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Phytochemical changes in fresh-cut jackfruit (*Artocarpus heterophyllus* L.) bulbs during modified atmosphere storage

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ABSTRACT

A minimal process was carried out for pitted jackfruit (*Artocarpus heterophyllus* L.) bulbs using additives $CaCl_2$, ascorbic acid (AA), and sodium benzoate in combination with mild acidified conditions for storage under modified atmosphere (MA), i.e., 3 kPa O_2 + 5 kPa CO_2, gas mixture flushed polyethylene (GFPE) bags, polyethylene terephthalate jars with silicon membrane on lid and polyethylene bag with air. Samples devoid of any additive based pretreatment but packaged in similar MA conditions were used as experimental control. A restricted loss of around 7%, 8%, 43%, and 31% was found for total phenolics (TP), total flavonoids (TF), total carotenoids (TC), and AA contents respectively in the pretreated samples kept under GFPE bags towards the end of 35 days storage at 6 °C. Among the phytochemicals evaluated, the radical-scavenging activity showed the highest correlation ($r = 0.979$) with AA followed by TP, TF and TC.

1. Introduction

Jackfruit (*Artocarpus heterophyllus* L.) is an exotic fruit grown in tropical climates. The fruit is a large composite with an average weight of 10 kg per unit. The yellowish bulbs constituting the perianth portion of the fruit are fleshy, fibrous, and rich in sugars as well as carotenoids. Each bulb has a single seed, which is edible after roasting. Rahman, Nahar, Jabbar, and Mosihuzzaman (1999) described the fruit as a rich source of carbohydrates, minerals, carboxylic acids, dietary fibre, and vitamins such as ascorbic acid (AA), and thiamine. The various parts of the jackfruit tree have also been reported as an ingredient in the preparations of different *Ayurvedic* and *Yunani* medicines (Mukherjee, 1993).

Use of fruits and vegetables as a source of certain phytochemicals, such as AA, carotenoids, phenolics, and flavonoids have health-promoting effects, since these compounds act as natural antioxidants. Natural antioxidants are widely reported to restrict oxidation-induced degenerative changes in cell physiology and ageing (Willett, 2002). Phenolics and their metabolites are common constituents of fruits and vegetables, and have a vital role against pathogenicity, infestation, and photo-oxidation (Scalbert, Johnson, & Saltmarsh, 2005). These compounds inactivate free radicals generated by lipid peroxidation, rendering anti-oxidative effects (Pokorny, 2001). Phenolics also play an important role as aroma constituents and provide astringency to food products. Flavonoids usually occur as glycosides and aglycones in plant tissue. The anti-oxidative function of flavonoids is due to their unsaturation in chemical bonding. Flavonoids are easily oxidised to quinones and have the tendency to function as a free radical scavenger (Kaur & Kapoor, 2001). Flavonoids are also responsible for rendering colour in different fruits and vegetables, as anthocyanins and related compounds. They are known to possess anti-microbial and insect repellent properties as well (Iwashina, 2003). AA is another phytochemical, having multiple functionalities including vitamin C activity and the ability to scavenge free radicals as well as reactive oxygen species (ROS). AA is often used as an absorbent for molecular oxygen and ROS. In fruits and vegetable processing, supplementation of AA in processed products minimises oxidative deterioration. Exogenous application of AA is well established in minimally-processed fresh-cut fruits and vegetables, to restrict enzymatic browning and oxidation-susceptible degenerative changes, involving deterioration of carotenoids, phenolics, and flavonoids (Biacs, Czinkotai, & Hoschke, 1992). Carotenoids, such as β-carotene, lycopene, lutein, and zeaxanthin, are known to exhibit antioxidant activity.

Pre-cutting of fruits and vegetables increases oxidative stress and they tend to lose keeping quality, not only in terms of microbial contamination, excessive softening, and browning, but also in terms of significant depletion of phytochemicals, such as phenolics, flavonoids, AA, and carotenoids. Infusion of additives during minimal processing has been described, to minimise these deteriorative changes in fresh-cut fruits and vegetables (Raju & Bawa, 2006). Modified atmosphere packaging (MAP) techniques in terms of

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low O_2 and high CO_2 levels, have also been proven to be beneficial in maintaining the quality of various fresh-cut fruits and vegetables (Alasalvar, Al-Farsi, Quantick, Shahidi, & Wiktorowicz, 2005; Oms-Oliu Odriozola-Serrano, Soliva-Fortuny, & Martin-Belloso, 2008).

In a previous study, Saxena, Bawa, and Raju (2008) reported that synergistic effect of anti-browning and anti-microbial compounds with reduced O_2 and elevated CO_2 atmosphere could enhance the keeping quality of fresh-cut jackfruit bulbs by minimising deteriorative changes in physiological, sensorial, and microbial attributes. Saxena, Bawa, and Raju (2009) have also reported on the stabilisation of high moisture jackfruit slices by a multitarget preservation technique. However, the status of phytochemicals in response to minimal processing in synergy with modified atmosphere (MA) conditions needs to be investigated with respect to retention of anti-oxidative phytochemicals. This study aims at understanding the role of minimal processing in combination with MAP in retention of natural antioxidants.

2. Materials and methods

2.1. Chemicals

Gallic acid, catechin, and α,α-diphenyl-β-picrylhydrazyl (DPPH) were procured from Sigma–Aldrich Chemical Co. Ltd. (St. Louis, MO). Folin–Ciocalteu reagent and 2,6-dichlorophenolindophenol were purchased from Qualigens, Mumbai, India, whilst the other chemicals and solvents used in the study were from S.D. Fine Chemicals Ltd., Mumbai, India.

2.2. Plant material

Jackfruits (*firm variety*) with brownish-yellow skin colour at the optimum ripening stage and without any physical blemishes or malformations were procured from the local market at Mysore, India. The maturity of the fruits was ensured by selecting the fruits with wider gaps between the spiny portions of outer barky layer. Initially 200 kg of jackfruit with an average weight of 8–10 kg per piece were sorted out and surface sanitised with 100 ppm chlorinated water. Manual cutting along the axis using sharp-edged stainless steel (SS) knives opened the fruits and the edible bulbs were removed from the rind. The yield of the pitted bulbs was found to be 35%. The bulbs were manually sliced using SS knives.

2.3. Pretreatments and modified atmosphere packaging

Half of the fruits were given a secondary phytosanitation wash in chilled chlorinated water (30 ppm) for 5 min. Theses surface sanitised jackfruit slices were subjected to a dip pretreatment in a solution containing $CaCl_2$ (1% w/v), ascorbic acid (0.02% w/v), citric acid (1% w/v), and sodium benzoate (0.045% w/v), for 30 min with fruit:solution ratio of 1:2. The remaining untreated slices were washed with distilled water and used as experimental control. The pretreated as well as untreated lots were drained using SS wire mesh trays for subsequent modified atmosphere packaging (MAP). The pretreated and untreated samples were subjected to three different MAP conditions as illustrated in our earlier work (Saxena et al., 2008):

(1) 3 kPa O_2 + 5 kPa CO_2 (balance of N_2) gas mixture flushed polyethylene (GFPE) bags (25 μm thickness, 12 cm length × 10 cm width, 400 cm^3 volume); (2) PET jars equipped with a silicon membrane (SM) window on the lid, 500 ml, diffusion area 4.5 cm^2; and (3) PE bags as such used in (1).

The pretreated and untreated samples stored under three different types of MA conditions were stored at 6 °C in a BOD incubator (Industrial and Laboratory Tools Corporation, Chennai, India) and various phytochemicals were analysed periodically. The experiment was repeated three times, using a completely randomised design. The results of each analysis were expressed as the means of three replications.

2.4. Total phenolics

Total phenolics (TP) contents in the methanol extracts were estimated colorimetrically using Folin–Ciocalteu (FC) reagent, as described by Singleton and Rossi (1965) and expressed as mg gallic acid equivalents per 100 g of fresh mass. Briefly, 5 g of sample were extracted with 50 ml methanol. One millilitre of this extract was mixed with 9 ml of distilled H_2O in a 25 ml volumetric flask, 1 ml of FC reagent was added and shaken. After six minutes, 10 ml of Na_2CO_3 (7%) were added and the volume made up to 25 ml with distilled H_2O. After incubation at room temperature for 90 min, the absorbance of the reaction mixture was measured at 750 nm against a reagent blank using a UV–visible spectrophotometer (Shimadzu-1609, Tokyo, Japan).

2.5. Total flavonoids

Total flavonoids (TF) were determined according to the method of Zhishen, Mengcheng, and Jianming (1999), and expressed as mg catechin equivalents per 100 g fresh weight. In brief, 5 g of the sample were extracted with 50 ml methanol. One millilitre of this extract was taken and 4 ml distilled H_2O, and 0.3 ml of $NaNO_2$ (5%) added. After 5 min 0.3 ml of $AlCl_3$ (10%) was added to the reaction mixture. After 6 min of equilibrium time, 2 ml of NaOH (1 M) were added. The final volume was made up with distilled H_2O and stirred. The absorbance of the reaction mixture was measured at 510 nm against a prepared reagent blank.

2.6. Total carotenoids

Total carotenoids (TC) were determined according to the procedure described by Marina, Velumuttu, and Pekka (1989). A known weight of sample was extracted with a solvent mixture containing 40 ml acetone and 60 ml hexane until the residue was colourless. The residue was allowed to settle and the homogenate filtered through Whatman No. 4 filter paper and decanted slowly in a separating funnel. Hexane (50 ml) was added to the separating funnel and acetone separated from the extract by repeated washings with distilled H_2O and NaCl solution (5%). The upper hexane layer containing pigment was transferred to a 100 ml volumetric flask and the volume made up with hexane. The experiment was carried out under a yellow fluorescent illumination, since carotenoids are highly susceptible to light, heat and air. The absorbance was measured at 450 nm with hexane as blank. The total carotenoids were expressed as β-carotene using $A^{1\%}_{1\ cm}$ (absorption coefficient) of 2500 and calculated using the following formula:

$$\text{Total carotenoids (mg/100 g)} = \frac{A_{450} \times \text{volume (ml)} \times 1000}{2500 \times \text{sample weight (g)}} \quad (1)$$

2.7. Ascorbic acid

Ascorbic acid (AA) was determined using the 2,6-dichlorophenol indophenol titrimetric method (AOAC, 1997) and results expressed as mg of AA per 100 g of the sample. Briefly, 10 g of sample were extracted with metaphosphoric acid (3%) and volume made up to 100 ml in a volumetric flask. Ten millilitres of the filtrate were titrated with dye until the distinct rose pink colour persisted for 15–20 s.

2.8. Browning index

Browning index (BI) was estimated by extracting a 5 g sample in 100 ml ethanol (67%) for 1 h. The extract was filtered through Whatman No. 1 filter paper and the browning index in terms of absorbance at 420 nm was measured for the filtrate using 67% ethanol as blank.

2.9. Radical scavenging activity

Radical scavenging activity (RSA) of the fruit extracts was measured using the free radical α,α-diphenyl-β-picrylhydrazyl (DPPH) (Blois, 1958). According to the method, 0.1 g of the sample were extracted in 2.9 ml of methanol by centrifuging at 5000 rpm for 15 min. The content was filtered through Whatman No. 1 filter paper. Methanolic DPPH (0.5 ml, 500 μM) was added to the tubes containing this supernatant and shaken vigorously. The tubes were incubated at room temperature for 45 min in the darkness. The changes in optical density (*OD*) of the samples were measured at 515 nm with methanol as blank. RSA was expressed as the percentage inhibition of DPPH radical and calculated using the following formula:

$$\%\ \text{Radical scavenging activity (DPPH)} = \frac{(\text{Control } OD - \text{Sample } OD)}{\text{Control } OD} \times 100 \quad (2)$$

2.10. Statistical analysis

All the values have been reported as the means of triplicate samples and were subjected to analysis of variance (ANOVA) at a significance level of $p < 0.05$. Means were compared by Duncan's multiple-range test using Statistica 7 software (StatSoft, Tulsa, OK).

3. Results and discussion

The modern concept of food product design has undergone a revolutionary change in the recent past with the inclusion and understanding of functional constituents within the foods. Fruits and vegetables are endowed with a significant quantity of natural antioxidants and efforts are being made to minimise the losses of these vital constituents during processing. A number of phytochemicals, i.e., AA, carotenoids, phenolics, and flavonoids constitute the antioxidant potential, characterised by the overall free RSA of these commodities. The preservation of fresh-cut fruits and vegetables poses a serious challenge in terms of these vital phytochemicals, due to the increased physiological stress caused by the pre-cutting process. Fresh-cut products are highly susceptible to oxidative deterioration due to increased respiratory activity and damage caused to the biological membranes, promoting tissue senescence (Lamikanra & Watson, 2001). Therefore, it is essential to minimise the oxidative stress and biological activity within fresh-cut commodities, to reduce the loss of phytochemicals responsible for the overall antioxidant potential of the tissue. Jackfruit is usually marketed as separated bulbs after pitting which makes the fruit highly susceptible to oxidative stress.

3.1. Total phenolics

Usually size reduction during minimal processing is accredited with the accumulation of total phenolics (TP) compound in many fruits and vegetables, where cells rapidly synthesise larger amount of phenolic acids as a defence for wound healing and to provide disease resistance. In the present study, it was observed that the TP content decreased during storage of fresh-cut jackfruit bulbs in dip-pretreated (Fig. 1a) as well as in untreated (Fig. 1b) bulbs. Dip pretreatment coupled with MAP showed a significantly ($p < 0.05$) lower TP loss as compared to untreated samples which recorded a higher degree of degradation after just 7 days. The percentage phenolics loss in the pretreated samples was found to be 7–15%, as compared to 15–26% in the case of untreated samples kept under MA conditions. The dip pretreatment given to fresh-cut jackfruit bulbs consisted of Ca salt infusion as a texturising agent, citric acid (CA) as an anti-respiratory substance, AA as an anti-browning agent, and sodium benzoate (SB) as preservative. The overall effect was based on synergism, leading to extension in shelf-life as well as a decrease in the respiration rate and oxidative stress (Saxena et al., 2008). The dip pretreatment and the MA conditions in synergism caused a higher retention of TP, due to decrease in the biological activity mediated by anti-respiratory function of the specific additives, as well as the low O_2 and high CO_2 atmosphere provided by the MA techniques. Mateos, Ke, Cantwell,

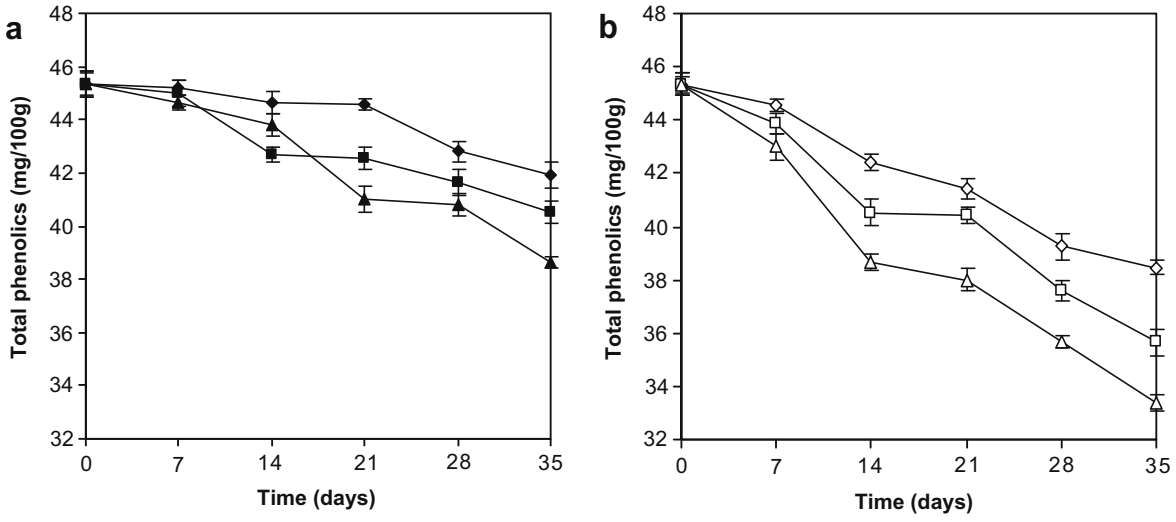

Fig. 1. Total phenolics content of fresh-cut jackfruit bulbs under different MAP during storage at 6 °C. Full symbols show (a) pretreated samples (♦) gas-flushed PE bags; (■) silicon membrane window PET jars; (▲) PE bags. Empty symbols represent (b) untreated samples (◇) gas-flushed PE bags; (□) silicon membrane window PET jars; (Δ) PE bags. Data represent the mean ± SD ($n = 3$).

and Kader (1993) highlighted the inhibition of enzyme-mediated phenolics metabolism in fresh-cut lettuce stored under low O_2 and high CO_2 atmosphere. In the present study gas-flushed polyethylene (GFPE) bags with 3 kPa O_2 + 5 kPa CO_2 showed maximum retention of TP followed by silicon membrane (SM) window PET jars and polyethylene (PE) bags as such, respectively (Fig. 1). The headspace gaseous composition (O_2 approx. 3.55% and CO_2 approx. 5.29%; data not presented) within the GFPE bags containing pretreated bulbs showed no symptoms of anaerobiosis, highlighting the positive synergistic effect between the dip pretreatment and MA conditions. Alasalvar et al. (2005) reported that storage under low O_2 atmosphere could reduce the accumulation of TP in shredded orange and purple carrot compared to those stored under air and high O_2 conditions. Anti-respiratory substances, such as CA and application of AA are known to be effective retardants of polyphenoloxidase (PPO) activity, due to the decrease in the availability of molecular oxygen. Our results are in agreement with Cocci, Rocculi, Romani, and Dalla Rosa (2006), who reported a restricted degradation in TP, due to the reducing action of AA added in the dip pretreatment given to fresh-cut apple stored under MA conditions.

Low O_2 and high CO_2 atmosphere caused a decrease in PPO activity (Tian, Li, & Xu, 2005). The decrease in TP during storage of fresh-cut commodities could be attributed to enzymatic degradation by peroxidase (POD) and PPO activities. POD has been widely reported to be responsible for the oxidation of mono and di-phenols in the presence of H_2O_2 (Robinson, 1991). Induction of POD has been attributed to membrane damage and oxidative stress (Gong & Tian, 2002). Oms-Oliu et al. (2008) observed lower induction of POD under O_2-enriched conditions and recommended that the incidence of anaerobiosis could be highly responsible for the activation of POD, possible under MA conditions. In the present study, the MA conditions were optimised, to ensure the absence of anaerobiosis and avoid degeneration of membranes and activation of POD, which may cause depletion in TP content adversely. The combined use of anti-respiratory additives and SB as a preservative could be an appropriate method to minimise TP loss in fresh-cut jackfruit bulbs. This minimal processing strategy facilitated reduction in tissue respiration, browning, and membrane damage due to the oxidative stress as well as eliminated the chances of anaerobiosis, which otherwise may crop up in the conventional MA conditions in the absence of dip pretreatment.

3.2. Total flavonoids

Flavonoids are known to play an important role in terms of antioxidant functionality and their loss during processing and storage needs to be restricted. Fig. 2a and b shows the changes in total flavonoids (TF) of dip-pretreated and untreated jackfruit bulb samples stored under different MA conditions. There was no significant difference in the retention of TF by the MA-packaged samples subjected to pretreatment, in comparison to the untreated ones. However, after a storage period of 14 d the loss in TF was more pronounced in untreated MAP samples ($p < 0.05$). As such, the loss in TF content was found to be 8–20% in the case of pretreated MA-packaged samples as compared to a significantly higher loss of 20–33% in the control samples under different MA conditions. Amongst the different MA techniques applied, GFPE bag (3 kPa O_2 + 5 kPa CO_2) samples showed significantly higher values of TF, as compared to passive MA, up to 35 days of cold storage ($p < 0.05$). As such, PE bags showed the least effect on the retention of the TF content. The SM window PET jars showed significantly ($p < 0.05$) higher TF retention, as compared to PE bags, but lower than the in case of GFPE bags. The comparatively lower O_2 and higher CO_2 atmosphere formed in GFPE bag samples minimised the oxidative degradation of TF content in the fruit, as compared to the other MA conditions used, showing that passive MA conditions could not modify the internal atmosphere adequately. McClure (1975) attributed TF losses to disintegration of tissue, including epidermal cells as well as biological membrane, and restriction of the same could be achieved by the texturisation of the samples with a calcium salt present in the pretreatment given in the present study. It is interesting to note that the fresh-cut mangoes subjected to UV radiation gave enhanced TF content during low temperature storage, which could be attributed to the induction of self-protective mechanism within the plant tissue (Gonzalez-Aguilar, Villegas-Ochoa, Martinez-Tellez, Gardea, & Ayala-Zavala, 2007). Therefore, such inductive physical pretreatments can also be adopted during minimal processing to restrict the changes in TF content in minimally-processed fresh commodities.

3.3. Total carotenoids

Jackfruits are rich in carotenoids, rendering golden yellowish colour to the bulbs. Carotenoids are highly susceptible to oxidative deterioration, at the same time being potential antioxidants. In the

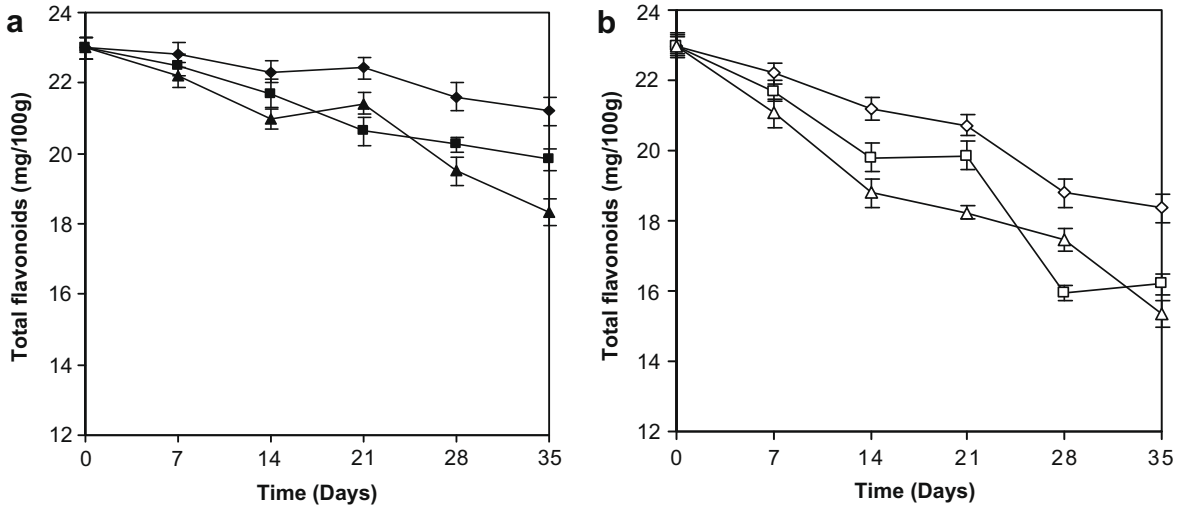

Fig. 2. Total flavonoids content of fresh-cut jackfruit bulbs under different MAP during storage at 6 °C. Full symbols show (a) pretreated samples (♦) gas-flushed PE bags; (■) silicon membrane window PET jars; (▲) PE bags. Empty symbols represent (b) untreated samples (◇) gas-flushed PE bags; (□) silicon membrane window PET jars; (Δ) PE bags. Data represent the mean ± SD ($n = 3$).

present study, the synergistic effect of MA storage showed a significantly ($p < 0.05$) higher retention of carotenoids in pretreated samples, vis-à-vis the untreated ones kept under MA conditions. The total carotenoids (TC) content showed a steady decline whilst the GFPE bag pretreated samples recorded comparatively lower destruction in TC content up to the 14th day of storage (Fig. 3a). This could be because of lower mean respiration rate (around 9.68 mg CO_2/kg/h; data not presented) of the sliced jackfruit bulbs packed in GFPE, as compared to SM window PET jars or PE bags. On the other hand, TC content was observed to decrease from the 7th day onwards in the control samples (Fig. 3b). The overall retention of TC was found to be in the range of 40–57%, in the case of pretreated samples, whilst the control ones showed a significantly lower retention (5–39%) under the various MA conditions during storage for 35 days. The higher retention of TC content could be attributed to anti-respiratory activity of the pretreatment involving acidification as the major anti-respiratory component. The low O_2 atmosphere generated by the MA conditions synergised with the pretreatment, causing higher retention of TC. AA as a constituent of pretreatment could also minimise the carotenoid loss due to the free RSA, resulting in the prevention of TC oxidation (Mercadante & Rodriguez-Amaya, 1998). Amongst the various MA techniques adopted in the study, GFPE bags gave the maximum retention of TC content significantly for both pretreated and control samples, followed by SM window PET jars and PE bags as such. The higher efficacy of active MA in GFPE bags could be due to the faster attainment and lower level of equilibrated O_2 within the headspace, causing high anti-respiratory activity. Shi and Le Maguer (2000) have reported a similar reduction in enzymatic oxidation for lycopene in tomatoes. Effective protection of carotenoids against oxidation is highly critical in the case of carotenoids-rich high moisture product, such as minimally-processed jackfruit bulbs.

3.4. Ascorbic acid

Ascorbic acid (AA) has an important role as a phytochemical, due to its functionality as an antioxidant besides its vitamin C activity. The physiological stress imposed upon fresh-cut commodities results in a significant reduction in AA content. Table 1 revealed that the addition of AA during dip pretreatment resulted in a 3.5-fold increase in AA content in pretreated samples. Initial AA content of pretreated samples was recorded as 23.5 ± 0.16 mg/100 g against control (7.1 ± 0.09 mg/100 g), which decreased rapidly during storage. In the present study, the pretreated samples kept under MA conditions showed a significantly ($p < 0.05$) higher retention of AA (56–69%), as against 10–49% in the case of untreated samples. Reports exist about higher retention of AA in fresh-cut commodities subjected to MAP (Odriozola-Serrano, Soliva-Fortuny, & Martin-Belloso, 2008) and pretreatment with additives such as CA and AA (Cocci et al., 2006). Significant changes were observed between the MA techniques used in terms of AA content and after 14 days the pretreated GFPE bag (3 kPa O_2 + 5 kPa, CO_2) samples were found to be more effective in restricting the decrease in AA. Lower respiratory activity could be attributed to higher retention of AA content, due to restriction in enzymatic oxidation of AA into dehydroascorbic acid, through headspace oxygen in the MA-packaged samples during storage. This phenomenon was largely influenced by the restriction in respiratory output and low O_2 atmosphere generated by MA. The control samples showed a rapid loss in AA from the 7th day onwards. The three types of MAP conditions resulted in varied responses in terms of AA loss. The maximum restriction in loss was found to be in case of GFPE bags, due to the effective low O_2 atmosphere generated within the package, followed by other passive types of packages, i.e., SM window PET jars and PE bags.

3.5. Browning index

Enzymatic browning in terms of browning index (BI) as A_{420} values has been presented in Table 1 for the pretreated and control samples under different MA conditions during storage. After 35 days of storage, control samples recorded nearly 1.5–1.7-fold higher BI values whilst pretreated samples showed a restricted rise of 1.2–1.4-fold under different MA conditions. The difference in browning intensity was found to be significant ($p < 0.05$) between the two experimental sets described and amongst the different MA conditions. After 14 days, pretreated GFPE bag (3 kPa O_2 + 5 kPa CO_2) samples were found to have restricted increase in BI as compared to other MA techniques used. Control MA samples showed a rapid rise in BI from the 7th day onwards. Constituents of the pretreatment, such as AA and CA, were found to be

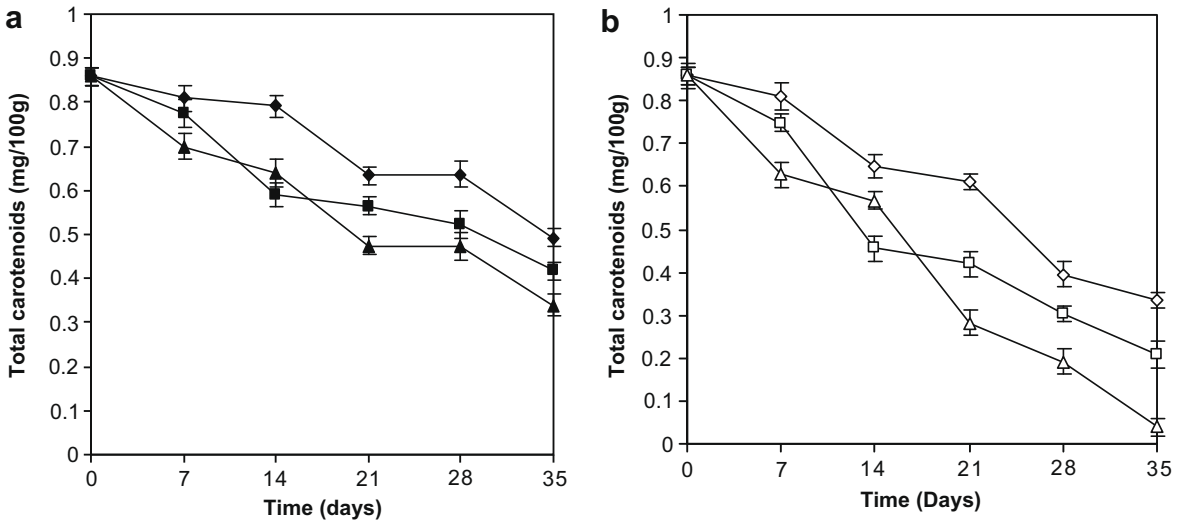

Fig. 3. Total carotenoids content of fresh-cut jackfruit bulbs under different MAP during storage at 6 °C. Full symbols show (a) pretreated samples (♦) gas-flushed PE bags; (■) silicon membrane window PET jars; (▲) PE bags. Empty symbols represent (b) untreated samples (◇) gas-flushed PE bags; (□) silicon membrane window PET jars; (Δ) PE bags. Data represent the mean ± SD ($n = 3$).

Table 1
Evolution of ascorbic acid and browning index of pretreated and untreated fresh-cut jackfruit bulbs packaged with different modified atmosphere packaging during storage at 6 °C.

Parameter	Sample	Type of MAP	Time (days)					
			0	7	14	21	28	35
Ascorbic acid (mg/100 g)	Pretreated	Gas-flushed PE bag	24.71^{a}	23.72^{a}	23.23^{a}	20.62^{b}	20.48^{b}	17.01^{c}
		Silicon membrane window PET jar	24.72^{a}	22.81^{b}	19.26^{bc}	18.82^{c}	17.89^{c}	15.62^{d}
		PE bag	24.72^{a}	22.13^{b}	21.62^{b}	17.39^{c}	15.62^{d}	13.83^{e}
	Untreated	Gas-flushed PE bag	7.12^{a}	6.42^{a}	5.26^{b}	5.14^{b}	3.84^{c}	3.45^{c}
		Silicon membrane window PET jar	7.13^{a}	5.62^{b}	3.84^{c}	3.18^{cd}	2.98^{d}	2.24^{e}
		PE bag	7.12^{a}	3.98^{bc}	3.23^{cd}	1.88^{e}	2.08^{de}	0.67^{f}
Browning index (A_{420})	Pretreated	Gas-flushed PE bag	0.0461^{a}	0.0471^{a}	0.0498^{b}	0.0490^{b}	0.0529^{c}	0.0552^{c}
		Silicon membrane window PET jar	0.0461^{a}	0.0481^{ab}	0.0516^{bc}	0.0573^{c}	0.0560^{d}	0.0602^{d}
		PE bag	0.0462^{a}	0.0498^{b}	0.0536^{c}	0.0536^{c}	0.0620^{d}	0.0653^{e}
	Untreated	Gas-flushed PE bag	0.0462^{a}	0.0515^{a}	0.0597^{b}	0.0616^{b}	0.0723^{c}	0.0744^{c}
		Silicon membrane window PET jar	0.0463^{a}	0.0551^{ab}	0.0647^{c}	0.0751^{d}	0.0766^{d}	0.0811^{e}
		PE bag	0.0461^{a}	0.0578^{bc}	0.0707^{d}	0.0684^{c}	0.0846^{e}	0.0915^{f}

Mean value followed by different superscript differs significantly by Duncan's multiple-range test ($p < 0.05$; $n = 3$).

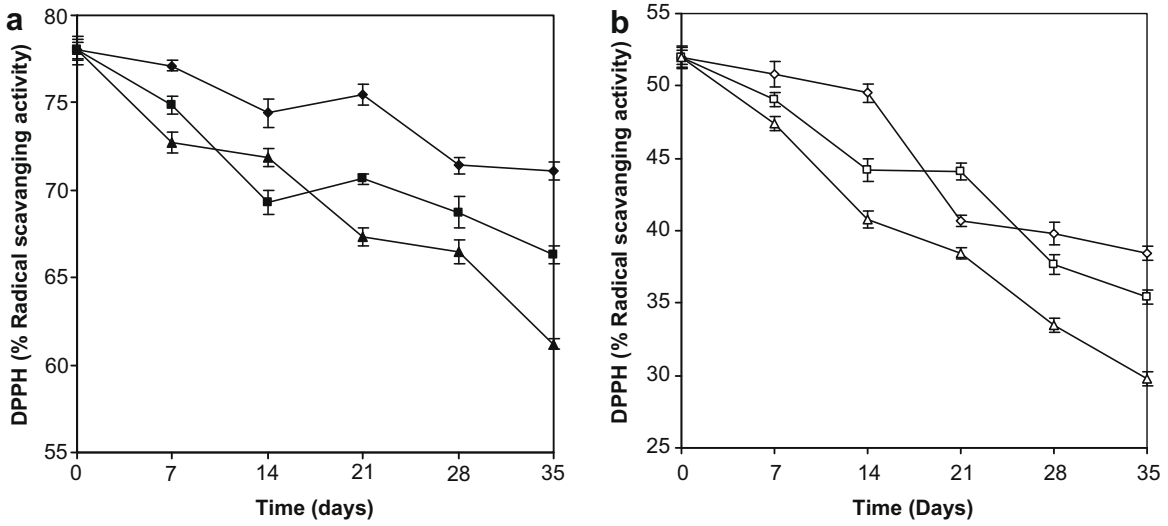

Fig. 4. Changes in antioxidant capacity expressed as % inhibition of DPPH in fresh-cut jackfruit bulbs under different MAP during storage at 6 °C. Full symbols show (a) pretreated samples (♦) gas-flushed PE bags; (■) silicon membrane window PET jars; (▲) PE bags. Empty symbols represent (b) untreated samples (◇) gas-flushed PE bags; (□) silicon membrane window PET jars; (Δ) PE bags. Data represent the mean ± SD ($n = 3$).

effective anti-enzymatic browning agents. AA functions as an anti-browning agent by absorption of molecular oxygen and carboxylic acids, such as CA, inactivates the enzyme PPO by chelating bivalent cations (Rico, Martın-Diana, Barat, & Barry-Ryan, 2007). Low O_2 atmosphere generated during the MA conditions also plays an important role in terms of anti-browning function, due to the anti-respiratory activity and lower availability of molecular oxygen required for the PPO-mediated enzymatic browning.

3.6. Radical scavenging activity

The combined antioxidant potential of the minimally-processed jackfruit bulbs showed a significant ($p < 0.05$) effect in terms of retention after processing and during storage between the pretreated and untreated samples kept under various MA conditions. The antioxidant potential was analysed as RSA in terms of % DPPH inhibition. Amongst the MA techniques applied active MA in GFPE bags (3 kPa O_2 + 5 kPa CO_2) showed significantly ($p < 0.05$) higher retention of RSA, as compared to passive MA, such as SM window PET jars and PE bags (Fig. 4a). The RSA decreased significantly ($p < 0.05$) in control samples under all MA conditions (Fig. 4b). Pre-cutting of the plant has been reported to cause physiological stress, resulting in a decrease in RSA, due to loss in phytochemical moieties responsible for antioxidant activity (Lana & Tijskens, 2006). Therefore, stabilisation of the phytochemicals content responsible for antioxidant activity is essential to retain anti-oxidative functions in terms of RSA. It is interesting to note that RSA had maximum positive correlation with AA content ($r = 0.979$) followed by TP, TF, and TC in all the samples (Table 2). However, the high correlation could also be attributed to exogenous application of AA as a constituent of the pretreatment. All the phytochemicals showed a strong negative correlation with BI ($r > 0.70$). The overall retention of RSA was a result of the stabilising pretreatment with emphasis on anti-respiratory, anti-physiological stress, and anti-browning functions. Restriction of respiratory activity by the chemical conditioning and low O_2 atmosphere rendered by MA could be the causative agent for the higher retention of phytochemicals responsible for antioxidation in terms of RSA. Supplementation of AA as an exogenous source during the pretreatment also helped in retaining adequate quantity of phytochemicals during the process. Additive-based minimal processing, devoid of thermal processing and coupled with MA could be an ideal process

Table 2
Correlations between various parameters of fresh-cut jackfruit bulbs packaged with different modified atmosphere packaging during storage at 6 °C.

	Total phenolics (mg/100 g)	Total flavonoids (mg/100 g)	Total carotenoids (mg/100 g)	Ascorbic acid (mg/100 g)	Browning index (A_{420})
Total phenolics (mg/100 g)	1				
Total flavonoids (mg/100 g)	0.9714	1			
Total carotenoids (mg/100 g)	0.9603	0.9404	1		
Ascorbic acid (mg/100 g)	0.6333	0.6237	0.5324	1	
Browning index (A_{420})	−0.9625	−0.9552	−0.9160	−0.7074	1
% Radical-scavenging activity (DPPH)	0.7184	0.7073	0.6035	0.9790	−0.7894

for retention of phytochemicals in jackfruit bulbs in specific and other fruits and vegetables in general.

4. Conclusions

Evaluation of a minimal process for fresh commodities in pre-cut form such as pitted jackfruit bulbs needs to lay emphasis on the anti-stress additives in synergy with MA. A pretreatment process protocol, constituting anti-respiratory, anti-stress, anti-browning, and preservative functions, minimised the loss in anti-oxidative phytochemicals, such as phenolics, flavonoids, carotenoids, and AA. Its synergistic effect, in combination with MAP consisting of 3 kPa O_2 + 5 kPa CO_2 gas mixture flushed PE bag, silicon membrane window PET jar, and PE bags, was found to maximise the beneficial effect of the pretreatment. As such the pretreatment and MA could minimise the loss of phytochemicals and RSA. A high positive correlation coefficient was obtained between RSA and AA ($r = 0.979$). Such evaluation of phytochemical status in processed foods, i.e., minimally-processed product, can help the modern health-conscious consumer.

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