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Quality evaluation of thermal processed tender jackfruit during storage

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Abstract
Tender jackfruit (*Artocarpus heterophyllus* L.), known for its unique quality attributes, is popular as a vegetable with high market value in South Asian countries. However, its year round availability is limited mainly due to seasonal nature, high perishability and limited technologies for storage and transportation. Thermal processing may be regarded as a promising one-step solution to these concerns. The present study examined the effect of thermal processing (sterilization at 121°C and pasteurization at 90°C) and preservatives (brine, potassium metabisulphite, citric acid and their combination) on quality attributes (texture, colour, ascorbic acid, titrable acidity, and microbiology) of canned tender jackfruit during two months of storage. All the samples analysed were microbiologically safe during the storage period. The outcome of two-factor completely randomized design revealed that degradation of quality attributes of samples during storage was statistically insignificant irrespective of preservative treatment and type of thermal processing. However, there was significant variation between sterilization and pasteurization, the latter being superior in quality retention and sensory perception. Based on the result of sensory analysis, the use of pasteurization based treatments with brine (overall acceptability), citric acid (colour and texture) and citric acid-potassium metabisulphite combination (flavour) may be advocated for thermal processing of tender jackfruit samples.

Key words: Pasteurization, Preservative, Sterilization, Storage, Tender jackfruit, Thermal processing.

Introduction

Jackfruit (*Artocarpus heterophyllus* L.) is a seasonal tropical fruit abundant in South and South East Asia. It is an ample source of vitamins, minerals and energy and is widely known for its attributes benefitting human health (Swami et al., 2012; Ranasinghe et al., 2019). It is referred as 'poor man's food' as it is cheap and abundant during summer season (Jagtap et al., 2010). Jackfruit in its tender form (about 60 days of maturity) is generally consumed as vegetable and is characterized by its flavour, colour and meat like texture. Moreover, it is a good source of vitamin C (ascorbic acid) and potassium compared to its matured or ripened stage and seed (Swami et al., 2012). These inherent quality and health benefits have been recognized traditionally, leading to a high market value for tender jackfruit, especially in South Asian countries.

Availability of tender jackfruit in the international market throughout the year is a critical aspect related to its trade. However, several factors limit its year round availability which include seasonal nature, geographically limited growth due to climatic variations, high perishability and difficulties related to storage and transportation due to limited technologies. In addition, there are challenges related to increased chance of browning, tissue softening and depletion of phytochemicals during its handling and processing (Rana et al., 2018). This warrants investigation on suitable preservation

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techniques with significant consideration on economic viability.

Several methods exist for food preservation based on minimal processing, and thermal and non-thermal principles (Prokopov and Tanchev, 2007; Pereira and Vicente, 2010; Jayathunge et al., 2019). Minimal processing intends to transport microbiologically safe food from site of production to consumer (Ohlsson, 1994; Escobedo-Avellaneda et al., 2018). Thermal processing typically consists of heat treatment of food from an external source before (aseptic processing) or after final packaging (canning). Non-thermal techniques such as high-pressure, microwave, ohmic and pulsed electric field methods induce local heating within the food matrix by uniform application of either pressure or electric field (Prokopov and Tanchev, 2007; Jayathunge et al., 2019). Minimally processed or fresh-cut vegetables remain suitable for consumption (microbiologically safe) for about a week or two only under refrigerated conditions.

Although non-thermal techniques have the advantages of short process time and minimum temperature gradient within the product (Barrett and Lloyd, 2012), they are very expensive and some of the their commercial applications are still in infancy. In contrast, thermal processing has been widely used and assures palatable products with a shelf life of 2 years or more (Barrett and Lloyd, 2012). Moreover, thermally processed products have commercial sterility accomplished by the combined effect of heat treatment and anaerobic condition created inside the container as in case of canning (Montanari et al., 2018). Hence, thermal processing may be chosen as the more suitable approach among others for year round perseveration of tender jackfruit. However, limited studies have been conducted on thermal processing and canning of tender jackfruit. Thus, this study was undertaken to examine the combined effect of type of thermal processing and preservative on selected quality attributes of thermally processed tender jackfruit during storage.

Material and Methods

Sample preparation

Tender jackfruit (*Artocarpus heterophyllus* L. cv '*Varikka*') samples harvested at 50-60 days after fruit formation were procured from Fruits Crops Research Station (erstwhile Pineapple Research Centre) of Kerala Agricultural University, Thrissur (Kerala, India). The samples were washed, peeled and cut into pieces of almost uniform size and subjected to blanching process at 100°C for 1 min using 0.3% citric acid as preservative in boiling water (Pritty and Sudheer, 2012). After blanching, tin cans (11.5 cm height and 10 cm diameter) were filled with about 250 g of sample and about 550 ml of solution containing a preservative with provision of suitable headspace (7 mm). Different preservative solutions used in the study included brine (2%), citric acid (0.3%) and potassium meta-bisulphite (KMS) (0.1%) at different concentrations (Singh et al., 1996; Thakur, 2018).

Thermal processing and storage

Thermal processing of tender jackfruit slices taken in tin cans was performed at the Canning Industries Cochin Limited, Thrissur (Kerala, India). The prepared cans were exhausted by conveying them through a tank of hot water (85°C) till their centre attained a temperature of 79°C (Srivastava and Sanjeev, 1994) and they were sealed airtight. Then the cans with different preservatives were subjected to thermal processing at a sterilization temperature (T_s) of 121°C for 38 min (corresponding to F_0=1) and pasteurisation temperature (T_p) of 90°C for 19 min (corresponding to F=10) as standardized by Pritty et al. (2013). Each preservative-temperature combination was regarded as a treatment and thus a total of five sterilization (ST) and pasteurization treatments (PT) were examined in this study as listed below.

ST1 : Canning with 2% brine and thermal processing at T_s

ST2 : Canning with 0.1% KMS and thermal processing at T_s

ST3 : Canning with 0.3% citric acid and thermal processing at T_s
ST4 : Canning with 2% brine + 0.1% KMS and thermal processing at T_s
ST5 : Canning with 0.3% citric acid + 0.1% KMS and thermal processing T_s
PT1 : Canning with 2% brine and thermal processing at T_p
PT2 : Canning with 0.1% KMS and thermal processing at T_p
PT3 : Canning with 0.3% citric acid and thermal processing at T_p
PT4 : Canning with 2% brine + 0.1% KMS and thermal processing at T_p
PT5 : Canning with 0.3% citric acid + 0.1% KMS and thermal processing at T_p

After thermal processing, the heat treated cans were cooled by dipping in cold water and stored at different conditions depending on the type of thermal process. The sterilised cans were kept at ambient conditions (20–32°C) and pasteurised cans were stored at refrigerated condition (3–5°C) during the study period (2 months).

Quality evaluation of thermal processed tender jackfruit

Quality attributes of thermal processed tender jackfruit samples namely texture, colour, vitamin C, titrable acidity, microbial load (10^{-1} dilution) were examined for 2 months at an interval of about 15 days. A two-factor completely randomised design (CRD) technique was performed to study the influence of temperature, time of processing, type of preservative and duration of storage on texture, colour, vitamin C, titrable acidity and microbial qualities of canned samples. In addition, sensory attributes of the samples were examined at the end of storage period.

Texture

Measurement of texture attributes (firmness and toughness) were performed using a Texture Analyzer (Stable Micro-System Ltd., UK) equipped with a load cell (50 N) and cylindrical probe (5 mm diameter). A double compression measurement was made on each sample with trigger force of 0.5 kg (depth of penetration=10 mm; velocity=10 mm/s) and corresponding force–distance curve was recorded. The maximum peak force and area under the curve represented firmness and toughness, respectively (Gonçalves et al., 2007; Liu et al., 2019). Three replicated measurements were performed for each sample.

Colour

The colour of samples was assessed using a Hunter Lab colorimeter (Mini Scan XE Plus, Hunter Associates Laboratory Inc., Reston, Virginia) which was expressed in terms of Commission International de l' Eclairage (CIE) space co-ordinates of L (lightness), a (redness) and b (yellowness) values. For measurement, the sample was filled in a transparent cup associated with the instrument without any void space. The colour measurement was replicated three times for each sample. The deviation of colour of samples from the reference standard (ΔE) was also recorded (Goncalves et al., 2007; Eyarkai Nambi et al., 2016). A high ΔE value denoted greater colour change and vice versa (Cemalettin and Mustafa, 2010). In addition, browning index (BI) was computed using CIE indices (Equation 2.1 and 2.2). It represented the purity of brown colour which was considered to be an important parameter related to browning (Lopez-malo et al., 1998).

$$\text{Browning Index, BI} = \frac{100\,(x - 0.31)}{0.17} \quad (2.1)$$

$$x = \frac{a + 1.75\,L}{(5.645\,L + a - 3.012\,b)} \quad (2.2)$$

Ascorbic acid

Ascorbic acid (vitamin C) was determined using dye method (Sadasivam and Manickam, 1992). Each sample was made into pulp and 10 ml of the homogenized pulp (V_s) was taken and made up to 100 ml with 4% oxalic acid solution. Then 5 ml of the made up solution was pipetted out into a conical flask and titrated against the 2,6-dichloroindophenol

dye (V_2). End point was the appearance of pale pink colour which persisted for a few minutes. The amount of dye consumed (V_1) was determined, which was equal to the amount of ascorbic acid present in the working standard solution. The quantity of ascorbic acid (mg) present in 100 gm of sample was calculated as follows.

$$\text{Ascorbic acid (mg/100 g)} = \frac{0.5}{V_1} \times \frac{V_2}{5} \times \frac{100}{V_s} \times 100 \quad (2.3)$$

Titrable acidity

The tender jackfruit slices were crushed and filtered through a muslin cloth. About 10 g of fresh filtered homogenized pulp were made up to 100 ml with distilled water. Then about 10 ml of the prepared solution was titrated against 0.1N NaOH solution using phenolphthalein as indicator. The appearance of a light pink colour was the end-point that quantified the NaOH required to neutralise the juice. The amount of titrable acidity (N_S)was calculated (Equation 2.4) and expressed as percent citric acid (Ranganna, 1986).

$$N_s\,(\%) = \frac{(\text{Normality of alkali} \times \text{Titre value} \times \text{Equivalent weight of acid} \times 100)}{(\text{Volume of sample taken} \times 100)} \quad (2.4)$$

Microbiological analysis and commercial sterility test

Microbial analysis in the study was performed using serial dilution and plating method (Ben-David and Davidson, 2014). Bacteria were cultured using nutrient agar medium while potato dextrose was used for fungal and yeast culture. Known quantities of nutrients respective to each microorganism were dissolved in 100 ml distilled water. The pH of the medium was adjusted using 0.1N NaOH and 0.1N HCl. An average of three replications was chosen as the final reading for each sample.

The cans subjected to different F_0 values (sterilization) were tested for commercial sterility (IS2168, 1971). About six cans were randomly selected from each batch processed to different F_0 values. Three cans from each batch were incubated at 55°C for 4 days and the remaining were incubated at 37°C for 14 days. Then the incubated cans were opened in aseptic conditions and the samples were transferred to sterile thioglycollate broth tubes. A layer of sterile liquid paraffin wax was applied in each tube to create anaerobic condition. The tubes were then incubated at 37°C for 48 h and observed for development of turbidity, which indicated the survival of micro-organisms. Tubes not showing any turbidity were incubated again for 48 h at 37°C to ascertain sterility (Sreenath et al., 2008).

Sensory analysis

Organoleptic evaluation of thermally processed tender jackfruit with respect to colour, flavour, texture and overall acceptability was adjudged on a 9 point hedonic scale (Ranganna, 1986) by a panel of 12 untrained judges. The average of the points given by the panel judges was used for subsequent analysis of variance (5% significance level) in SPSS software package. The sensory evaluation session was carried out at the end of storage period. The result obtained from sensory analyses was analysed based on mean rank value in conjunction with Kendall's coefficient of concordance (W) statistic. The statistic assessed whether any significant agreement among judges existed or not with regard to organoleptic attributes.

Results and Discussion

Effect of thermal processing on texture of canned tender jackfruit

Table 1 and 2 lists the values of firmness and toughness, respectively, noted for different treatments during the storage period. The textural attributes were found to be considerably higher in case of pasteurization treatments (overall mean=35.70 N) and found to be statistically significant compared to sterilization counterparts (overall mean=24 N). The low values noted for samples subjected to sterilization treatments could be attributed to their higher temperature and hence higher tissue softening effect. However, no

significant difference in both firmness and toughness values was noted across different sterilization treatments with preservatives at any point of storage analysis. Both the firmness and toughness of canned tender jackfruit was found to have a decreasing trend during storage. The mean value of firmness (irrespective of treatments) decreased from 2.40 to 2.07 N and 37.51 to 33.90 N in case of sterilization and pasteurization treatments, respectively. Similarly, the variation in toughness of sterilization and pasteurization treatments was noted to be from 4.67 to 2.27 N.s and 78.45 to 58.46 N.s, respectively. The per cent difference in firmness between first and last day of storage (Table 1) was found to be highest in case of ST4 (18.81%) followed by ST3 (15.78%) considering all treatments together. The change was found to be least in case of PT2 (6.69%) and PT4 (8.65%) treatments. Similarly, ST1 (62.98%) had a greater decrease in toughness (Table 2) among other treatments while least difference was noted in case of PT1 (22.82%). These results were in agreement with the findings of Nisha et al. (2006) as reported based on their analyses with potato cubes, whole

Table 1. Effect of thermal processing, preservative and storage on firmness of canned tender jackfruit samples

Treatment	Storage interval (days)					PD	Mean
	0	15	30	45	60		
Sterilization*							
ST1	2.53	2.42	2.41	2.39	2.26	10.66	2.40
ST2	2.52	2.40	2.37	2.37	2.24	11.00	2.38
ST3	2.28	2.17	2.06	2.04	1.92	15.78	2.09
ST4	2.19	2.14	2.07	1.89	1.77	18.81	2.01
ST5	2.47	2.42	2.22	2.18	2.17	12.34	2.29
Mean	2.4 (0.16)	2.31 (0.14)	2.23 (0.16)	2.18 (0.22)	2.07 (0.22)		
Pasteurization							
PT1	38.26^{ab}	37.73^{ab}	36.58^{ab}	34.64^{ab}	34.02^{ab}	11.10	36.25
PT2	35.88^{b}	34.58^{c}	34.41^{d}	33.54^{b}	33.48^{b}	6.69	34.38
PT3	38.68^{a}	37.83^{a}	36.64^{a}	34.00^{b}	33.78^{ab}	12.66	36.19
PT4	37.83^{ab}	37.69^{abc}	35.43^{abcd}	35.31^{a}	34.56^{a}	8.65	36.16
PT5	36.88^{ab}	36.60^{abc}	36.03^{abc}	34.35^{ab}	33.65^{ab}	8.75	35.50
Mean	37.51 (1.13)	36.89 (1.38)	35.82 (0.92)	34.37 (0.67)	33.9 (0.42)		

PD: per cent decrease in attribute values between first and last day of storage Values in parentheses denotes standard deviation*Sterilization treatments have non-significant effects

Table 2. Effect of thermal processing, preservative and storage on toughness of canned tender jackfruit samples

Treatment	Storage interval (days)					PD	Mean
	0	15	30	45	60		
Sterilization*							
ST1	5.93	5.39	2.98	2.42	2.19	62.98	3.78
ST2	3.51	3.48	3.43	2.44	2.29	34.66	3.03
ST3	5.08	4.89	4.19	2.8	2.73	46.28	3.94
ST4	4.77	4.44	3.86	2.19	2.01	57.82	3.45
ST5	4.09	3.95	3.04	2.44	2.15	47.43	3.13
Mean	4.67 (0.93)	4.43 (0.75)	3.5 (0.52)	2.46 (0.22)	2.27 (0.27)		
Pasteurization							
PT1	78.78^{abc}	74.99^{c}	72.96^{c}	63.47^{c}	60.80^{a}	22.82	70.2
PT2	77.07^{cd}	70.41^{e}	66.03^{d}	59.45^{d}	58.31^{bc}	24.33	66.25
PT3	76.32^{d}	74.97^{cd}	66.15^{d}	60.22^{d}	56.09^{e}	26.51	66.75
PT4	79.82^{ab}	77.45^{b}	73.93^{b}	64.79^{b}	58.07^{bcd}	27.24	70.81
PT5	80.30^{a}	79.45^{a}	75.07^{a}	65.96^{a}	59.01^{ab}	26.51	71.96
Mean	78.45 (1.72)	75.45 (3.38)	70.83 (4.39)	62.78 (2.84)	58.46 (1.7)		

PD: per cent decrease in attribute values between first and last day of storageValues in parentheses denotes standard deviation*Sterilization treatments have non-significant effects

green gram and red gram splits.

Effect on thermal processing on colour of canned tender jackfruit

Figure 1 depicts the browning index value of samples (computed using mean of *L*, *a* and *b* values) subjected to different treatments during storage period. The magnitude of browning index values of sterilized samples (overall mean=43.81) was noted to be significantly higher to that of pasteurization (overall mean=22.42). This may be attributed to excessing browning caused due to exposure of samples to high temperature in sterilization. The browning index value showed a slight increasing trend during storage in case of sterilized samples (Fig. 1a) while no specific trend was noted for pasteurized samples (Fig. 1b). The browning was found to be the highest and lowest in ST1 and ST2 respectively, irrespective of the storage period across different preservative treatments based on sterilization. Similarly, the treatments PT2 and PT3 yielded low and high browning index values among others in case of pasteurised samples. It may be noted that treatments with lowest browning (ST2 and PT2) irrespective of type of thermal process were based on KMS. The ability of KMS to inhibit browning by reducing o-quinones to diphenol or convert them to other colourless compounds (Arora et al., 2018; Marshall et al., 2000) might have resulted in reduced browning in these treatments.

The effect of thermal processing, preservative and storage on ΔE values of canned tender jackfruit samples are given in Table 3. The ΔE values varied significantly (CD = 0.142) substantially between sterilization (overall mean=23.23) and pasteurization (overall mean=5.70) samples which might be attributed to the effect of temperature of the thermal processing methods (Ali et al., 2008; Cemalettin and Mustafa, 2010; Pritty et al., 2013). During storage, ΔE value increased for all the sterilized samples and pasteurized samples with brine treatment (PT1 and PT3), although most of them were not statistically significant. Contrasting result was obtained for pasteurized samples treated with KMS, citric acid or their combination as preservative. The mean ΔE values varied from 17.26–34.41 and 4.06–6.86 ranges in case of sterilization and pasteurization respectively, across different preservative treatments. The least ΔE values during storage were noted for ST5 and PT1 treatments in case of sterilization and pasteurization respectively. Similar variation in ΔE values were also reported for carrot juices (Sims et al., 1993; Bao and Chang, 1994), tomato paste (Barreiro et al., 1997) and peach puree (Avila and Silva, 1999). The ΔE values obtained in this study were comparable to those obtained while blanching of beetroot, green pea, eggplant and green pepper (Eyarkai Nambi et al., 2016).

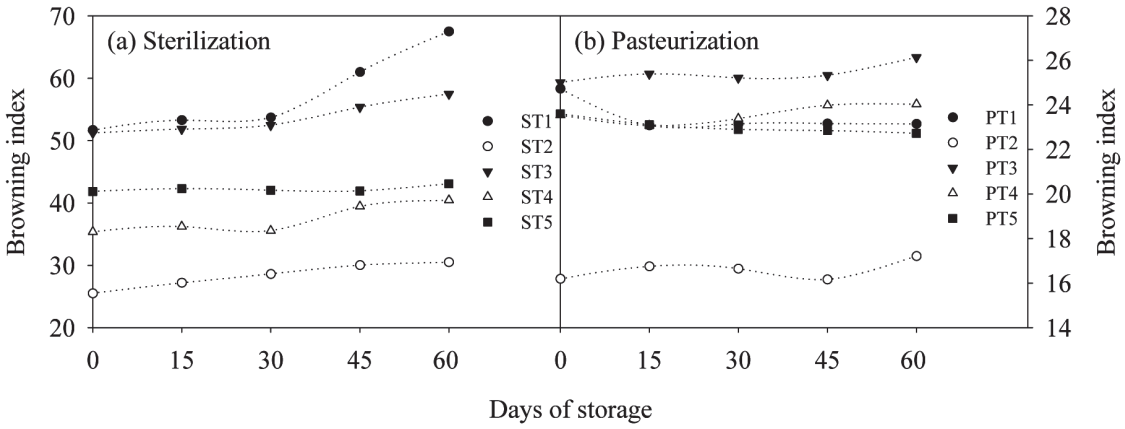

Figure 1. Browning index of thermal processed canned tender jackfruit samples during storage

Table 3. Effect of thermal processing, preservative and storage on total colour difference (ΔE) of canned tender jackfruit samples

Treatment	Storage interval (days)					PI	Mean
	0	15	30	45	60		
Sterilization							
ST1	29.65^{e}	32.73^{e}	32.06^{e}	37.33^{e}	40.30^{e}	35.92	34.41
ST2	14.09^{a}	16.92^{ab}	19.12^{b}	21.03^{b}	21.52^{b}	52.65	18.54
ST3	22.20^{d}	22.58^{d}	23.09^{d}	24.75^{cd}	26.05^{c}	17.33	23.73
ST4	19.03^{c}	19.57^{c}	21.50^{c}	24.40^{c}	26.60^{cd}	39.75	22.22
ST5	16.21^{b}	16.60^{a}	17.18^{a}	17.41^{a}	18.89^{a}	16.52	17.26
Mean	20.24 (6.08)	21.68 (6.63)	22.59 (5.76)	24.98 (7.51)	26.67 (8.26)		
Pasteurization							
PT1	2.47^{ab}	3.04^{ab}	4.04^{a}	4.60^{a}	6.12^{cd}	147.45	4.06
PT2	8.61^{e}	6.59^{c}	6.16^{c}	6.30^{c}	4.57^{a}	-46.99	6.45
PT3	8.12^{d}	7.28^{d}	7.13^{e}	6.45^{c}	5.32^{abc}	-34.51	6.86
PT4	2.20^{a}	2.48^{a}	4.86^{b}	7.77^{d}	8.57^{e}	288.88	5.18
PT5	7.13^{c}	6.66^{cd}	6.17^{d}	5.22^{b}	4.63^{ab}	-35.13	5.96
Mean	5.71 (3.12)	5.21 (2.26)	5.67 (1.22)	6.07 (1.22)	5.84 (1.65)		

PI: per cent increase in attribute values between first and last day of storage. Values in parentheses denotes standard deviation

Effect on thermal processing on ascorbic acid of canned tender jackfruit

The ascorbic acid content of both sterilized (overall mean = 6.02 mg/100 g) and pasteurized (overall mean = 6.06 mg/100 g) samples were found to be statistically on par (Table 4). A decreasing trend was noted for ascorbic acid content of apple pulp during storage (Yasser et al., 2010). This was reflected by a decrease of its mean value (irrespective of treatments) from 6.09 to 5.92 mg/100 g and 6.13 to 5.97 mg/100 g for sterilized and pasteurized tender jackfruit samples. However, the reduction was found to be insignificant during the examined storage period as a maximum of 4.64% reduction (in case of ST1) was noted across different treatments. Significant difference between treatments was observed even for those subjected to same type of thermal processing. For example, the attribute value noted for treatments ST2 and ST4 were significantly higher than other preservative treatments subjected to sterilization. Similar result was noted for PT2 and PT4 treatments in case of pasteurization. It may be noted that these treatments used KMS as preservative and its anti-oxidant property might have reduced the loss of ascorbic acid during storage (Negi and Roy, 2000;

Table 4. Effect of thermal processing, preservative and storage on ascorbic acid of canned tender jackfruit samples

Treatment	Storage interval (days)					PD	Mean
	0	15	30	45	60		
Sterilization							
ST1	5.36^{d}	5.34^{c}	5.29^{e}	5.28^{e}	5.11^{e}	4.64	5.28
ST2	6.94^{a}	6.91^{ab}	6.90^{a}	6.90^{a}	6.88^{a}	0.92	6.91
ST3	5.56^{c}	5.54^{c}	5.54^{c}	5.48^{d}	5.34^{cd}	3.85	5.49
ST4	6.94^{a}	6.93^{a}	6.89^{ab}	6.86^{abc}	6.85^{ab}	1.40	6.89
ST5	5.66^{b}	5.54^{c}	5.52^{cd}	5.48^{d}	5.41^{c}	4.45	5.52
Mean	6.09 (0.78)	6.05 (0.80)	6.03 (0.80)	6.00 (0.81)	5.92 (0.87)		
Pasteurization							
PT1	5.56^{c}	5.54^{c}	5.50^{c}	5.48^{c}	5.34^{c}	3.90	5.48
PT2	6.97^{a}	6.97^{a}	6.94^{a}	6.92^{a}	6.92^{a}	0.82	6.94
PT3	5.62^{c}	5.54^{c}	5.50^{c}	5.48^{d}	5.42^{c}	3.65	5.51
PT4	6.94^{ab}	6.92^{ab}	6.88^{ab}	6.86^{ab}	6.86^{ab}	1.17	6.89
PT5	5.56^{d}	5.54^{c}	5.54^{c}	5.48^{c}	5.34^{c}	3.85	5.49
Mean	6.13 (0.75)	6.10 (0.77)	6.07 (0.77)	6.05 (0.77)	5.97 (0.83)		

PD: per cent decrease in attribute values between first and last day of storage. Values in parentheses denotes standard deviation

Table 5. Effect of thermal processing, preservative and storage on titrable acidity of canned tender jackfruit samples

Treatment	Storage interval (days)					PD	Mean
	0	15	30	45	60		
Sterilization							
ST1	0.26	0.26	0.26[b]	0.13[b]	0.06[c]	75.00	0.19
ST2	0.26	0.26	0.26[b]	0.13[b]	0.13[b]	50.00	0.20
ST3	1.15	0.64	0.51[a]	0.32[a]	0.32[a]	72.22	0.59
ST4	0.26	0.26	0.26[b]	0.13[b]	0.13[b]	50.00	0.20
ST5	1.15	0.64	0.51[a]	0.32[a]	0.32[a]	72.22	0.59
Mean	0.61 (0.49)	0.41 (0.21)	0.36 (0.14)	0.2 (0.11)	0.19 (0.12)		
Pasteurization							
PT1	0.26	0.26	0.26[c]	0.13[b]	0.13[b]	50.00	0.20
PT2	0.26	0.26	0.26[c]	0.13[b]	0.13[b]	50.00	0.20
PT3	1.28	0.64	0.64[a]	0.38[a]	0.38[a]	70.00	0.67
PT4	0.26	0.26	0.26[c]	0.13[b]	0.13[b]	50.00	0.20
PT5	1.41	0.51	0.51[b]	0.38[a]	0.38[a]	72.73	0.64
Mean	0.69 (0.60)	0.38 (0.18)	0.38 (0.18)	0.23 (0.14)	0.23 (0.14)		

PD: per cent decrease in attribute values between first and last day of storage. Values in parentheses denotes standard deviation

Dev et al., 2006; Sra et al., 2011).

Effect on thermal processing on titrable acidity of canned tender jackfruit

The titrable acidity of canned tender jackfruit exhibited a decreasing trend after 30 days of storage (Table 5). Its mean values decreased from 0.61 to 0.19% and 0.69 to 0.23% for sterilization and pasteurization respectively. The maximum reduction in titrable acidity (75%) was noted for ST1 and minimum for ST2, ST4, PT1, PT2 and PT4 (50%) treatments. However, no much disparity existed between sterilized (overall mean=9.43%) and pasteurized (overall mean=8.69%) samples as verified by statistical analysis.

As expected, high values of titrable acidity were noted for preservative treatments with citric acid or its combination with KMS (ST3, ST5, PT3, PT5). This may be due to additional hydrogen ions in the sample contributed by citric acid. The mean values of titrable acidity did not vary much among other treatments. For treatments with citric acid or its combination with KMS, an exponential decay in titrable acidity values was noted during storage. This might have been due to the utilization of citric acid as compatibilizer during hydrolysis of polysaccharides and non-reducing sugars to hexose sugars (Dev et al., 2006; Mathias et al., 2019).

Microbiological analysis of canned tender jackfruit

The results of microbiological analyses revealed that bacteria, yeast and fungus were absent in all pasteurised and sterilised samples examined (except PT3) and hence regarded as microbiologically safe. The sample PT3 yielded a bacterial count of 20/ml after two months of storage. As this value was within the permissible limit (50/ml) prescribed by Prevention of Food Adulteration Rules, 1956 (PFA, 2002), it was also considered to be microbiologically safe. All the sterilization treatments were found to be commercially sterile as no turbidity was formed in the thioglycollate tubes inoculated with samples. We further conducted microbiological analysis of the samples used in the study about one year after thermal processing. Interestingly, these samples were also found to remain microbiologically safe.

Sensory evaluation of canned tender jackfruit

The mean rank assigned for different treatments on evaluation of organoleptic attributes namely, colour, flavour, texture and overall acceptability together with their Kendall's W are presented in Table 6. Based on the mean rank values, PT3 was regarded as an appropriate treatment with regard to colour and texture. Similarly, the treatments PT1 and PT5 were selected based on overall acceptability and

Table 6. Mean rank and Kendall's coefficient of concordance (W) of sensory evaluation

Treatment	Mean rank			
	Colour	Flavour	Texture	Overall acceptability
ST1	3.71	4.21	4.29	4.21
ST2	4.00	3.96	4.46	4.21
ST3	3.21	3.71	4.13	3.88
ST4	4.79	4.79	3.54	4.33
ST5	3.96	3.96	4.38	3.58
PT1	7.67	7.21	7.13	7.71
PT2	7.17	6.21	6.21	6.88
PT3	7.92	7.42	8.13	7.42
PT4	6.13	6.00	5.63	6.29
PT5	6.46	7.54	7.13	6.50
Test statistics				
n	12	12	12	12
Kendall's W	0.38	0.30	0.31	0.32
Chi-square	41.15	32.85	33.13	34.86
df	9	9	9	9
p-value	5×10^{-06}	1×10^{-04}	1×10^{-04}	6×10^{-05}

n: number of judges; *df*: degrees of freedom

flavour, respectively. It may be noted that all these treatments were based on pasteurization which may be related with better retention of sensory attributes when compared to that of sterilized samples. The Kendall's W varied in 0.30–0.38 range across different attributes examined. For all the sensory attributes, the low *p*-value associated with Kendall's W suggested that the null hypothesis of no concordance between judges might be rejected at 5% level of significance (α=0.05).

Thermal processing yielded microbiologically safe tender jackfruit which could be safely stored for two months as verified in this study. In most cases, the degradation of quality attributes of thermal processed tender jackfruit during storage was statistically insignificant irrespective of preservative treatment and type of thermal processing. Significant difference in the quality attribute values were noted between thermal processing types (sterilization and pasteurization). The samples subjected to pasteurization retained quality more effectively than those of sterilization. Furthermore, the pasteurized samples outperformed sterilized counterparts with regard to sensory perception. Within pasteurization, better results were noted for thermal processing at 90°C and canning with 2% brine (overall acceptability), 0.3% citric acid (colour and texture) and citric acid (0.3%) - KMS (0.1%) combination (flavour) treatments and hence their use could be advocated for thermal processing of tender jackfruit samples.

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