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Influence of pre-treatments, packaging and storage temperature on shelf life, physico-chemical and microbial quality of minimally processed tender jackfruit (*Artocarpus heterophyllus* Lam.)

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Abstract

Despite being the largest fruit in the world, huge quantities of jackfruit are wasted in almost all jackfruit-growing countries. Post-harvest handling and market gluts are some of the bottlenecks posing challenges in the value chain. Tender jackfruit is widely consumed for its culinary applications to prepare various dishes owing to the meat like texture. About 60 % of tender jackfruit is comprised of inedible portions. When minimally processed, it becomes 100 % edible, adds convenience and can be prepared and consumed in less time. The present study evaluated the impact of antioxidants ascorbic and citric acids in combination with the antimicrobial compound sodium benzoate, packaging of the product in LDPE and PP over-wrapped with cling film, followed by storage at ambient and low temperatures. The pretreatments and packaging materials effectively prolonged the shelf life of minimally processed jackfruit by up to nine days when stored at low temperatures. The protocol adopted was effective in quality maintenance in terms of PLW, ascorbic acid, total carbohydrates, total phenols and retarded proliferation of bacteria, mould and yeast. *E.coli* and *Staphylococcus aureus* could not be detected throughout the storage period.

Key words: Tender jackfruit, minimal processing, pretreatments, packaging, storage, shelf life, physico-chemical, microbial quality

Introduction

Jackfruit, a member of Moraceae family, originated in Western Ghats of India and is widely distributed across the tropics (Jagadeesh *et al.*, 2007). Among the fruits grown in Kerala, jackfruit tops the list in terms of area (91982 ha) and production (263000 tonnes), contributing to 14.01 % share in India's jackfruit production (NHB, 2022). Recognizing its significance, the Government of Kerala has designated jackfruit as the state fruit. Based on texture, fruits with firm texture and crunchy flakes are known as *varikka* and those with soft, fibrous and melting texture as *koozha* types in the State. Jackfruit is rich in dietary fiber, moderate amounts of vitamin C and protein, and is renowned for its distinctive flavor. It has the recognition of being the largest fruit in the world, can weigh between 23 and 50 kg (Ranasinghe *et al.*, 2019, Gomez *et al.*, 2024). Despite its nutritional and culinary importance, cultivation and marketing of jackfruit remain unorganized.

Marketing the whole fruit poses economic challenges, as only 30-35 % of its weight is edible. The high transportation costs limit its profitability (Azmi *et al.*, 2016). According to FAO, approximately 75 % of the jackfruit produced in India is wasted annually (Sawe, 2017). Minimally processed fruits and vegetables have found a niche area in hypermarkets owing to their ready to use or ready to cook characteristics. Minimal processing includes light processing operations such as washing, peeling, trimming, slicing, pre-treatment *etc.* and the identity of such items remains intact unlike their conventionally processed counterparts. The inedible portions of these raw materials can be removed in the field itself and thereby environmental pollution in urban areas can be reduced. Ultimately, consumers get a cent per cent edible, convenient, and ready to eat or ready to cook food that can be prepared and consumed in less time.

Minimal processing disrupts delicate tissues, triggers the enzymatic activities that promote browning reaction, degradation of nutrients and accelerate the physiological processes (Saxena *et al.*, 2009). Advanced techniques for extending the shelf life of fresh cut products include pretreatments with natural compounds, innovative packaging, and edible coating. Key challenges in minimally processed jackfruit can be mitigated using anti-browning agents like ascorbic acid and honey (Hussain *et al.*, 2023) and citric acid (Ekanayaka *et al.*., 2015).

Tender jackfruit is widely consumed as various dishes. The hard rind and core are the inedible portions of tender jackfruit. Therefore, when tender jackfruit is subjected to minimal processing, it becomes 100 % edible. Tender jackfruit has the texture similar to that of meat, thus providing an alternative food item to completely vegan consumers. The present study aims to evaluate the impact of pretreatments, packaging materials and storage temperature on the shelf life and quality of minimally processed tender jackfruit.

Materials and methods

Raw material: Inflorescence of jackfruit trees of cultivar 'Muttom Varikka' was tagged immediately after anthesis. Tender jackfruit of about 45 days maturity were harvested and transported to the laboratory of the Department of Postharvest Management in plastic crates.

Preparation of minimally processed tender jackfruit: Tender jackfruits were surface sanitized with 100 ppm chlorine solution followed by peeling the hard rind with a sharp knife. The peeled fruits were subsequently halved longitudinally to remove the hard leathery core and chopped into smaller cubes (3-4 cm^3) and rinsed in warm water (50±2 °C) for 5 minutes, followed by pretreatments: one set was immersed in citric acid solution (0.5 %) in combination with sodium benzoate (0.05 %), while another set was treated in ascorbic acid (0.5 %) combined with sodium benzoate (0.05 %) for 15 minutes. After the pretreatments, the cubes were laid out on perforated stainless steel trays to drain off excess water. Approximately 250 g each of the samples, were packed in two packaging materials *viz*, LDPE bags (200 gauge) and polypropylene trays over -wrapped with polyolefin film of 25 µ thickness, after removing excess surface moisture (Fig. 1). The packaged samples were then stored at ambient (32 ± 2 ^{0}C) and low temperature (5-7 °C). Whole tender jackfruits as such served as control samples. Each experiment was conducted in triplicate. The various treatments are outlined as follows:

Treatments: Following are the details: T_1-Whole tender jackfruit stored at ambient temperature (AT); T_2- Whole tender jackfruit stored at low temperature (LT); T_3-CA+ Tender jackfruit slices+PP+AT; T_4-CA+ Tender jackfruit slices +LDPE+AT; T_5-CA+ Tender jackfruit slices +PP+LT; T_6-CA+ Tender jackfruit slices +LDPE+LT; T_7- AA+ Tender jackfruit slices +PP+AT; T_8-AA+ Tender jackfruit slices +LDPE+AT; T_9-AA+ Tender jackfruit slices +PP+LT; T_{10}-AA+ Tender jackfruit slices +LDPE+LT

Where, CA-Citric acid (0.5 %) + Sodium benzoate (0.05 %), AA- Ascorbic acid (0.5 %) + Sodium benzoate (0.05 %), PP- Polypropylene trays over -wrapped with polyolefin film and LDPE- Low density polyethylene cover

Determination of shelf life: The shelf life was calculated as number of days taking into consideration appearance, microbial load and weight loss (Moradinezhad *et al.*, 2021).

Recovery percentage: Recovery percentage is obtained by calculating the percent ratio of weight in grams of fruits after peeling rind along with the core to the weight in grams of whole fruit.

Recovery (%)= [(Weight of fruit after peeling and removal of core/ Weight of whole fruit) x 100]

Physiological loss in weight: Physiological loss in weight of tender jackfruit samples were investigated and calculated by the method described by Kumar *et al.* (2021) as per the formula:

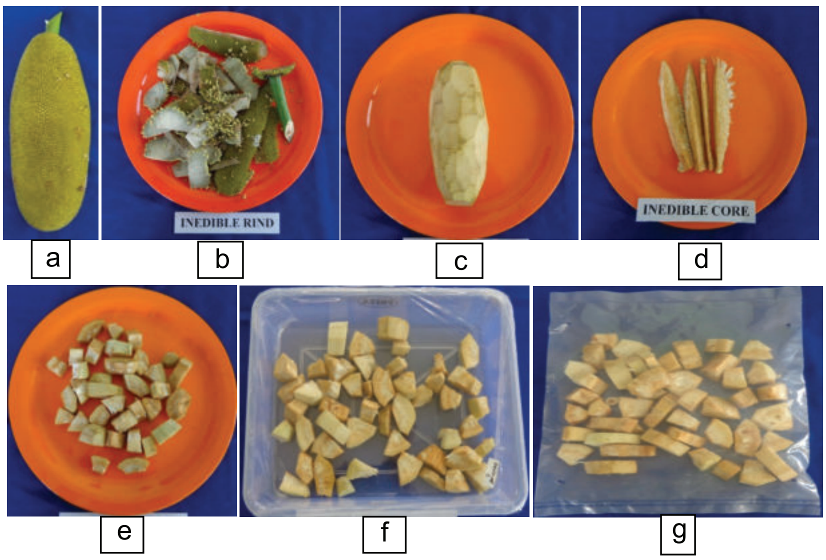

Fig.1.Minimal processing of tender jackfruit a) Tender jackfruit, b) Inedible rind, c) Peeled tender jackfruit, d) Inedible core, e) Minimally processed tender jackfruit, f) Tender jackfruit slices packed in PP trays over-wrapped with polyolefin film and g) Tender jackfruit slices packed in LDPE pouch

PLW (%)= [(Initial weight- Final weight)/ Initial weight] x 100

Titratable acidity: Titratable acidity was estimated by titrating known amount of aliquot with 0.1 N sodium hydroxide, using phenolphthalein as an indicator and expressed in percentage (Manzoor *et al.*, 2021).

Ascorbic acid: Ascorbic acid content was determined by using the 2, 6-dichlorophenol indophenol dye titration assay as described by Xing *et al.* (2011). Samples (5 g) were ground with 4 % oxalic acid, followed by centrifuging at 10,000×g for 15 min. 5 mL supernatant was titrated with standard 2, 6-dichlorophenol indophenol.

Total phenols: The TPC of tender jackfruit were determined using Folin-ciocalteu and 20 % sodium carbonate (Asami *et al.*, 2003). Total phenol content was calculated from the standard curve and expressed as milligram per 100g (The absorbance was measured at 650 nm using a UV-visible spectrophotometer (Shimadzu, 1800-series, Japan). Standard curve was prepared using different concentrations of gallic acid.

Total carbohydrate content: Anthrone method was used for determining carbohydrate content of tender jackfruit (Ranganna, 1997). 100 mg of sample was digested for 3 hours with 5 mL of 2.5 N HCl and cooled to room temperature. After neutralizing the solution with sodium carbonate, the sample was filtered and volume was made up to 100 mL with distilled water and centrifuged. 4 mL ice-cold anthrone reagent was added to 1 mL of the sample. The absorbance of the sample was read at 630 nm.

Microbial load: Estimation of microbial population was done by serial dilution plate count method as described by Moradinezhad *et al.* (2021). 10 g of sample was added to 90 mL distilled water to form a suspension. From this suspension, subsequent dilutions of 10^{-1}, 10^{-2}, 10^{-3} and 10^{-6} were prepared.

Estimation of fungal, yeast, bacterial population, *E. coli* and *Staphylococcus aureus*: About 20 mL of melted and cooled potato dextrose agar (PDA) media was poured to the petridish containing 1 mL of sample and was swirled. The yeast population was estimated using Sabouroud dextrose agar medium, fungi in Martin Rose Bengal agar medium, *E.coli* in Bromocreso Purple (BCP) lactose broth and *Staphylococcus aureus* in Mannitol Salt Agar (MSA) medium. The samples were incubated at room temperature for 4-5 days. The bacterial, fungal and yeast colonies were counted and expressed as CFU/g.

Statistical analysis: The entire experiment was laid out in a Completely Randomized Design with ten treatments and three replications. The experiment was conducted twice. The data were analyzed to test the significance of difference between the treatments through Analysis of Variance using the Web Based Agricultural Statistics Software Package (WASP) with a level of significance of p-value less than 0.05 to be statistically significant.

Results and discussion

Recovery of edible portion: Proportion of edible and inedible portions of tender jackfruit revealed that the edible portion constituted 40 % of total fruit weight, while the rind and core accounted for 47.82 % and 13.04 % respectively (Fig. 2). Consequently, total inedible portion was 60.06 %. The findings of the present study is in consonance with those reported by other researchers with slight variation. Ibrahim *et al.* (2013) reported that tender jack fruit contains 47 % edible and 53 % inedible portions. This variability in the proportion of edible and inedible fractions could be attributed to differences in fruit maturity, variety and growing conditions which influence the structural composition of the fruit. Tender jackfruit typically contains a higher proportion of edible portion compared to its ripe counterpart (Ulloa *et al.*, 2017).

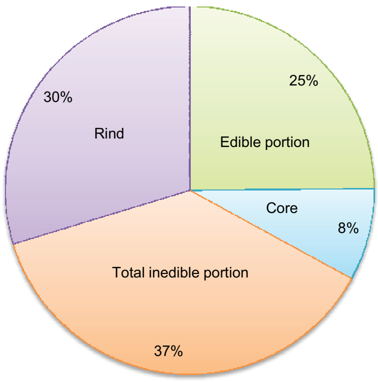

Fig. 2. Proportion of edible and inedible portions of tender jackfruit

Physiological loss in weight: The physiological loss in weight (PLW) of fresh-cut fruits is predominantly driven by transpiration and respiratory activity as a result of exposing more surface area. In present study, the PLW of all the treatments increased during storage (Table 1 and Fig. 3). Control samples stored at low temperature recorded PLW of 27.85 % on 8th DAS whereas those stored at ambient temperature showed PLW of 16.90 % on 5th DAS. Jackfruit requires an optimum temperature of 12 to 13 ^{0}C, when stored at a temperature of 5 to 7^{0}C, resulted in rapid weight loss. Significantly lower PLW (1.43 %) was observed in the samples pretreated with ascorbic acid in combination with sodium benzoate and packed in polypropylene trays over-wrapped with polyolefin film and subsequently held at low temperature (T9), followed by the samples treated with citric acid and sodium benzoate and packed in LDPE (T5) at low temperature (2.32 %), whereas T6 (citric acid in combination with sodium benzoate packed in LDPE under ambient storage) recorded the highest PLW (12.10 %) on 9th DAS. Lowest PLW in T9 may be due to modified atmosphere and low temperature storage that reduced the O_2 concentration and increased CO_2 levels inside the package. PP packages exhibited lower water vapour and gas transmission rates than LDPE (Wani *et al.*, 2015). Bhatia *et al.* (2013) reported similar findings in pomegranate arils packed in polypropylene and Alam *et al.* (2013) in papaya. The favourable effects could be due to pretreatment with ascorbic and citric acids, which inhibited the enzymatic browning, thereby disrupting the oxidative phosphorylation pathway. This lowers the respiration rate, subsequently reducing moisture loss during storage (Hussain *et al.*, 2023).

Titratable acidity: A decreasing trend in titratable acidity was noticed across all treatments throughout the storage period (Table 2) without significant variation. By the end of the storage period, the highest titratable acidity (0.633 %) was observed in samples treated with ascorbic acid and sodium benzoate, packed in polypropylene trays over-wrapped with polyolefin film at low temperature (T10) and those treated with citric acid and sodium benzoate packed in LDPE at low temperature (T6), while the lowest (0.627) was in whole tender fruits (control) under ambient storage (T1) and the slices treated with citric acid and sodium benzoate packed in LDPE, kept at low temperature (T5). Organic acids are metabolized faster than complex compounds during respiration. In the current study, prereatments, packaging materials and storage temperature did not have any significant effect on titratable acidity. These findings align with those of Wu *et al.* (2012), in fresh cut apples. However, Boodia *et al.* (2009) reported that the titratable acidity of fresh-cut green jackfruit increased during storage when treated with citric and ascorbic acids.

Ascorbic acid: A downward trend in ascorbic acid content was noticed in all the samples during storage (Table 3). Ascorbic acid content drastically reduced in samples stored under ambient condition than low temperature, irrespective of packaging material and pretreatments. At the end of 9th day, significantly higher ascorbic acid content (4.790 mg/100 g) was recorded in

Table 1. Physiological loss in weight (%) of whole and minimally processed tender jackfruit during storage

Treatments		Storage period							
		2nd day	3rd day	4th day	5th day	6th day	7th day	8th day	9th day
WTJ+AT	T_1	4.663^b	9.033^b	13.533^b	16.900^{b*}	-	-	-	-
WTJ+LT	T_2	12.400^a	14.233^a	17.200^a	19.500^a	21.413^a	25.566^a	27.856^{a*}	-
CA+ TJS+PP+AT	T_3	2.393^c	5.233^c	6.500^d	7.433^{d*}	-	-	-	-
CA+ TJS +LDPE+AT	T_4	0.143^g	1.843^f	3.620^f	5.303^{e*}	-	-	-	-
CA+ TJS +PP+LT	T_5	0.496^e	0.900^h	0.966^h	1.066^g	1.866^d	1.963^d	2.158^d	2.323^c
CA+ TJS +LDPE+LT	T_6	2.373^c	4.780^d	7.000^c	7.673^c	8.033^b	10.300^b	11.766^b	12.100^a
AA+ TJS +PP+AT	T_7	0.146^g	0.550^i	0.660^{i*}	-	-	-	-	-
AA+ TJS +LDPE+AT	T_8	1.906^d	3.843^e	5.463^{e*}	-	-	-	-	-
AA+ TJS +PP+LT	T_9	0.120^g	1.333^g	0.508^j	0.589^h	0.723^e	0.870^e	0.930^e	1.433^d
AA+ TJS +LDPE+LT	T_{10}	0.383^f	1.672^f	2.800^g	4.766^f	5.270^c	6.796^c	6.953^c	7.176^b
CD at 5%		0.104	0.185	0.136	0.097	0.152	0.122	0.073	0.164

*Unmarketable, WTJ- Whole tender jackfruit, TJS- Tender jackfruit slices, AT-Ambient temperature, LT-Low temperature, PP –Polypropylene trays over-wrapped with polyolefin film, LDPE- Low density polyethylene cover, CA-citric acid (0.5 %) + Sodium benzoate (0.05 %), AA-Ascorbic acid (0.5 %) +Sodium benzoate. Different small letters within every column represent statistically significant differences ($P<0.05$).

Table 2. Titratable acidity (%) of whole and minimally processed tender jackfruit during storage

Treatments		Storage period			
		Initial	3rd day	6th day	9th day
WTJ+AT	T_1	0.787	0.631	0.633	0.627
WTJ+LT	T_2	0.800	0.643	0.637	0.631
CA+ TJS+ PP+AT	T_3	0.785	0.637*	-	-
CA+ TJS+LDPE+AT	T_4	0.797	0.637*	-	-
CA+ TJS+PP+LT	T_5	0.797	0.640	0.633	0.627
CA+ TJS+LDPE+LT	T_6	0.800	0.638	0.633	0.633
AA+ TJS+PP+AT	T_7	0.800	0.635*	-	-
AA+ TJS +LDPE+AT	T_8	0.797	0.637*	-	-
AA+ TJS+PP+LT	T_9	0.800	0.637	0.637	0.630
AA+ TJS+LDPE+LT	T_{10}	0.790	0.623	0.640	0.633

Treatment details are given under Table 1.

the samples treated with ascorbic acid and sodium benzoate, packed in LDPE and stored at low temperature (T10) which was on par with the samples (4.707 mg/100 g), that received the same pretreatments but packed in polypropylene trays held at low temperature (T9). Lowest ascorbic acid content (2.900 mg/100 g) was recorded in the whole fruits (control) stored at low temperature (T2). The degradation in ascorbic acid was likely due to the conversion of L-ascorbic acid to dehydro- ascorbic acid, catalyzed by enzyme ascorbic acid dehydrogenase. Similar findings were reported in pineapple (Danyen *et al.,* 2011) and pomegranate arils (Naik *et al.,* 2017). Citric acid acts as a strong chelating agent that binds copper and iron which catalyzes the oxidation of ascorbic acid. PP was more effective in retaining ascorbic acid than LDPE. PP has lower oxygen permeability (1,500 cc/m^2/mL/day at 1 atm) compared to LDPE (3,000 cc/m^2/mL/day at 1 atm).

Table 3. Ascorbic acid (mg/ 100 g) content of whole and minimally processed tender jackfruit during storage

Treatments		Storage period			
		Initial	3rd day	6th day	9th day
WTJ+AT	T_1	7.967	7.670^{ab}	5.033^{b}	3.803^{d}
WTJ+LT	T_2	8.003	7.682^{a}	3.033^{e}	2.900^{f}
CA+ TJS+ PP+AT	T_3	8.000	3.500^{g}*	-	-
CA+ TJS+LDPE+AT	T_4	8.077	3.500^{g}*	-	-
CA+ TJS+PP+LT	T_5	7.983	7.694^{a}	4.133^{d}	3.783^{de}
CA+ TJS+LDPE+LT	T_6	7.860	7.654^{abc}	6.004^{a}	4.650^{bc}
AA+ TJS+PP+AT	T_7	8.067	4.863^{f}*	-	-
AA+ TJS +LDPE+AT	T_8	8.033	4.839^{f}*	-	-
AA+ TJS+PP+LT	T_9	8.000	5.341^{e}	4.937^{bc}	4.707^{ab}
AA+ TJS+LDPE+LT	T_{10}	8.040	6.492^{d}	5.005^{bc}	4.790^{a}
SEM ±		0.003	0.01	0.01	0.01

Treatment details are given under Table 1. Different small letters within every column represent statistically significant differences ($P<0.05$).

Total phenols: The total phenol content exhibited a progressive decline throughout the storage period irrespective of pre-treatments, packaging material and storage temperature (Table 4). Retention of total phenols was significantly higher (0.582 mg/g) in the sample treated with ascorbic acid and sodium benzoate packed in polypropylene trays over-wrapped with polyolefin film at low temperature (T9) followed by (0.558 mg/g) the whole fruit stored at low temperature (T2) on 9th day of storage. The samples stored under ambient condition retained lower phenol content. The decline in total phenol content was likely due to the minimal processing operations, such as peeling and cutting, which activated the polyphenol oxidase enzyme resulting in exposing more surface area of the samples to oxygen leading to the degradation of functional compounds (Leon *et al.*, 2015). Intact tender jackfruit (treatments T_1 and T_2) retained higher phenolic content compared to minimally processed samples. Phenolic compounds are present in the vacuoles of the fruit cells, separated from the PPO enzyme present in plastids. Minimal processing damages vacuoles resulting in interaction with PPO, which causes hydroxylation of monophenols to o-diphenols and the oxidation of o-diphenols to o- quinones and further to melanin, leading to browning reaction (Cantos *et al.*, 2002). Low temperature reduces enzymatic activity (Li *et al.*, 2017). Additionally, PP packaging serves as an effective barrier to oxygen and moisture, further retarding the oxidative reactions (Nath *et al.*, 2012). Similar results were also reported by Shrestha *et al.* (2020) in fresh cut apple slices.

Table 4. Total phenols (mg/g) of whole and minimally processed tender jackfruit during storage

Treatments		Storage period			
		Initial	3rd day	6th day	9th day
WTJ- +AT	T_1	0.751	0.764^{b}	0.451^{d}	0.400^{d}
WTJ+LT	T_2	0.754	0.811^{a}	0.590^{c}	0.558^{b}
CA+ TJS+ PP+AT	T_3	0.751	0.292^{j*}	-	-
CA+ TJS+LDPE+AT	T_4	0.754	0.319^{i*}	-	-
CA+ TJS+PP+LT	T_5	0.752	0.400^{h}	0.251^{f}	0.241^{f}
CA+ TJS+LDPE+LT	T_6	0.754	0.497^{g}	0.405^{e}	0.377^{e}
AA+ TJS+PP+AT	T_7	0.754	0.587^{f*}	-	-
AA+ TJS +LDPE+AT	T_8	0.754	0.661^{de*}	-	-
AA+ TJS+PP+LT	T_9	0.754	0.668^{d}	0.660^{b}	0.582^{a}
AA+ TJS+LDPE+LT	T_{10}	0.754	0.728^{c}	0.680^{a}	0.417^{c}
CD at 5%			0.010	0.001	0.005

Treatment details are given under Table 1. Different small letters within every column represent statistically significant differences ($P<0.05$)

Total carbohydrate: Jackfruit is a rich source of carbohydrate and tender jackfruit is abundant in starch, a polysaccharide. Carbohydrates of the tender jackfruit fell throughout the storage period (Table 5). At the end of storage period, carbohydrate content was significantly higher (7.370 mg/g) in the whole tender jackfruit held at low temperature. Minimal processing induced faster respiration and transpiration that may have reduced the carbohydrate content in tender jackfruit slices as compared to intact fruits. Among the minimally processed samples, significantly higher carbohydrate content (6.570 mg/g) was found in samples treated with ascorbic acid and sodium benzoate, packed in polypropylene trays over-wrapped with polyolefin film and stored at low temperature (T9) followed by (T10) that received the same pretreatments but packed in LDPE and stored at low temperature (5.337 mg/g). The highest retention of carbohydrate (6.570 mg/g) in T9 and T10 might be due to the pretreatment of ascorbic acid coupled with packaging in polypropylene and low temperature storage that reduced metabolic activities due to atmospheric modification of gases within the package. Similar findings were reported in mango slices (Chauhan *et al.*, 2006). Ascorbic acid neutralizes the free radicals, preventing damage to the cell structure, and inhibits the breakdown of carbohydrate (Fan *et al.*, 2023).

Total plate count: The microbial population of the minimally processed tender jackfruit increased during storage (Table 6). Towards the end of storage, bacterial population was lowest (7x10^5 CFU/g) in the samples treated with ascorbic acid and sodium benzoate, packed in polypropylene trays over-wrapped

Table 5. Total carbohydrate (mg/g) content of whole and minimally processed tender jackfruit during storage

Treatments		Storage period			
		Initial	3rd day	6th day	9th day
WTJ+AT	T_1	12.537	6.557^{h}	6.170^{d}	4.577^{f}
WTJ+LT	T_2	12.523	11.537^{a}	8.907^{ab}	7.370^{a}
CA+ TJS+ PP+AT	T_3	12.523	6.100^{i*}	-	-
CA+ TJS+LDPE+AT	T_4	12.523	6.043^{j*}	-	-
CA+ TJS+PP+LT	T_5	12.527	8.523^{e}	8.137^{c}	4.977^{e}
CA+ TJS+LDPE+LT	T_6	12.523	9.663^{b}	5.090^{e}	5.317^{d}
AA+ TJS+PP+AT	T_7	12.537	8.917^{c*}	-	-
AA+ TJS +LDPE+AT	T_8	12.537	7.823^{f*}	-	-
AA+ TJS+PP+LT	T_9	12.523	8.913^{cd}	8.917^{a}	6.570^{b}
AA+ TJS+LDPE+LT	T_{10}	12.533	7.443^{g}	4.440^{f}	5.337^{c}
CD at 5%		0.000	0.103	0.019	0.017

Treatment details are given under Table 1. Different small letters within every column represent statistically significant differences (P<0.05).

with cling film (T9). No fungal growth was detected in T9 as well while whole fruits (control) under ambient conditions had the highest bacterial, fungal and yeast load which were 75 $x10^5$, $21.33x10^3$, and 82.66x 10^3 CFU/g, respectively. Pretreatments with ascorbic and citric acids reduced the pH thereby limiting growth of microbes. Increase in microbial count was recorded during storage of freshly cut papaya (Gonzalez-Aguilar *et al.*, 2009). In the present study, sodium benzoate along with citric and ascorbic acids effectively inhibited the microbial growth by lowering the intracellular pH of microorganisms, disrupting their metabolism. Similar findings were also reported by Nath *et al.* (2012) in pear slices and Hussain *et al.* (2023) in fresh cut jackfruit**.** *E.coli* and *Staphylococcus aureus* could not be detected in any of the samples throughout the storage period.

Shelf life: The shelf life of tender jackfruit slices was significantly influenced by pretreatments, packaging and storage conditions. Minimally processed tender jackfruit slices treated with citric and ascorbic acids separately, in combination with sodium benzoate and packed in both polypropylene trays over-wrapped with polyolefin film and LDPE pouches, stored at low temperature (T5, T6, T9 and T10) recorded the longest shelf life of nine days (Fig. 3). Tender jackfruit (intact fruits) had a shelf life of 5 days under both ambient and low temperature storage. Lowest shelf life of three days was recorded in minimally processed slices held under ambient conditions. The low temperature storage combined with pretreatments and packaging in LDPE and PP mitigated adverse changes of minimal processing (Latifah *et al.*, 2000). Gorny *et al.* (2002), reported that ascorbic acid extended the shelf life of pear slices.

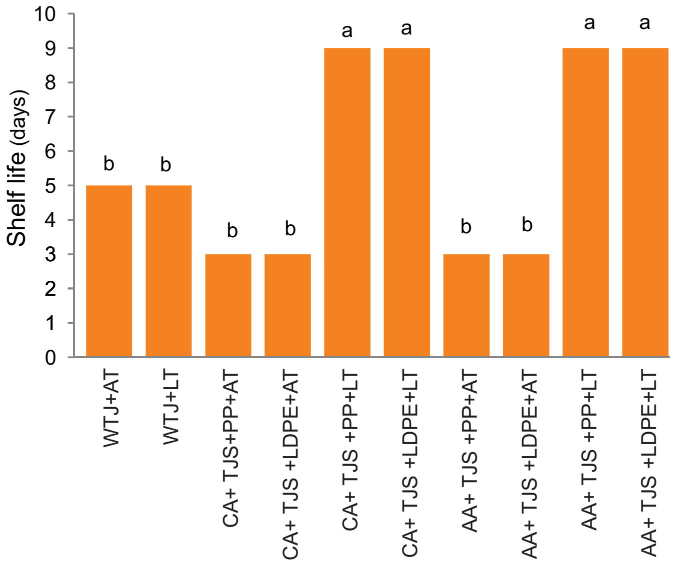

Fig. 3. Shelf life of whole and minimally processed tender jackfruit during storage. Abbreviations are given below Table 1. Different small letters within every column represent statistically significant differences (P<0.05).

The study shows that low-temperature storage and suitable packaging together with pretreatment with ascorbic acid and sodium benzoate help to greatly maintain the quality and increase the shelf life of tender jackfruit. Forty percent of the fruit's weight came from the edible section; sixty percent came from the inedible sections. Low temperature storage with polypropylene packaging showed the lowest physiological loss in weight (PLW) and the best retention of nutrients including ascorbic acid, total phenols, and carbohydrates. These results underline the need of ideal storage conditions in preserving the quality and increasing the shelf life of tender jackfruit.

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Table 6. Microbial population (CFU/g) of whole and minimally processed tender jackfruit during storage

Treatments		Bacterial load in NA ($X10^5$)			Fungal load in MRBA ($X10^3$)			Yeast load in SDA ($X10^3$)		
		Initial	3rd day	9th day	Initial	3rd day	9th day	Initial	3rd day	9th day
WTJ+AT	T_1	3.666^{bc}	35.000^{c}	75.000^{a}	0.000^{b}	9.000^{b}	21.333^{a}	0.000^{d}	24.000^{c}	82.666^{a}
WTJ+LT	T_2	6.333^{b}	13.666^{f}	33.333^{d}	0.000^{b}	3.666^{c}	12.000^{b}	0.000^{d}	0.000^{g}	0.000^{e}
CA+ TJS+ PP+AT	T_3	1.666^{cd}	75.000^{b*}	-	0.000^{b}	0.000^{d}	0.000^{d}	2.000^{c}	9.000^{d*}	-
CA+ TJS+LDPE+AT	T_4	6.333^{b}	33.333^{c*}	-	1.333^{b}	8.666^{b*}	-	0.000^{d}	4.000^{ef*}	-
CA+ TJS+PP+LT	T_5	0.000^{d}	1.666^{g}	7.000^{e}	0.000^{b}	0.000^{d}	3.333^{c}	0.000^{d}	1.333^{fg}	7.000^{d}
CA+ TJS+LDPE+LT	T_6	1.666^{cd}	21.333^{e}	45.333^{c}	0.000^{b}	0.000^{d}	3.333^{c}	0.000^{d}	6.000^{de}	30.666^{c}
AA+ TJS+PP+AT	T_7	43.333^{a}	85.333^{a*}	-	9.000^{a}	20.333^{a*}	-	26.333^{a}	66.000^{a*}	-
AA+ TJS +LDPE+AT	T_8	6.333^{b}	21.666^{e*}	-	0.000^{b}	0.000^{d*}	-	0.000^{d}	5.000^{ef*}	-
AA+ TJS+PP+LT	T_9	0.000^{d}	0.000^{g}	9.000^{e}	0.000^{b}	0.000^{d}	0.000^{d}	0.000^{d}	0.000^{g}	2.666^{e}
AA+ TJS+LDPE+LT	T_{10}	2.333^{cd}	26.333^{d}	52.666^{b}	0.000^{b}	3.000^{c}	19.000^{a}	7.666^{b}	32.000^{b}	73.000^{b}
± SEM		1.043	1.346	1.312	0.459	0.931	0.816	0.596	1.295	1.178
CD at 5%		3.073	3.971	4.040	1.354	2.743	2.478	1.750	3.821	3.636

Treatment details are given under Table 1. Different small letters within every column represent statistically significant differences (P<0.05).

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