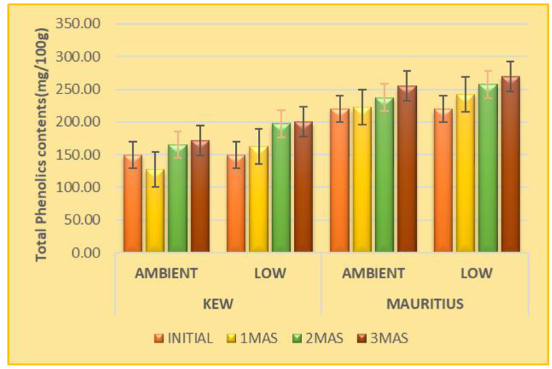
Carotenoids play an important role in human health, particularly in contributing to the antioxidant capacity of fruits and their products. Carotenoids in fruits occur in several forms and colours, of which α carotene, β carotene, lycopene, xanthophylls etc. are a few. The role of carotenoids in several vital physiological processes is well studied in humans and has been found to protect from several degenerative diseases. IM pineapple slices from the varieties Kew and Mauritius had an initial total carotenoid content of 0.215 and 0.809 mg 100 g^{-1}, respectively (Fig. 1a.). Carotenoid retention in the product revealed significant variation with regard to variety and storage condition. Higher carotenoids in the variety Mauritius was due to the inherent varietal character. Total carotenoids showed a decreasing trend during storage, irrespective of the storage condition. Combined effect of varieties and storage temperature had significant variation in total carotenoids in intermediate moisture slices. Fall in carotenoids may be due to its oxidative degradation during storage. 52 to 59 percent decline in β carotene content of intermediate moisture carrot shreds developed through hurdle technology was reported by Chaturvedi et al. (2013). Its retention was higher in the samples held under refrigerated storage. Total carotenoid content of IM pineapple slices from the varieties Kew and Mauritius after 3 months of storage under ambient conditions was 0.125 and 0.520 mg 100 g^{-1}, respectively whereas in samples held in refrigerated storage had 0.169 and 0.697 mg 100 g^{-1}. Loss of carotenoids in intermediate moisture food products (osmotically dehydrated and candy) from papaya was also noticed by Atri et al. (2016).

Total phenolics contents

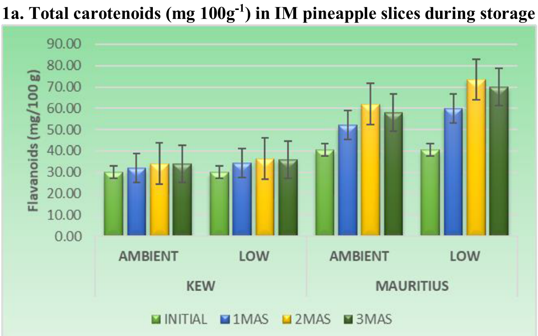
Phenolic compounds are potent antioxidant compounds having considerable free radical scavenging activity.



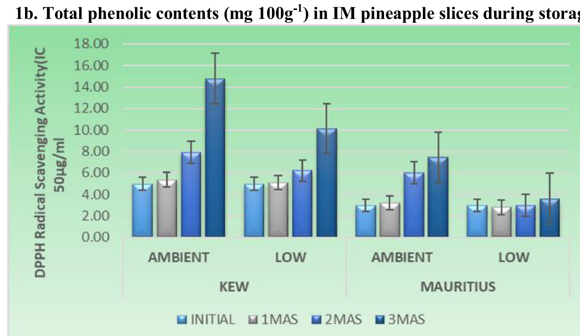
1a. Total carotenoids (mg 100g^{-1}) in IM pineapple slices during storage



1b. Total phenolic contents (mg 100g^{-1}) in IM pineapple slices during storage



1c. Total flavonoids (mg 100g^{-1}) in IM pineapple slices during storage



1d. DPPH radical scavenging activity (IC$_{50}$ µl ml^{-1}) of IM pineapple slices during storage

Fig. 1 a Total carotenoids (mg 100 g^{-1}) in IM pineapple slices during storage. **b** Total phenolic contents (mg 100 g^{-1}) in IM pineapple slices during storage. **c** Total flavonoids (mg 100 g^{-1}) in IM pineapple slices during storage. **d** DPPH radical scavenging activity (IC$_{50}$ µl ml^{-1}) of IM pineapple slices during storage

Many fruits are good sources of phenolic compounds and are thought to have wide range of health protective properties. IM slices from Mauritius had higher total phenolics contents (220 mg) compared to the slices from Kew (150 mg/ 100 g) (Fig. 1b.). Retention of phenols was significantly higher in the refrigerated product compared to the ones held under ambient conditions. Varietal characteristics and storage temperature had significant effect on retention of total phenolics content in intermediate moisture slices. Significantly higher total phenolics contents in IM slices from Mauritius can be due to the differences in chemical constitution between the varieties. Total phenolics contents in IM slices showed an increasing trend during storage, irrespective of varieties and storage condition. Ascorbic acid and potassium metabisulphite in the osmotic solution may have enabled the infusion of phenols into the fruit tissue and might have retarded the subsequent degradation of polyphenols during dehydration. Increase in total phenolics content (TPC) was reported by Lutz et al. (2015) in dehydrated tomato and green apple. Migration of phenolic compounds into the fruit under special circumstances was reported by Kucner et al. (2012). Furthermore, formation of Maillard reaction products might have resulted in the development of novel phenolic compounds as a result of dehydration. Significantly higher total polyphenols were observed by Nyangena et al. (2019) in dried mango slices of varieties Apple and Ngowe compared to fresh fruits.

Total flavonoids

Flavonoids, a derivative of phenols, contribute significantly to the antioxidant properties of fruits and fruit products. Further, they also impart attractive colour to fruits. They are also believed to have free radical scavenging activity and thus play a vital role in protecting human health. IM pineapple slices from the variety Mauritius had significantly higher flavonoids (40.50 mg) than the product from Kew (30.0 mg 100 g^{-1}) (Fig. 1c.). This variation in total flavonoid content may be due to the inherent varietal characteristic between the two varieties studied. The effect of varieties and storage temperature on the total flavonoids content of intermediate moisture pineapple slices was significant. The total phenolics and content of total flavonoids in the methanolic extracts of pineapple variety 'Calendar' were 51.1 ± 0.2 mg g^{-1} and 55.2 ± 0.2 mg quercetin/g, respectively (Hossain and Rahman 2011). Flavonoid content of IM pineapple slices showed an upward trend during the first 2 months of storage, followed by a decline towards the end of storage. Samples held under refrigerated storage retained significantly higher flavonoids compared to the product stored under ambient conditions. IM pineapple slices from Kew and Mauritius kept under refrigerated storage had 36.0 and 70.0 mg 100 g^{-1}, respectively whereas the product under ambient storage retained 34.0 and 58.0 70.0 mg 100 g^{-1}, after 3 months of storage. Higher retention of flavonoids may be due to the combined effect of ascorbic acid and potassium metabisulphite, two powerful antioxidant compounds incorporated into the humectants, which might have resulted in the infusion of flavonoids into IM pineapple slices. Nyangena et al. (2019) also reported that dried slices of Apple and Ngowe varieties of mango contained higher amount of flavonoids compared to fresh ones.

2, 2-diphenyl-1-picrylhydrazyl (DPPH) radical-scavenging activity

Antioxidant activity of food items is tested by their ability to scavenge free radical compounds. DPPH radical scavenging activity was highest (3.0 μl ml^{-1}) in IM slices from the variety Mauritius as compared to those from Kew (5.0 μl ml^{-1}) (Fig. 1d.). The same trend continued throughout storage. A lower IC_{50} value is an indication of greater radical scavenging activity. After 3 months of storage, significantly lower IC_{50} values of 3.62 μl ml^{-1} and 7.46 μl ml^{-1} were recorded in slices prepared from Mauritius held under refrigerated and ambient conditions, whereas those from Kew under the same storage conditions recorded 10.14 μl ml^{-1} and 14.78 μl ml^{-1}, respectively. Incorporation of ascorbic acid and potassium metabisulphite, two potent antioxidant compounds to the osmotic solution might have helped in better retention of other natural antioxidant compounds naturally found in pineapple fruits. Formation of concentrated layer of sugar at the periphery of samples during osmotic dehydration may act as a barrier to the soluble components transfer, resulting in a higher retention of it on the final product (Naknaen et al. 2016). However, they also found a decline in radical scavenging activity with increase in the proportion of sorbitol in osmotic solutions in dehydrated cantaloupe. Type of variety and storage temperature influenced the DPPH radical scavenging activity of intermediate moisture pineapple slices significantly. Samples held under refrigerated storage exhibited significantly higher DPPH scavenging activity compared to the ones stored under ambient conditions. Higher free radical scavenging potential of the product from the variety Mauritius may be due to its varietal characteristics of higher contents of total phenolics, carotenoids and flavonoids, compared to those in Kew. Retention of higher radical scavenging capacity of IM slices held in refrigerated storage might be due to the higher levels of antioxidant compounds as a result of slower rates of biochemical reactions at low temperature. Higher DPPH radical scavenging activity in passion fruit genotypes possessing high levels of phenolic compounds was reported by Charan et al. (2018). Polyphenol compounds found in cantaloupe are a type of antioxidant and in addition, the Maillard reaction products might be also responsible for its powerful antioxidant capacity (Naknaen et al. 2016). Most dehydrated fruits and vegetables had increased oxygen radical absorbance capacity (ORAC), ranging from 9.5% (carrot) to 52.9% (egg plant) as reported by Lutz et al. (2015).

Organoleptic quality

Organoleptic properties of fresh and processed food samples are the most important quality criteria that determine consumer preference. The flavour of fresh and processed fruit products are mainly determined by the taste and aroma. High organoleptic scores, along with better nutritional attributes make the product highly preferred by consumers, particularly the health conscious ones. IM slices developed from the variety Mauritius had higher overall acceptability (8.0) compared to those from Kew (7.6) (Tables 3 and 4). However the variation in organoleptic attributes was insignificant, immediately after development of the product. Higher overall acceptability was recorded in the product from Mauritius throughout storage, compared to the one from Kew. This might be due to the ideal sugar-acid blend in the variety Mauritius. After 3 months of storage, significant difference was observed with respect to appearance, colour and overall acceptability. Further, IM slices from Mauritius and Kew held in refrigerated storage had higher overall acceptability (8.0 and 7.8, respectively) compared to the product under ambient conditions (7.4 and 7.2). However, IM slices from both varieties were found acceptable by the panelists throughout the storage period, which proves that development of IM slices from pineapple using combination of preservation methods (hurdle technology) is a viable technique to maintain quality of the product. Varietal difference and variation in storage temperature had significant effect on the overall acceptability of intermediate moisture pineapple slices. Further, addition of sorbitol to sucrose might have made the product softer, easily chewable and flavourful. An increase in the amount of sorbitol in the sucrose-sorbitol mixture caused a decrease in the hardness of osmo-dried cantaloupe (Naknaen et al. 2016). Significant reduction in hardness was reported in sorbitol treated osmotically dehydrated apple slices (Chauhan et al. 2011).

Microbial quality

Microbiological safety of food is paramount to the consumers' health and therefore, its compromise results in serious health issues like food borne illnesses. Food borne microbes, particularly the spore formers are more dangerous compared to the non-spore forming

Table 3 A Organoleptic quality of intermediate moisture pineapple slices during storage

	Organoleptic quality (Initial)								Organoleptic quality (1MAS)							
Treatments	**Appearance**	**Colour**	**Flavour**	**Texture**	**Odour**	**Taste**	**After taste**	**Overall acceptability**	**Appearance**	**Colour**	**Flavour**	**Texture**	**Odour**	**Taste**	**After taste**	**Overall acceptability**
K*- A*	7.6 (18.6)	7.6 (15.9)	7.5 (19.2)	7.8 (20.3)	7.3 (18.3)	7.8 (17.9)	7.6 (17.9)	7.6 (13.8)	7.3 (18.1)	7.7 (24.6)	7.5 (18.2)	7.6 (19)	7.0 (14.2)	7.6 (14.2)	7.5 (17.7)	7.6 (16.9)
K* - L*	7.6 (18.6)	7.6 (15.9)	7.5 (19.2)	7.8 (20.3)	7.3 (18.3)	7.8 (17.9)	7.6 (17.9)	7.6 (13.8)	7.3 (17.4)	7.9 (26.5)	7.5 (18.6)	7.5 (18.9)	7.3 (15.6)	7.7 (15.6)	7.5 (21.4)	7.7 (18.3)
MS* - A*	7.9 (22.4)	8.3 (25.1)	7.7 (21.8)	7.9 (20.7)	7.7 (22.7)	8.2 (23.1)	8.0 (23.1)	8.0 (19.1)	7.2 (15.8)	7.2 (15.8)	7.6 (20.7)	7.8 (20.9)	7.3 (20.1)	8.0 (20.1)	7.7 (20.1)	7.8 (20.7)
MS*- L*	7.9 (22.4)	8.3 (25.1)	7.7 (21.8)	7.9 (20.7)	7.7 (22.7)	8.2 (23.1)	(8.0) 23.1	8.0 (19.1)	7.9 (22.6)	7.2 (15.0)	7.9 (24.3)	7.9 (23.1)	7.6 (23.8)	8.2 (23.8)	7.7 (22.8)	8.2 (26.1)
KW value	1.193	7.27	0.556	0.151	1.522	2.760	2.760	3.170	2.304	9.370	2.036	1.440	5.520	5.521	1.216	4.390

$\chi 2 = 7.815$ (4,0.05)

*K** Kew, *MS** Mauritius, *A** Ambient, *L** Low temperature

Table 4 B Organoleptic quality of intermediate moisture pineapple slices during storage

Organoleptic quality (2MAS)									Organoleptic quality (3 MAS)							
Treatments	**Appearance**	**Colour**	**Flavour**	**Texture**	**Odour**	**Taste**	**After taste**	**Overall acceptability**	**Appearance**	**Colour**	**Flavour**	**Texture**	**Odour**	**Taste**	**After taste**	**Overall acceptability**
K*- A*	7.8 (24.8)	7.7 (23.4)	7.6 (20.3)	7.4 (19.5)	6.8 (17.6)	7.4 (17.4)	7.0 (14.7)	7.4 (14.7)	7.2 (15.9)	7.1 (14.6)	7.8 (21.2)	7.2 (19.0)	6.8 (17.4)	7.2 (15.4)	7.1 (19.0)	7.2 (13.8)
K* - L*	8.0 (26.0)	7.8 (25.8)	7.6 (20.5)	7.6 (22.9)	7.0 (20.0)	7.6 (18.9)	7.4 (20.9)	7.8 (20.9)	8.3 (29.8)	8.4 (30.1)	7.9 (22.9)	7.7 (23.7)	7.2 (21.5)	7.6 (22.1)	7.8 (25.2)	7.8 (23.1)
MS* - A*	7.5 (17.7)	7.5 (19.6)	7.4 (17.4)	7.4 (20.3)	7.0 (19.5)	7.6 (20.2)	7.2 (21.9)	7.8 (21.9)	7.3 (16.8)	7.4 (18.1)	7.5 (17.2)	7.0 (16.9)	6.9 (17.9)	7.4 (19.6)	7.0 (17.0)	7.4 (18.6)
MS*- L*	7.6 (21.3)	7.5 (21.1)	7.8 (23.8)	7.8 (27.1)	7.4 (24.8)	8.0 (25.5)	7.6 (24.5)	8.0 (24.5)	7.5 (19.4)	7.5 (19.2)	7.7 (20.5)	7.5 (22.3)	7.4 (25.1)	7.8 (24.9)	7.4 (20.6)	8.0 (26.5)
KW value	3.39	1.77	1.73	2.79	2.23	3.19	4.79	4.59	10.28	10.85	1.46	2.25	3.14	4.12	2.99	8.13
$\chi2 = 7.815$ (4,0.05)																

*K** Kew, *MS** Mauritius, *A** Ambient, *L** Low temperature microbes. Bacteria thrive in low –acid foods, while fungi prefers acidic foods and yeasts are considered to be mostly osmophilic or halophilic in nature. Microbial load (bacteria, fungi and yeast) in the product gives an indication on the safety and hygiene during preparation and after development. None of the microorganism tested was detected in any of the samples, immediately after development. Microbial population remained insignificant throughout the storage period. After 1 month of storage yeast (11.0×10^{-4}) was detected in IM slices from Kew and bacteria (1.0×10^{-5}) in the samples from Mauritius, both under ambient conditions (Table 2). After 3 months, bacteria (2.5×10^{-5}) and yeast (15.0×10^{-4}) were detected in the samples from Kew under ambient conditions while under refrigerated storage bacterial and yeast population were 3.0×10^{-5} and 2.6×10^{-4}, respectively. Only bacterial growth (2.0×10^{-5}) was detected in IM slices from Mauritius under both ambient and refrigerated conditions, after 3 months of storage. Fungi were not detected in any of the samples throughout the storage period under ambient and low temperature. Similar range of microbial population, total bacterial count (2.1) and mould count (2.08) were observed by Chaturvedi et al. (2013) in intermediate moisture carrot shreds during storage. Low a_w of the product and combination of preservation methods may have resulted in low microbial load in IM slices. Packaging in polyethylene laminated aluminum pouches and subsequent storage, particularly at low temperature may have prevented microbial proliferation. The type of microflora in dried products depends on the characteristics of the products, such as pH, composition, pre-treatments, types of endogenous and contaminated microflora and method of drying (Sagar and Kumar, 2010).

Conclusions

Development of intermediate moisture slices from pineapple using combination of preservation methods (humectants, antioxidants, antimicrobials and dehydration) is a viable technique to maintain its overall quality attributes. Polyethylene laminated aluminium pouches is an ideal packaging material to retain the quality of the product. Further, holding the product at low temperature (refrigerated storage) was found better in quality retention compared to ambient storage. The technique proved beneficial in maintaining the physical attributes of the product namely, moisture, water activity and colour. The technique was equally effective in the retention of bioactive compounds. It also ensured a microbiologically safe and organoleptically superior product.

Abbreviations

IM: intermediate moisture; M: Mauritius; K: Kew; A: Ambient temperature; L: Low temperature

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Not applicable.

Authors' contributions

SG conceived the research, wrote and edited the manuscript. BK and MKM assisted in analytical work and compilation of data. The overall supervision was done by MJ. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/ or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical approval and consent to participate

Not applicable.

Consent for publication

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Competing interests

The authors declare that they have no competing interests.

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References

Agarwal, G. P., & Hasija, S. K. (1986). *Microorganisms in the laboratory*, (p. 155). Lucknow: Print House India Ltd.

Asami, D. K., Hong, Y. J., Barret, D. M., & Mitchel, I. (2003). Comparison of the total phenolic and ascorbic acid content of freeze-dried and air dried marionberry, strawberry and corn grown using conventional, organic and sustainable agricultural practices. *Journal of Agriculture and Food Chemistry*, *51*, 1237–1241. https://doi.org/10.1021/jf020635c.

Atri, S., Dhiman, A. K., Sharma, R., & Kaushal, M. (2016). Standardization of pre-treatments for the development of intermediate moisture food products from papaya (*Carica papaya* L.). *International Journal of Food Fermentation Technology.*, *6*(1), 143–149. https://doi.org/10.5958/2277-9396.2016.00037.4.

Braca, A., Tommasi, D., Di Bar, L., Pizza, C., Politi, M., & Morelli, I. (2001). Antioxidant principles from *Bauhinia tarapotensis*. *Journal of Natural Products.*, *64*, 892–895. https://doi.org/10.1021/np0100845.

Chang, C., Yang, M., Wen, H., & Chern, J. (2002). Estimation of of total flavanoid content in propolis by two complementary colorimetric methods. *Journal of Food and Drug Analysis*, *10*, 178–182. https://doi.org/10.38212/2224-6614.2748.

Charan, S. M., Gomez, S., Sheela, K. B., Joseph, M., & Sruthi, C. V. (2018). Quality characteristics and antioxidant activity of passion fruit (*Passifloraedulis* Sims.) accessions. *Indian Journal of Horticulture.*, *75*(2), 185–190. https://doi.org/10.5958/0974-0112.2018.00034.8.

Chaturvedi, A., Sujatha, V., Ramesh, C., & Dilip Babu, J. (2013). Development of shelf stable intermediate carrot (*Daucus carota*) shreds. *International Food Research Journal.*, *20*(2), 775–781.

Chauhan, O. P., Singh, A., Singh, A., Raju, P. S., & Bawa, A. S. (2011). Effects of osmotic agents on colour, textural, structural, thermal and sensory properties of apple slices. *International Journal of Food Properties.*, *14*(5), 1037–1048. https://doi.org/10.1080/10942910903580884.

Din, A., Nadeem, M., Saeed, F., Ahmad, M. H., Tufail, T., UlAin, H. B., … Anjum, F. M. (2019). Development and optimization of processing techniques for intermediate moisture muskmelon chunks. *Food Science and Nutrition*, *7*, 3253–3260. https://doi.org/10.1002/fsn3.1183.

FAO (Food and Agriculture Organization of the United Nations) (2003). *Handling and preservation of fruits and vegetables by combined methods for rural areas*,

Agricultural Services Bulletin 149 (p. 44). Rome: Food and Agriculture Organisation.
Hajare, S., Dhokane, V., Shashidhar, R., Saroj, S. D., Sharma, A., & Bandekar, J. R. (2006). Radiation processing of minimally processed pineapple (AnanascomosusMerr.): Effect on nutritional and sensory quality. *Journal of Food Science.*, *71*(6), 501–505. https://doi.org/10.1111/j.1365-2621.2006.tb15641.x.
Hossain, M. A., & Rahman, S. M. M. (2011). Total phenolics, flavonoids and antioxidant activity of tropical fruit pineapple. *International Food Research Journal.*, *44*, 672–676. https://doi.org/10.1016/j.foodres.2010.11.036.
Kucner, A., Klewicki, R., & Sojka, M. (2012). The influence of selected osmotic dehydration and pretreatment parameters on dry matter and polyphenol content in high bush blueberry (*Vaccinium corymbosum* L.) fruits. *Food and bioprocess technology*, (6), 2031–2047. https://doi.org/10.1007/s11947-012-0997-0.
Lawless, H. T., & Heymann, H. (2003). *Sensory evaluation of food: Principles and practices*, (2nd ed.,). New York: Springer.
Lutz, M., Hernandez, J., & Henriquez, C. (2015). Phenolic content and antioxidant capacity in fresh and dry fruits grown in Chile. *CyTA Journal of Food.*, *13*(4), 541–547. https://doi.org/10.1080/19476337.2015.1012743.
Mishra, B. B., Gautam, S., Chander, R., & Sharma, A. (2015). Characterization of nutritional, organoleptic and functional properties of intermediate moisture shelf stable ready-to-eat *Carica papaya* cubes. *Food Bioscience*, *10*, 69–79. https://doi.org/10.1016/j.fbio.2015.02.001.
Naknaen, P., Rattanwedee, M., & Kam-Onsri, A. (2016). Effect of partial replacement of sucrose with humectants in the osmotic solution on the characteristics of osmo-dried cantaloupe. *International Journal of Fruit Science.*, *16*(3), 225–241. https://doi.org/10.1080/15538362.2015.1087359.
National Horticulture Board (NHB). (2020). Ministry of Agriculture and farmers welfare, Government of India
Nyangena, O. I., Owino, O. W., Imathiu, S., & Ambuko, J. (2019). Effect of pretreatments prior to drying on antioxidant properties of dried mango slices. *Scientific African*, *6*(e00148), 1–9. https://doi.org/10.1016/j.sciaf.2019.e00148.
Panwar, S., Gehlot, R., & Siddiqui, S. (2013). Effect of osmotic agents on intermediate moisture aonla segments during storage. *International Journal of Agriculture and Food Science Technology.*, *4*(6), 537–542. https://doi.org/10.1007/s13197-016-2299-4.
Ranganna, S. (1997). *Handbook of Analysis & Quality Control for fruit and vegetable products*, (2nd ed., p. 1112). New Delhi: Tata McGraw Hill Publishing Company Limited.
Sagar, V. R., & Kumar, S. P. (2010). Recent advances in drying fruits and vegetables: A review. *Journal of Food Science and Technology.*, *47*(1), 15–26. https://doi.org/10.1007/s13197-010-0010-8.
Shrivastava, A., & Gowda –Doreyappa, I.N. (2016). Development of intermediate moisture slices of papaya (*Carica papaya* L.) by hurdle technology. *Journal of Horticultural Science.*, *11*(1), 67–71. https://doi.org/10.13140/RG.2.1.2511.6886.

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