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Effect of selected high pressure processing parameters on the sensory attributes and shelf life of jackfruit (*Artocarpus heterophyllus* L.) bulb packed using different packaging materials

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Abstract

The effect of selected high pressure processing (HPP) parameters on the sensory attributes and shelf life of jackfruit bulb packed using vacuum skin (VS) and vacuum nylon (VN) packaging was studied. The samples were stored at chilled temperature (4°C) for shelf life study. HPP significantly ($p < 0.05$) increased the shelf life of VS- and VP-packed jackfruit bulbs to 60 d during chilled storage. In terms of colour stability during storage, both VS- and VP-packed HP-treated jackfruit bulbs exhibited no significant differences ($p > 0.05$) in L^*, a^*, and b^* values. Also, the VS- and VP-packed HP-treated samples exhibited no significant differences ($p > 0.05$) in terms of texture. However, the sensory evaluation carried out among 48 panellists showed that there were significant differences ($p < 0.05$) between the untreated and HP-treated jackfruit bulbs. The aforementioned results had proven that HPP treatment of 500 MPa for 5 min could successfully extend the shelf life and retain the physicochemical properties of jackfruit bulbs, regardless of the types of packaging used.

Introduction

Jackfruit (*Artocarpus heterophyllus* L.) is well known for possessing antioxidant, antibacterial, anti-inflammatory, and other beneficial attributes (Baliga *et al.,* 2011; Swami *et al.,* 2012). For instance, as reported by de Faria *et al.* (2009), jackfruit contains many carotenoids that can act as antioxidants to prevent cancer or cardiovascular disease (Krinsky *et al.,* 2003; Stahl and Sies, 2005). In light of this, numerous effort have been taken to extend the short shelf life of jackfruit bulbs and preserve their nutritional quality via different types of post-harvest technology or processing method (Saxena *et al.,* 2008; 2013; Taib *et al.,* 2013).

High pressure processing (HPP) is a novel non-thermal processing technology which can preserve food via inactivation of vegetative microorganisms and enzymes. Various studies on the effect of HPP with combination of heat treatment have been conducted on different types of vegetables and fruit juices, with surprising results obtained in terms of extended shelf life and retained physicochemical properties of the foods (Paciulli *et al.,* 2016). Vacuum skin packaging is an innovative technique that has the capability to securely enclose a product without affecting the shape of the product. This packaging provides an outstanding approach to preserve the freshness, colour, and texture of the product in a more natural way. The transparent and thin film closely adheres to the surface of the product, allowing good visibility that showcases the fresh and natural appearance of the product. Consequently, this enhancement of product appearance would surely gain the consumer's attention. Furthermore, it can prolong the shelf life of perishable product when used in combination with non-thermal processing methods such as modified atmosphere packaging or high pressure processing (HPP) (Garriga *et al.,* 2004; Macé *et al.,* 2013; Denoya *et al.,* 2015). HP-treated samples are commonly vacuum-packed in polyethylene bag or aluminium-based retort pouch (Barba *et al.,* 2013; Kaushik *et al.,* 2018), whereas vacuum skin packaging film is specifically used for meat-based products (Kameník *et al.,* 2014). A search of the literature revealed that the use of vacuum skin packaging film for HP-treated fresh jackfruit bulbs has not been investigated. Thus, the objective of the present work was to investigate the effect of selected HPP at a pressure of 500 MPa and holding time of 5 min on the sensory properties and shelf life stability (in terms of microbiological growth and change in the colour quality) of jackfruit bulbs packaged using different packaging materials.

Materials and methods

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Materials

Growth media namely plate count agar, eosin methylene blue (EMB) agar, and potato dextrose agar (PDA) were purchased from Merck (Darmstadt, Germany). Other chemicals such as acids (H_2SO_4, HCl), alkaline (NaOH), salt buffers (NaCl, sodium acetate, borate buffer, potassium phosphate), and indicators (2-cyanocetamide, bromothymol blue) were of analytical grade, and also purchased from Merck (Darmstadt, Germany). Pectin and polygalacturonic acid were purchased from Sigma-Aldrich (St. Louis, USA). Commercially matured jackfruits (*Artocarpus heterophyllus*) were provided by Duria Manufacturing Sdn. Bhd. (Kamunting, Perak, Malaysia). The jackfruit bulbs were manually removed from ripened jackfruits. Each product pouch contained approximately 350 g of these bulbs, and was vacuum-sealed using either skin-film or nylon cast polypropylene, and stored at chilled temperature (4°C) (Vargas-Ortiz *et al.,* 2013). Vacuum skin (VS) packaging was performed using a thermoforming packaging machine (Multivac Model 175 MF, Wolfertschwenden, Germany). The thermoforming tray was formed in the dimensions of 23 cm (length) × 12.7 cm (width).

HPP method

Both VS- and VN-packed samples were subjected to a high pressure treatment of 500 MPa for 5 min at room temperature using a Hiperbaric 120 processing unit (Hiperbaric España, Burgos, Spain). The come up time of 500 MPa via aforementioned HPP unit was 1 min, while the depressurising time was within 5 s (Gomes *et al.,* 2017). The initial and final temperature of sample was at 25°C (room temperature) and 30°C, respectively. At the end of each treatment, the packaged samples were stored at 4°C prior to analysis.

Sensory studies

The sensory evaluation of untreated and HP-treated jackfruit bulbs packed using VS and VN packaging was based on a discrimination method (triangle test) carried out following the ISO standard 4210 (ISO, 2004). The triangle test was performed to determine the perceptible sensorial differences between HP-treated and untreated jackfruit bulbs. The test was carried out by 48 untrained panellists (students and staff of the Faculty of Food Science and Technology, Universiti Putra Malaysia). For the test, the jackfruit samples were put in plastic cups, and coded using random three-digit numbers. Panels were instructed to taste all three samples, of which two were identical. Panels were then instructed to indicate the odd sample. To establish significance at a 95% confidence level, a minimum of 22 out of the 48 panellists should make the correct judgement (ISO, 2004).

Texture analysis

The texture of the samples was analysed using a TA-XT2*i* texture analyser unit (Stable Micro Systems, Surrey, UK). The parameters were set following the method described by Caner *et al.* (2008), with slight modifications. Briefly, the following settings were used: pre-test speed 5.0 mm/s, test speed 1.0 mm/s, and post-test speed 8.0 mm/s; penetration depth of 4.0 mm and a rest period of 5 s between two cycles; trigger force 5.0 N. A cylinder probe (2 mm diameter) was used and always returned to trigger point prior to the second cycle. Measurements were made on three jackfruit bulbs per pack of sample. The values for hardness and chewiness were then calculated using the Exponent Stable Micro Systems version 4.0.13.0 equipment software (Stable Micro Systems, Surrey, UK).

Shelf life studies

Microbiological analysis

Total plate count, total presumptive coliform, and yeast and mould count of jackfruit samples were analysed at days 0, 5, 10, 20, 30, 40, 50, and 60, following the FDA standard methods. In short, 25 g of sample was homogenised with 225 mL of 0.1% peptone water, and further decimal dilutions were made with the same 0.1% peptone water. Each diluted sample (1 mL) was spread-plate onto plate count agar (PCA) plates, and incubated at 37°C for 48 h. Total presumptive coliform, and yeast and mould count were analysed in a similar way using EMB agar plates and PDA agar plates, respectively. All microbial data were expressed as logarithms of number of colony forming units (log CFU g^{-1}).

Colour analysis

The colour of the samples was measured at days 0, 10, 20, 30, and 40 using a Minolta Chroma Meter CR-410 (Konica Minolta Instrument, Osaka, Japan). The colour was expressed in L^* value representing the lightness of sample, a^* value representing the redness of sample, and b^* value representing the yellowness of sample. The total colour difference (Δ E) was determined using Eq. 1:

$$\Delta E = \sqrt{(a^* - a_0{}^*)^2 + (b^* - b_0{}^*)^2 + (L^* - L_0{}^*)^2} \quad \text{(Eq. 1)}$$

where, $L_0{}^*$, $a_0{}^*$, $b_0{}^*$ = values of untreated jackfruit bulbs.

Statistical analysis

All experiments were duplicated, and all data were subjected to one-way analysis of variance (ANOVA) using Minitab Statistical Software Release 16.1 (Minitab Inc., PA, USA). Statistical significance was established at $p < 0.05$ using Tukey's test to evaluate the differences between mean values.

Results and discussion

Sensory evaluation

The results of the triangle test indicated that there was a significant difference ($p < 0.05$) between the HP-treated and untreated jackfruit bulbs. For VS-packaged jackfruit bulbs, 22 out of 48 panellists correctly identified the odd sample. Meanwhile, for VN-packaged jackfruit bulbs, 25 panellists correctly identified the odd sample. The panellists were able to differentiate the distinct difference between HP-treated and untreated jackfruit bulbs mainly due to the increased hardness and chewiness of the jackfruit bulbs. The texture of HP-treated jackfruit bulbs exhibited a significant increase in hardness and chewiness due to the de-esterification of the low-methoxy-pectin released during HPP treatment which results in the formation of a gel network (Tangwongchai *et al.,* 2000). Thus, the panellists were able to discriminate between the fresh untreated jackfruit bulbs and HP-treated bulbs solely based on their texture, irrespective of their appearance, flavour, and colour. As reported in previous research works, the odour and flavour of fresh fruits are not affected by HPP due to the minimal effect that high pressure has on the covalent bonding of small molecular compounds (Tauscher, 1995; Oey *et al.,* 2008a). As a result, HP-treated samples can primarily be differentiated from untreated fresh samples through the changes in texture attributes, since the flavour is usually retained.

Texture

As shown in Table 1, the hardness of untreated jackfruit bulbs packed using VS and VN packaging varied from 116.46 to 121.63 g. However, both VS- and VN-packed jackfruit bulbs exhibited a significant ($p < 0.05$) increase in hardness and chewiness by almost two-fold after HPP. Thus, it can be concluded that the hardness and chewiness of jackfruit bulbs were significantly ($p < 0.05$) affected by HPP, irrespective of the types of packaging material (Tangwongchai *et al.,* 2000). In short, the increase in hardness and chewiness of jackfruit bulbs was due to the formation of gel network that was induced by HPP (Tangwongchai *et al.,* 2000). The formation of gel network can be explained by the release of pectin esterase during HPP which undergoes demethylation process when contact with highly methylated pectin substrate, thus forming divalent ions between the de-esterified pectin (Oey *et al.,* 2008a). This leads to increase in hardness.

Table 1. Effect of HPP at 500 MPa for 5 min on the texture of jackfruit bulbs packed using vacuum skin (VS) and vacuum nylon (VN) packaging.

Treatment	Hardness (g)	Chewiness
VS	121.63 ± 31.47^{B}	72.84 ± 44.63^{B}
VN	116.46 ± 86.45^{B}	76.55 ± 36.09^{B}
VS-HPP	238.36 ± 65.15^{A}	138.07 ± 32.48^{A}
VN-HPP	229.25 ± 53.25^{A}	131.31 ± 42.94^{A}

Data are means ± standard deviations ($n = 6$). Means in each column with different letters are significantly different ($p < 0.05$).

Shelf life studies

Microbiological analysis

As shown in Figure 1, the initial total plate count (TPC) for both VS- and VN-packed untreated samples were log 4.23 and 4.87 CFU g^{-1}, respectively. This is in line with other reports as the preparation of fresh jackfruits bulbs were controlled in a hygienic handling environment (Kaushik *et al.,* 2014a; Andrés *et al.,* 2016a). Thus, the initial TPC for fresh jackfruit bulbs was expected to be lower. Generally, the microbial load for both VS- and VN-packed untreated samples exhibited an increasing trend within 20 d of storage, followed by a gradual decrease. This gradual decrease towards the end of the storage period was most likely due to the depletion of nutrient in the food system. In contrast, the TPC for both VS- and VN-packed samples treated by HPP was below the detection limit throughout the 60 d of storage. This indicated that all bacteria were destroyed by the HP treatment of 500 MPa for 5 min, and the dead cells remained inactivated throughout the shelf life study period. These results are in line with reports related to the shelf life extension of fruits using HPP. As revealed by Bull *et al.* (2004), the shelf life of HP-treated Valencia and Navel orange juices was extended to up to 12 weeks, during which the microbial load was kept below log 2 CFU mL^{-1}. Meanwhile, Błaszczak *et al.* (2017) successfully increased the microbial stability of Aronia juice to up to 80 d by subjecting it to HPP at 600 MPa for 15 min. The inactivation of microorganisms is mainly due to protein and enzyme denaturation, whereby

HPP induced changes in the cell morphology and biochemical reactions in microorganisms (Linton and Patterson, 2000; Smelt *et al.,* 2001). In the context of the present work, the result evidenced that a HP treatment at 500 MPa for 5 min successfully inactivated mesophilic bacteria throughout the studied storage days, thus securing the minimum safety level for the jackfruit bulbs.

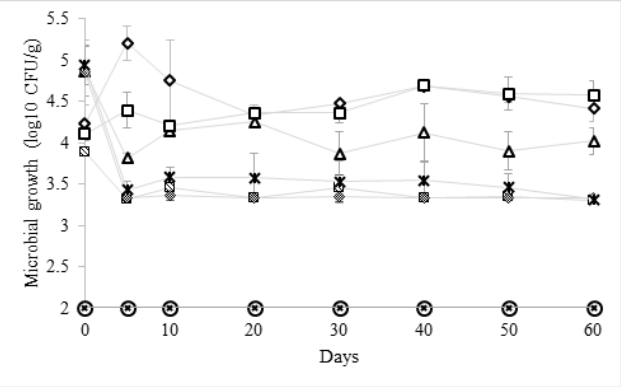

Figure 1. Total plate count for jackfruit bulbs with treatments of: ◇VS packaging only; △VN packaging only; ○VS packaging + HPP; × VN packaging + HPP; Coliform bacteria count in jackfruit bulbs with treatments of: ◆VS packaging only; ▨VN packaging only; ○VS packaging + HPP; × VN packaging + HPP; Yeast and mold count in jackfruit bulbs with treatments of: ✱VS packaging only; □ VN packaging only; ○VS packaging + HPP; × VN packaging + HPP.

Coliform bacteria are commonly used as an indicator microorganism or contamination index, and reflect the potential presence of pathogenic bacteria in food (Pereda *et al.,* 2007). In the present work, the initial presumptive coliform count for both VS- and VN-packed untreated samples were log 3.89 and 4.85 CFU g^{-1} (Figure 1), respectively. Both VS- and VN-packed untreated samples then exhibited a decrease in coliform load at day 5, which subsequently remained unchanged throughout the storage duration. As revealed by LeChevallier *et al.* (1996), the growth of coliform bacteria is greatly dependent on nutrients. In other words, the growth of coliform bacteria will be suspended if there is limited nutrient. As was expected, both VS- and VN-packed HP-treated jackfruit bulbs exhibited non-detectable levels of coliform bacteria. This result is in line with those reported in other studies. For example, the growth of coliform bacteria in sugarcane juice was completely suppressed by HPP at 600 MPa for 6 min (Huang *et al.,* 2015). Meanwhile, Chai *et al.* (2014) concluded that HPP was highly effective for the inactivation of coliform bacteria and yeasts and moulds in *Angelica keiskei* juice. In addition, Kaushik *et al.* (2014b) found that coliform bacteria were highly sensitive to pressurisation when the mango pulp used in their study was subjected to HPP, with pressures ranging from 100 to 600 MPa. Thus, in the present work, the result obtained reiterated the fact that coliform bacteria can effectively be inactivated by HPP, since no growth of coliform bacteria was detected during the 60 d of storage.

As shown in Figure 1, the yeast and mould count (YMC) for both VS- and VN-packed untreated samples were log 4.10 and 4.94 CFU g^{-1}, respectively. Meanwhile, for all HP-treated samples, the YMC was below the detection limit. These results are in line with other research works. Total inactivation of yeasts and moulds was attained when pomegranate juice was subjected to HPP at 400 MPa (Chen *et al.,* 2013). In addition, Błaszczak *et al.* (2017) reported that a pressure level at or over 400 MPa was effective in suppressing the growth of yeasts and moulds below the detection limit. Both groups of authors attributed the inhibition of yeasts and moulds to the low pH range of the fruits and the need for special nutrients.

Overall, the aforementioned results and literature search strongly supported HPP's lethality on microorganisms. In the context of the present work, the pasteurisation of jackfruit bulbs was assured at a HP treatment of 500 MPa for 5 min. The microbial loads for both VS- and VN-packed HP-treated samples were kept below the detection limit throughout the storage period of 60 d. In other words, the results have shown that HPP had successfully extended the shelf life of jackfruit bulbs to up to 60 d under refrigeration.

Colour

The changes in the CIELAB colour parameters (L^*, a^*, and b^* values) of untreated and HP-treated jackfruit bulbs packed using VS and VN were monitored throughout a storage period of 40 d (Table 2). The L^* value, which represents the lightness of the sample, was significantly different ($p < 0.05$) between untreated and HP-treated jackfruit bulbs after treatment. The L^* values for untreated jackfruit bulbs varied from 68.57 to 70.97, whereas for HP-treated jackfruit bulbs, they ranged from 67.98 to 69.80 on the day after treatment. The decrease in L^* value in the present work is in contrast with the data reported in other research works. Liu *et al.* (2014) reported no significant changes in HP-treated mango nectars, while similar results are revealed by Ahmed *et al.* (2005) in their HP-treated mango pulp. However, Andrés *et al.* (2016b) noticed that there was a noticeable decrease in the L^* value

of smoothies subjected to a pressure of more than 600 MPa. This decrease in *L** value might be due to the disintegration effect of HPP in breaking down micelles into fragments, resulting in colour degradation (Andrés *et al.,* 2016b). During the 40 d of storage, the *L** values for both VS- and VN-packed HP-treated jackfruit bulbs showed no significant changes ($p > 0.05$). On the other hand, untreated jackfruit bulbs exhibited a decrease in lightness due to enzymatic browning (Oey *et al.,* 2008b).

Similarly, the *a** values for untreated and HP-treated jackfruit bulbs were significantly different ($p < 0.05$). The decrease in the *a** values of HP-treated jackfruit bulbs is similar to the results reported by Varela-Santos *et al.* (2012) on pomegranate juice and Andrés *et al.* (2016b) on smoothies made up of orange, papaya, melon, carrot, and skimmed milk. The authors deduced that the incomplete inactivation of browning enzymes in the fruits resulted in the loss of the red colour which is represented by the *a** value.

In contrast, the yellow colour (represented by *b** value) was not significantly different ($p > 0.05$) between the HP-treated and untreated jackfruit bulbs, suggesting that the carotenoid pigments responsible for the yellow colour of jackfruit bulbs are pressure-stable (García *et al.,* 2001; Oey *et al.,* 2008a). This finding is in line with a study reported

Table 2. Effect of HPP at 500 MPa for 5 min on the colour (*L*, a*, b**, and Δ E values) of jackfruit bulbs packed using vacuum skin (VS) and vacuum nylon (VN) packaging.

Treatment	Day				
	0	10	20	30	40
L* **value**					
VS	70.97 ± 3.29^{Ab}	70.54 ± 4.54^{Ab}	74.63 ± 3.39^{Aa}	69.14 ± 3.44^{Ab}	70.60 ± 3.25^{Ab}
VN	68.57 ± 3.59^{ABa}	64.76 ± 3.32^{Cb}	67.09 ± 2.35^{Bab}	66.91 ± 3.03^{Aab}	66.26 ± 2.21^{Bab}
VS-HPP	69.80 ± 2.09^{ABa}	66.34 ± 2.24^{BCa}	67.51 ± 2.63^{Ba}	67.65 ± 3.23^{Aa}	66.40 ± 4.50^{Ba}
VN-HPP	67.98 ± 3.26^{Ba}	67.96 ± 1.78^{ABa}	68.20 ± 2.85^{Ba}	67.06 ± 2.88^{Aa}	65.98 ± 2.73^{Ba}
a* **value**					
VS	5.33 ± 1.21^{Aa}	6.64 ± 2.00^{Aa}	6.69 ± 1.82^{Aa}	5.86 ± 1.04^{Ba}	5.70 ± 1.66^{Aa}
VN	5.95 ± 1.44^{Aa}	6.06 ± 0.97^{Aa}	6.93 ± 1.19^{Aa}	6.94 ± 1.00^{Aa}	6.11 ± 1.27^{Aa}
VS-HPP	3.49 ± 0.99^{Bab}	3.74 ± 1.28^{Bab}	4.12 ± 1.35^{Ba}	3.21 ± 1.10^{Cb}	3.05 ± 1.11^{Cb}
VN-HPP	3.48 ± 0.97^{Bab}	2.77 ± 1.27^{Bb}	3.54 ± 1.15^{Bab}	3.40 ± 0.90^{Cab}	4.21 ± 0.78^{Ba}
b* **value**					
VS	46.38 ± 2.74^{Aa}	47.30 ± 3.80^{Aa}	46.51 ± 4.83^{Ba}	45.47 ± 4.28^{Aa}	44.67 ± 3.98^{Ba}
VN	47.29 ± 4.76^{Aa}	46.34 ± 2.53^{Aa}	44.97 ± 3.38^{Ba}	47.42 ± 2.61^{Aa}	47.59 ± 2.34^{ABa}
VS-HPP	46.91 ± 4.75^{Aa}	47.36 ± 2.80^{Aa}	50.79 ± 4.94^{Aa}	48.91 ± 3.31^{Aa}	49.07 ± 4.34^{Aa}
VN-HPP	47.39 ± 5.25^{Aa}	46.75 ± 2.98^{Aa}	50.01 ± 3.26^{Aa}	47.56 ± 4.56^{Aa}	47.02 ± 3.00^{ABa}
Δ E					
VS	4.06 ± 2.01^{Ab}	5.32 ± 3.29^{Aab}	7.19 ± 3.07^{Aa}	5.10 ± 2.45^{Aab}	5.27 ± 2.30^{ABab}
VN	5.28 ± 3.11^{Aa}	6.44 ± 2.08^{Aa}	4.44 ± 2.81^{Ba}	4.87 ± 1.88^{Aa}	4.33 ± 2.18^{Ba}
VS-HPP	4.00 ± 1.15^{Ab}	5.68 ± 1.62^{Aab}	5.90 ± 1.59^{ABa}	6.41 ± 2.20^{Aa}	7.06 ± 1.90^{Aa}
VN-HPP	6.18 ± 2.68^{Aa}	6.53 ± 2.82^{Aa}	5.82 ± 1.41^{ABa}	6.10 ± 1.98^{Aa}	5.27 ± 2.25^{Ba}

Data are means ± standard deviations ($n = 6$). Means in each column with different uppercase superscripts, and means in each row with different lowercase superscripts are significantly different ($p < 0.05$). *L** value represents the lightness of sample; *a** value represents the redness of sample; *b** value represents the yellowness of sample; and ΔE represents the total colour difference of sample. VS = vacuum skin packaging; VN = vacuum nylon packaging; VS-HPP = vacuum skin packaging with high pressure processing; and VN-HPP = vacuum nylon packaging with high pressure processing.

by Andrés *et al.* (2016b) whereby the *b** values of smoothies remained constant even after being subjected to HPP at or over 450 MPa. Notably, in the present work, the *b** values for HP-treated samples were relatively stable during the 40 d of storage. However, the untreated samples exhibited a decrease in *b** values starting from day 20. The gradual decrease was expected and could be attributed to the enzymatic reaction that occurred.

The total colour difference (ΔE value), which indicates the magnitude of colour change between untreated and treated samples, was not significantly different ($p > 0.05$) between samples. This indicated that the colour of HP-treated jackfruit bulbs was similar to that of untreated bulbs. Based on visual observation, there were no distinct colour differences observed immediately after the HP treatment. This observation is in agreement with those revealed by Oey *et al.* (2008a) and Daoudi *et al.* (2002). The authors concluded that no visual colour differences were observed immediately after HP treatment. A noticeable difference in the ΔE value of untreated jackfruit bulbs was observed on day 20. In contrast, the ΔE value of HP-treated jackfruit bulbs remained unchanged and was relatively stable throughout the storage period. In short, a high *L** value and high *b** value was preferred as it represent the fresh appearance of jackfruit bulbs.

Conclusion

HPP at 500 MPa for 5 min successfully extended the shelf life of jackfruit bulbs to up to 60 d under chilled storage. The microbial loads of HP-treated jackfruit bulbs were kept below the detection limit (log 2 CFU/g) throughout the storage period. Despite the results of the colour analysis, which showed that HPP retained the colour of jackfruit bulbs, the triangle test carried out by 48 panellists showed that there was a significant difference ($p < 0.05$) between untreated and HP-treated jackfruit bulbs, with the difference most probably in terms of their texture increased in hardness, (238.36 g) and chewiness (138.07 g). The effect of HPP on the cell structure and conformational change of protein structure could be considered for further study.

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References

Ahmed, J., Ramaswamy, H. S. and Hiremath, N. 2005. The effect of high pressure treatment on rheological characteristics and colour of mango pulp. International Journal of Food Science and Technology 40(8): 885-895.

Andrés, V., Villanueva, M.-J. and Tenorio, M.-D. 2016a. Influence of high pressure processing on microbial shelf life, sensory profile, soluble sugars, organic acids, and mineral content of milk- and soy-smoothies. LWT - Food Science and Technology 65: 98-105.

Andrés, V., Villanueva, M. J. and Tenorio, M. D. 2016b. The effect of high-pressure processing on colour, bioactive compounds, and antioxidant activity in smoothies during refrigerated storage. Food Chemistry 192: 328-335.

Baliga, M. S., Shivashankara, A. R., Haniadka, R., Dsouza, J. and Bhat, H. P. 2011. Phytochemistry, nutritional and pharmacological properties of *Artocarpus heterophyllus* Lam (jackfruit): a review. Food Research International 44(7): 1800-1811.

Barba, F. J., Esteve, M. J. and Frigola, A. 2013. Physicochemical and nutritional characteristics of blueberry juice after high pressure processing. Food Research International 50(2): 545-549.

Błaszczak, W., Amarowicz, R. and Górecki, A. R. 2017. Antioxidant capacity, phenolic composition and microbial stability of aronia juice subjected to high hydrostatic pressure processing. Innovative Food Science and Emerging Technologies 39: 141-147.

Bull, M. K., Zerdin, K., Howe, E., Goicoechea, D., Paramanandhan, P., Stockman, R., ... and Stewart, C. M. 2004. The effect of high pressure processing on the microbial, physical and chemical properties of Valencia and Navel orange juice. Innovative Food Science and Emerging Technologies 5(2): 135-149.

Caner, C., Aday, M. S. and Demir, M. 2008. Extending the quality of fresh strawberries by equilibrium modified atmosphere packaging. European Food Research and Technology 227: 1575-1583.

Chai, C., Lee, J., Lee, Y., Na, S. and Park, J. 2014. A combination of TiO_2-UV photocatalysis and high hydrostatic pressure to inactivate *Bacillus cereus* in freshly squeezed *Angelica keiskei* juice. LWT - Food Science and Technology 55(1): 104-109.

Chen, D., Xi, H., Guo, X., Qin, Z., Pang, X., Hu, X., ... and Wu, J. 2013. Comparative study of quality of cloudy pomegranate juice treated by high

hydrostatic pressure and high temperature short time. Innovative Food Science and Emerging Technologies 19: 85-94.

Daoudi, L., Quevedo, J. M., Trujillo, A.-J., Capdevila, F., Bartra, E., Mínguez, S. and Guamis, B. 2002. Effects of high-pressure treatment on the sensory quality of white grape juice. High Pressure Research 22(3-4): 705-709.

de Faria, A. F., de Rosso, V. V. and Mercadante, A. Z. 2009. Carotenoid composition of jackfruit (*Artocarpus heterophyllus*), determined by HPLC-PDA-MS/MS. Plant Foods for Human Nutrition (64): 108-115.

Denoya, G. I., Vaudagna, S. R. and Polenta, G. 2015. Effect of high pressure processing and vacuum packaging on the preservation of fresh-cut peaches. LWT - Food Science and Technology 62(1): 801-806.

García, A. F., Butz, P., Bognàr, A. and Tauscher, B. 2001. Antioxidative capacity, nutrient content and sensory quality of orange juice and an orange-lemon-carrot juice product after high pressure treatment and storage in different packaging. European Food Research and Technology 213: 290-296.

Garriga, M., Grèbol, N., Aymerich, M. T., Monfort, J. M. and Hugas, M. 2004. Microbial inactivation after high-pressure processing at 600 MPa in commercial meat products over its shelf life. Innovative Food Science and Emerging Technologies 5(4): 451-457.

Gomes, W. F., Tiwari, B. K., Rodriguez, Ó., de Brito, E. S., Fernandes, F. A. N. and Rodrigues, S. 2017. Effect of ultrasound followed by high pressure processing on prebiotic cranberry juice. Food Chemistry 218: 261-268.

Huang, H.-W., Chang, Y. H. and Wang, C.-Y. 2015. High pressure pasteurization of sugarcane juice: evaluation of microbiological shelf life and quality evolution during refrigerated storage. Food and Bioprocess Technology 8(12): 2483-2494.

International Organization for Standardization (ISO). 2004. ISO 4120:2004 Sensory analysis - methodology - triangle test. Geneva: ISO.

Kameník, J., Saláková, A., Pavlík, Z., Bořilová, G., Hulanková, R. and Steinhauserová, I. 2014. Vacuum skin packaging and its effect on selected properties of beef and pork meat. European Food Research and Technology 239: 395-402.

Kaushik, N., Kaur, B. P. and Rao, P. S. 2014a. Application of high pressure processing for shelf life extension of litchi fruits (*Litchi chinensis* cv. Bombai) during refrigerated storage. Food Science and Technology International 20(7): 527-541.

Kaushik, N., Kaur, B. P., Rao, P. S. and Mishra, H. N. 2014b. Effect of high pressure processing on color, biochemical and microbiological characteristics of mango pulp (*Mangifera indica* cv. Amrapali). Innovative Food Science and Emerging Technologies 22: 40-50.

Kaushik, N., Rao, P. S. and Mishra, H. N. 2018. Comparative analysis of thermal-assisted high pressure and thermally processed mango pulp: influence of processing, packaging, and storage. Food Science and Technology International 24(1): 15-34.

Krinsky, N. I., Landrum, J. and Bone, R. A. 2003. Biologic mechanisms of the protective role of lutein and zeaxanthin in the eye. Annual Review of Nutrition 23(1): 171-201.

LeChevallier, M. W., Shaw, N. J. and Smith, D. B. 1996. Factors limiting microbial growth in distribution systems: full-scale experiments. United States: The Water Research Foundation.

Linton, M. and Patterson, M. F. 2000. High pressure processing of foods for microbiological safety and quality (a short review). Acta Microbiologica et Immunologica Hungarica 47(2-3): 175-182.

Liu, F., Wang, Y., Li, R., Bi, X. and Liao, X. 2014. Effects of high hydrostatic pressure and high temperature short time on antioxidant activity, antioxidant compounds and color of mango nectars. Innovative Food Science and Emerging Technologies 21: 35-43.

Macé, S., Joffraud, J.-J., Cardinal, M., Malcheva, M., Cornet, J., Lalanne, V., ... and Dousset, X. 2013. Evaluation of the spoilage potential of bacteria isolated from spoiled raw salmon (*Salmo salar*) fillets stored under modified atmosphere packaging. International Journal of Food Microbiology 160(3): 227-238.

Oey, I., Lille, M., Van Loey, A. and Hendrickx, M. 2008a. Effect of high-pressure processing on colour, texture and flavour of fruit-and vegetable-based food products: a review. Trends in Food Science and Technology 19(6): 320-328.

Oey, I., Van der Plancken, I., Van Loey, A. and Hendrickx, M. 2008b. Does high pressure processing influence nutritional aspects of plant based food systems? Trends in Food Science and Technology 19(6): 300-308.

Paciulli, M., Medina-Meza, I. G., Chiavaro, E. and Barbosa-Cánovas, G. V. 2016. Impact of thermal and high pressure processing on quality parameters of beetroot (*Beta vulgaris* L.). LWT - Food Science and Technology 68: 98-104.

Pereda, J., Ferragut, V., Quevedo, J. M., Guamis, B. and Trujillo, A. J. 2007. Effects of ultra-high

pressure homogenization on microbial and physicochemical shelf life of milk. Journal of Dairy Science 90(3): 1081-1093.

Saxena, A., Bawa, A. S. and Srinivas Raju, P. 2008. Use of modified atmosphere packaging to extend shelf-life of minimally processed jackfruit (*Artocarpus heterophyllus* L.) bulbs. Journal of Food Engineering 87(4): 455-466.

Saxena, A., Saxena, T. M., Raju, P. S. and Bawa, A. S. 2013. Effect of controlled atmosphere storage and chitosan coating on quality of fresh-cut jackfruit bulbs. Food and Bioprocess Technology 6: 2182-2189.

Smelt, J. P., Hellemons, J. C. and Patterson, M. 2001. Effects of high pressure on vegetative microorganisms. In Hendrickx, M. E. G., Knorr, D., Ludikhuyze, L., Van Loey, A. and Heinz, V. (eds). Ultra High Pressure Treatments of Foods. United States: Springer.

Stahl, W. and Sies, H. 2005. Bioactivity and protective effects of natural carotenoids. Biochimica et Biophysica Acta (BBA) - Molecular Basis of Disease 1740(2): 101-107.

Swami, S. B., Thakor, N. J., Haldankar, P. M. and Kalse, S. B. 2012. Jackfruit and its many functional components as related to human health: a review. Comprehensive Reviews in Food Science and Food Safety 11(6): 565-576.

Taib, M. R., Muhamad, I. I., Ngo, C. L. and Ng, P. S. 2013. Drying kinetics, rehydration characteristics and sensory evaluation of microwave vacuum and convective hot air dehydrated jackfruit bulbs. Sciences and Engineering 65(1): 51-57.

Tangwongchai, R., Ledward, D. A. and Ames, J. M. 2000. Effect of high-pressure treatment on the texture of cherry tomato. Journal of Agricultural and Food Chemistry 48(5): 1434-1441.

Tauscher, B. 1995. Pasteurization of food by hydrostatic high pressure: chemical aspects. Zeitschrift für Lebensmittel-Untersuchung und Forschung 200(1): 3-13.

Varela-Santos, E., Ochoa-Martinez, A., Tabilo-Munizaga, G., Reyes, J. E., Pérez-Won, M., Briones-Labarca, V. and Morales-Castro, J. 2012. Effect of high hydrostatic pressure (HHP) processing on physicochemical properties, bioactive compounds and shelf-life of pomegranate juice. Innovative Food Science and Emerging Technologies 13: 13-22.

Vargas-Ortiz, M. A., De la Cruz-Medina, J., Espinosa de los Monteros, J. J., Oliart-Ros, R. M., Rebolledo-Martinez, A., Ramírez, J. A. and García, H. S. 2013. Effect of high hydrostatic pressure on the physiology of Manila mango. Plant Foods for Human Nutrition 68: 137-144.