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FULL PAPER

Effect of calcium lactate and sucrose on the quality attributes and storage stability of vacuum impregnated jackfruits

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Abstract

Vacuum impregnation (VI) is a non-destructive unit operation. VI has been extensively studied with regard to the modification of the physicochemical properties of food products. The VI process allows the introduction of cryoprotectants and preservatives into the intercellular spaces of the plant tissues. Jackfruit is rich in nutrients and due to the increasing demand for minimally processed fruits, jackfruits are cut, packed, and stored before being sold to customers. However, minimal processing causes mechanical injury, leading to an increase in metabolic activity. A way of extending the storage stability of minimally processed jackfruit is required. Thus, the objective of this study is to determine the physicochemical and sensory properties, microbiological quality, and storage stability of vacuum impregnated jackfruit using different texture enhancers, calcium lactate (1.5%) and sucrose (20%) sprayed with fermented jackfruit leaf solution (50%) and stored at 4°C. The samples were stored for 10 days and were analyzed every second day. The firmness and microscopic structure of calcium lactate impregnated samples were significantly higher and more rigid than control and sucrose impregnated samples. Sensory evaluation showed that sucrose impregnated samples had significantly higher scores for taste, aroma, and overall acceptability. Based on visual observation, control samples begin to get mouldy from day 6 while both treated samples had zero mould growth throughout storage. In conclusion, VI extends the shelf life of fresh-cut jackfruit up to 10 days by enhancing the texture and slowing the quality degradation. It is believed that VI treatment provides an alternative method to preserve the food quality of fresh-cut fruits.

1. Introduction

Vacuum impregnation (VI) is a processing operation that allows the impregnation of fruit and vegetable in their porous tissues (Tappi *et al*., 2016). Large volumes of intercellular spaces in tissues of fruits and vegetables can be filled with impregnating solution through VI (Radziejewska-Kubzdela *et al*., 2014). The pressure inside is reduced in the first phase of the process which induces the removal of gas from the tissue. The transition in the deformation-relaxation process allows tissue impregnation to occur (Radziejewska-Kubzdela *et al*., 2014). VI is used to directly introduce specific compounds such as cryoprotectants, browning inhibitors, and texture enhancers into the matrix of food tissue (Mao *et al*., 2017). The penetration of the compounds into the tissue matrix is much faster and more homogenous compared to the traditional diffusion process (Tappi *et al*., 2016). It is also used as a pre-treatment for freeze-drying, drying, and freezing.

VI shows a high potential in modifying physicochemical properties and enhancing the sensory attributes of fruits and vegetables (Radziejewska-Kubzdela *et al*., 2014). VI with calcium salts are considered for fortification of fruits to obtain higher calcium content for consumers and it is also found to increase the firmness of the fruits (Tappi *et al*., 2016). Calcium lactate has been used for shelf-life extension of fresh-cut cantaloupe which also led to a higher firmness

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without undesirable bitterness (Mao *et al*., 2017). The VI with sucrose solution increases the nutritive value and modifies sensory attributes (Radziejewska-Kubzela *et al*., 2014). The plant tissue metabolizes the exogenously fed sucrose first, thus it helps in extending the shelf life and decreases the deterioration of the fruit or plant tissue. Therefore, subjecting minimally processed jackfruit to vacuum impregnation may enhance the qualitative parameters of the fruit during storage.

The jackfruit is a tropical climacteric fruit that belongs to the Moraceae family which is native to India and common in Asia, Africa, and some parts of South America (Ranasinghe *et al.,* 2019). The jackfruit consists of 30% of an edible portion which is the pulp, 12% seed and about 50% rind which is considered waste (Benkeblia, 2018). The pulp that is usually consumed by people cannot be stored for a long time due to its high perishable nature. Ripe jackfruits tend to face spoilage and rapid deterioration due to the lack of postharvest knowledge (Sagar *et al*., 2018). Jackfruit has a high potential for minimal processing as the edible portion makes up 30 – 35% of the fruit (Ramli *et al.*, 2017). Thus, several attempts have been done to extend the shelf life of jackfruit by processing it into various products such as canned jackfruit, pickled jackfruit, dried jackfruit, and jackfruit puree (Benkeblia, 2018; Ranasinghe *et al.,* 2019). However, it is rarely sold as fresh cut fruit because pre-cut fruits have higher oxidative stress which leads to loss of quality due to the release of enzymes that disintegrates the cell wall and causes microbial contamination (Ramli *et al*., 2017). Therefore, for fresh consumption, jackfruits are usually exported as whole fruits. The demand for marketing jackfruit as ready-to-eat fresh produce has been expanding in the last 20 years due to the increasing demand in the overall fresh produce consumption (Benkeblia, 2018). In 2017, the export of jackfruit from Malaysia to UAE increased to RM 278,460 (19.9 mt) sales per year (Safari *et al.,* 2019). Full-ripe jackfruit has a shorter shelf life, which is around five to six days, so the jackfruit must reach the importer's retail stores within the 6 days of shelf life (Safari *et al.,* 2019). This short period creates constraint and pressure for the exporters, and they are constantly looking forward towards enhancement of postharvest technologies to be able to retain the freshness and extend the shelf life of fresh fruits (Safari *et al.,* 2019).

Solutions that were proposed to enhance the shelf life of fresh-cut jackfruit are Modified Atmosphere Packaging (MAP) with storage at low temperature can extend the shelf life of the jackfruit and pretreatment with 1-methycyclopropane (1-MCP) together with the application of edible coating as it reduces respiration rate, ripening rate and weight loss of the jackfruit (Ranasinghe *et al*., 2019). In the same way, VI of calcium lactate and sucrose in jackfruits tend to help in extending the shelf life. Information regarding the effectiveness of impregnation of calcium lactate and sucrose on the physicochemical properties of jackfruit is still not well explored. However, findings by Tappi *et al*. (2016) and Mao *et al.* (2017) prove that calcium lactate and sucrose improve the firmness of fruits and vegetables and this finding opens a wide range of possibilities for improving the storage ability of jackfruits. The main purpose of this study was to determine the effectiveness of vacuum impregnation together with a coating of fermented jackfruit leaves. The effect of textural enhancers such as calcium lactate and sucrose on the quality and storage stability of fresh-cut jackfruits were investigated also.

2. Materials and methods

2.1 Sample collection and analysis

Jackfruit samples were purchased from Pasar Borong Selangor as a whole fruit. The whole fruit was cut, and the fruitlets were removed. The fruitlets were visually inspected. Fruitlets that are in regular shape, free from defects, well-matured were selected to be used as samples. Samples were also in standard size 41.3±0.5 g, 6.0±0.2 cm (length), 3.7±0.4 cm (width). The samples were divided into three groups which are control, impregnated with 1.5% calcium lactate and impregnated with 20% sucrose. All samples were sprayed with 50% fermented jackfruit leaf solution. The control and impregnated samples were then subjected to 2, 4, 6 and 10 days of storage at chilled temperature (4±0.3°C). All samples were triplicates to ensure reproducibility.

2.2 Impregnating solutions

According to Naser *et al.* (2018), persimmon fruit slices were treated with three levels of calcium lactate which were 0%, 0.5% and 1%. According to Lovera *et al.* (2014) papaya cubes were subjected to calcium lactate concentration of 0.5% and 1.5%. Thus, the jackfruit bulbs were subjected to 3 concentrations of calcium lactate (0.5%, 1.5% and 2%). The concentration of calcium lactate solution was determined after determining the level of bitterness being imparted by the solution. A 1.5% concentration of calcium lactate (w/v) was ideal as it did not give off a significant bitter taste in the fruit. Sucrose concentration was determined by identifying the isotonic solution by immersing the fruits in various sucrose concentrations (4%, 8%, 12%, 16% and 20%) for a period of 6 hrs. The weight loss was recorded at every hour and the concentration was selected based on the lowest weight loss recorded by the

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samples for 6 hrs. Sucrose solution (20% w/v) was determined as the isotonic sucrose solution after the weight loss recorded was the lowest throughout the 6-hour period. Yadav and Singh (2012) reported that the appropriate time to identify the best sucrose concentration is 6 hrs.

2.3 Vacuum impregnation

Fruitlets were submerged in a beaker containing the solutions of interest and were immediately introduced to VI process at temperature of 25±2°C, which was carried out in a desiccator connected to a vacuum controller (VACUUBRAND GMBH + CO KG, Wertheim, Germany) and a vacuum pump, as described by Panarese *et al*. (2013). Based on preliminary experiments, a protocol with a minimum absolute pressure of 150 mbar is chosen to establish maximum weight gain and avoid tissue damage. During the first phase of VI, the pressure was gradually decreased from 1000 mbar to 150 mbar and was kept at 150 mbar for 10 mins. During the second phase, the vacuum was released, and the pressure progressively increased to atmospheric pressure and was kept at atmospheric pressure for 20 mins. The total treatment time was 60 mins, and this cycle was repeated twice. After VI process, the excess solution on the surface of the fruitlets was removed with tissue paper and the weight gain of each fruitlet was recorded.

2.4 Fermented jackfruit leaves solution

Vacuum impregnated fruitlets were sprayed with fermented jackfruit leaves solution, which was prepared according to the Koh *et al*. (2020) procedure. Each sample was coated with 0.5 mL solution and the solution was sprayed homogenously using a spray bottle for all sides.

2.5 Storage of samples

Non-impregnated and impregnated fruitlets were placed in a closed polystyrene container (4 fruitlets per container) with saturated humidity and left in darkness at 4±0.3°C for 0, 2, 4, 6, 8 and 10 days.

2.6 Physical analysis

2.6.1 Weight gain

The initial weight of the samples was recorded. After impregnation, the weight of the samples was recorded as the samples were weighed again using an analytical balance (Mettler Toledo, USA). The weight gain was determined by subtracting the final weight of the sample with the initial weight. The experiment was done in triplicates for each non-impregnated and impregnated fruitlet.

$$\text{Weight gain (\%)} = \frac{\text{initial weight} - \text{final weight}}{\text{initial weight}} \times 100$$

2.6.2 Drip loss

The weight of non-impregnated and impregnated fruitless was recorded before and after storage at 4±0.3° C for every 2 days until 10 days. The drip loss of the fruitlets was expressed as the percentage (%) according to the storage period of 0, 2, 4, 6, 8 and 10 days. The experiment was done in triplicates for each non-impregnated and impregnated fruitlet.

2.6.3 Colour analysis

The colour measurements were performed using a chroma meter (CR-410, Konica Minolta, Chiyoda City, Tokyo, Japan). The illumination area and observer of ϕ50 mm/ϕ53 mm and 2° closely matches CIE 1931 Standard Observer (illuminant D65) were used, respectively. The L*, a*, b* values of the fruitlets were recorded for non-impregnated and all impregnated fruitlets every 2 days for 10 days. The experiment was done in triplicates for each non-impregnated and impregnated fruitlet.

2.6.4 Texture analysis (Firmness)

The firmness of the samples was determined using TA.HD.plus Texture Analyser (Heavy Duty Texture Analyser, Stable Micro Systems, UK). The procedure was set up according to a previous study carried out also with fresh-cut melon samples (Raybaudi-Massilia *et al*., 2008). A 2 mm diameter stainless steel cylindrical probe with a flat end was used and resistance strength of samples (15 mm diameter and 20 mm height) against 10 mm penetration distance at a rate of 5.0 mm/s was measured as peak force (N). Samples were analysed according to the storage period of day 0, 2, 4, 6, 8 and 10. The experiment was done in triplicates for each non-impregnated and impregnated fruitlet.

2.6.5 Overall visual observation

The visual observation of non-impregnated and all impregnated fruitlets was taken with a camera (Apple iPhone 6 Plus, Apple Inc., Hessen, Germany) for every 2 days for 10 days. The appearance, colour, presence of moisture, odour and mould growth were observed. The experiment was done in triplicates for each non-impregnated and impregnated fruitlet.

2.7 Chemical analysis

2.7.1 Soluble solid content

Non-impregnated and impregnated fruitlets were blended in a ratio of 1:2 and 1 mL of the filtered juice was used to determine the total soluble solids using a digital refractometer (PR-201α, ATAGO, Tokyo, Japan). The total soluble solids were expressed as Brix. The experiment was done in triplicates for each non-

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impregnated and impregnated fruitlet.

2.7.2 pH value

The samples were homogenized with water in the ratio of 1:2. Clear juice were obtained by filtering the fruit juice. The pH value was measured using a pH meter 3505 (Jenway, UK). Samples were analyzed according to the storage period of day 0, 2, 4, 6, 8 and 10. The experiment was done in triplicates for each non-impregnated and impregnated fruitlet.

2.7.3 Ascorbic acid content

Ascorbic acid standard solution, 10 mL was titrated with dye solution until a permanent faint pink Colour was obtained. The amount of dye solution required to oxidize 1 mg of ascorbic acid was recorded. The samples were then weighed to 40 g and homogenized with 200 mL of oxalic acid for 3 × 10 s. The homogenized solution was filtered through cotton wool, washed with oxalic acid and the volume of filtrate was determined (V_f). The filtrate, 10 mL was titrated with the dye solution and the ascorbic acid content in the sample was then calculated as mg/100 g sample. Samples were analyzed according to the storage period of day 0, 2, 4, 6, 8 and 10. The experiment was done in triplicates for each non-impregnated and impregnated fruitlet.

$$\text{Dye factor} = \frac{\text{amount of ascorbic acid in 10 mL standard solution}}{\text{Vol. of dye to oxidise 1 mg ascorbic acid}}$$

$$\text{Ascorbic acid content } \left(\frac{\text{mg}}{100\text{ g}}\right) = \frac{\text{titre (ml)} \times \text{dye factor (mg/mL)} \times \text{Vf} \times 100}{\text{aliquot for extraction (g)} \times \text{Vs}}$$

2.7.4 Reducing sugar content

Samples were blended and 5 mL of sample was diluted into a 250 mL volumetric flask. Solution of 10 mL is then transferred into 100 mL volumetric flask and diluted to volume. Copper reagent, 2 mL is added to all tubes and mixed well followed by 10 mins of vigorous heating in boiling water bath and cooled under running water for 5 mins. Arsenomolybdate reagent, 1 mL were added to all the tubes and mixed well. The absorbance of the blanks, samples and standard sugar solutions was read at 520 nm using a spectrophotometer (Perkin Elmer, USA).). The average absorbance of a blank was subtracted from the average absorbance of the samples and the sugar content is determined from a curve previously established with sugar solutions. Samples were analyzed according to the storage period of day 0, 2, 4, 6, 8 and 10. The experiment was done in triplicates for each non-impregnated and impregnated fruitlet.

$$\text{Amount of sugar in sample, X2} = (\text{X1} \times \text{DF of Solution A} \times \text{DF of Solution B} \times \text{DF of solution in the tube})$$

2.8 Sensory evaluation

A total of 60 untrained panelists aged from 22 to 35 corresponding to 25 men and 35 women were involved in the sensory evaluation. They were required to evaluate the non-impregnated and impregnated fruitlets of 0, 2, 4, 6, 8 and 10 days in terms of Colour, aroma, flavour (sweetness), texture (firmness), chewiness, aftertaste and overall appearance. For each category, they were given a 7-points Hedonic scale (7 – extremely like; 4 – neither like or dislike; 1 – extremely dislike).

2.9 Microscopic structure properties

The sample was cut into a number of 1 cm^2 slice, put into separate vials and fix in a fixative (4% Glutaraldehyde) for 2 days at 4°C. The samples were then washed with 0.1 M Sodium Cacodylate Buffer for 3 changes of 30 mins each and post fix in 1% Osmium Tetroxide for 2 hrs at 4°C. Samples were then washed again with 0.1 M Sodium Cacodylate Buffer for 3 changes of 30 mins each, followed by dehydration with a series of acetone. The samples are transferred into specimen basket and put into a critical dryer for about 30 mins and then stuck onto the stub using double-sided tape or colloidal silver and were gold coated in a sputter coater. The samples were then viewed under Scanning Electron Microscope (SEM) (Oxford Instruments Nano Analysis, United Kingdom).

2.10 Statistical analysis

The statistical significance (p<0.05) of the treatments was tested by means of two-way analysis of variance (ANOVA) using Minitab Statistical Software (Minitab 19, LLC, Dayton, OH, USA). The Tukey–Kramer multiple comparison test was used to evaluate true differences in treatment means.

3. Results

3.1 Physical analysis

3.1.1 Weight gain

Figure 1 shows the significant increase of weight gain for calcium lactate and sucrose impregnated jackfruits as compared to the initial weight of 41.3±0.5 g.

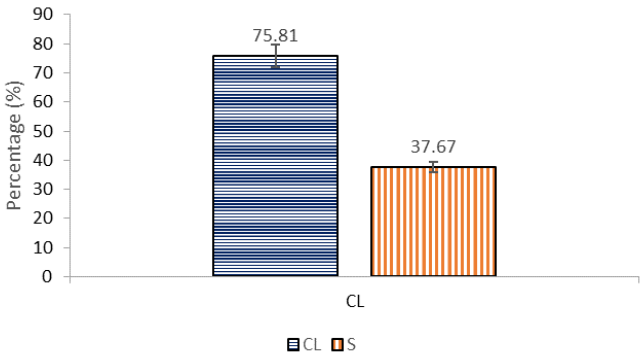

Figure 1. The weight gain of jackfruit samples after vacuum impregnation with calcium lactate (CL) and sucrose.

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The weight gain was recorded as 75.81% and 37.67% of jackfruit after impregnation with 1.5% (w/v) of calcium lactate and 20% of sucrose, respectively.

3.1.2 Texture analysis (firmness)

Figure 2 shows that there was a significant decrease in the firmness of the jackfruit pulps after 10 days of storage in all three samples which could be due to the degradation of the cell wall caused by ripening enzymes (Galvez *et al.,* 2019). The firmness of samples impregnated with calcium lactate is significantly higher (380.0 N) compared to control samples (248.44 N) as the application of calcium tends to decrease softening and maintain the firmness of the fruit (Ngamchuachit *et al.,* 2014).

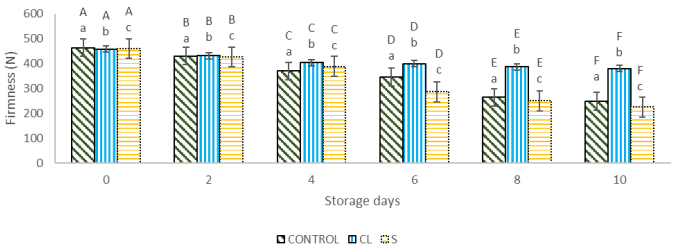

Figure 2. The firmness of jackfruit samples after vacuum impregnation with calcium lactate (CL) and sucrose. Bars are presented as Mean±SEM. Bars with different lowercase notations within the same storage days are significantly different (P>0.05) while bars with different uppercase notations within the same treatment are significantly different (P>0.05).

3.1.3 Colour analysis

Based on Figure 3, the L* values increase and decreases during the storage period. The b* values decreased in all samples throughout the storage period. The L* and b* values correlate with each other as the browning of the sample reduces the lightness and thus, reducing the yellowness of the samples (Ramli *et al*., 2017). The a* values showed an increasing trend throughout storage period for control and treated samples. The L* values and a* values have an inversely proportional correlation as the L* value decreases due to browning, a* value increases (Chauhan *et al*., 2011).

3.1.4 Drip Loss

Figure 4 shows that, after 10 days of storage, the calcium lactate impregnated leaves showed a significant drip loss up to 1.1 mL/g as compared to the initial drip loss of 0.2 mL/g recorded in day 2 of storage. Meanwhile for sucrose impregnated leaves, the drip loss was recorded as 0.14 mL/g at day 10 of storage. Both impregnated samples showed a significant different in drip loss throughout the end of storage as compared to the non-impregnated samples.

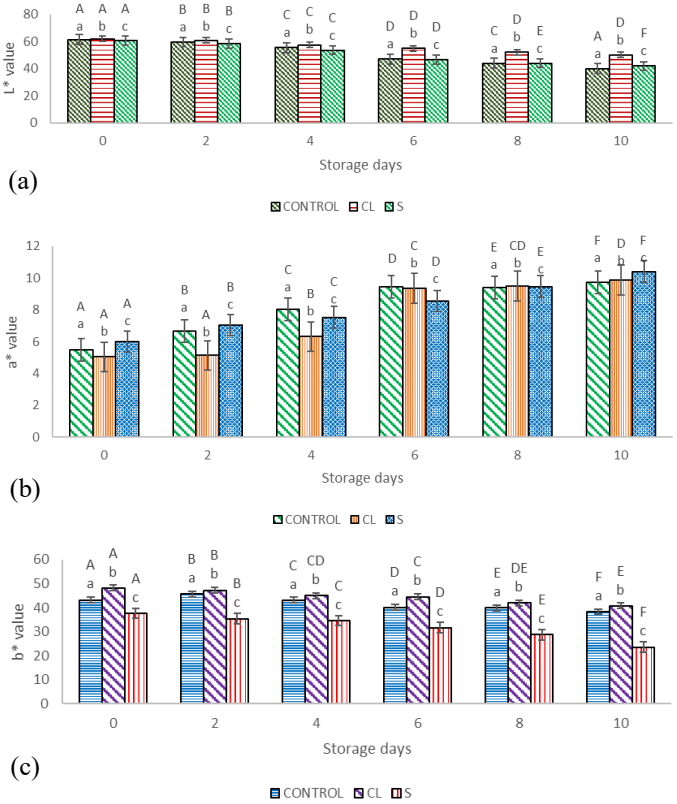

Figure 3. Effect of different impregnating solutions on colour changes during storage at 4 °C. Jackfruits were either non-impregnated or impregnated with 1.5 % calcium lactate or 20 % sucrose solution and were stored for 10 days. Colour parameters: (a) L* (from 0 black to 100 white), (b) a* (from -a* green to +a* red), (c) b* (from -b* blue to +b* yellow). Bars are presented as Mean±SEM. Bars with different lowercase notations within the same storage are significantly different (P>0.05) while bars with different uppercase notations within the same treatment are significantly different (P>0.05).

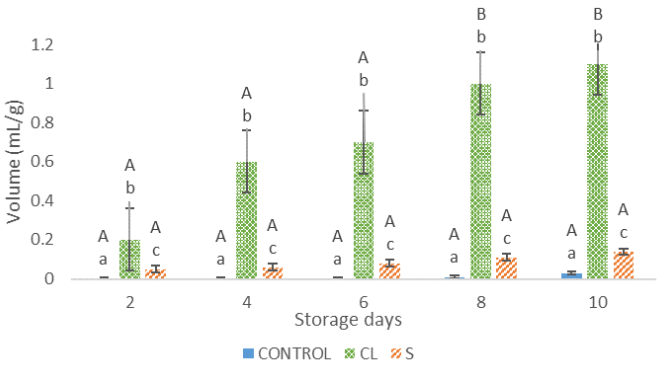

Figure 4. The drip loss of non-impregnated jackfruits, vacuum impregnated with 1.5% calcium lactate and 20% sucrose during 10 days at 4°C. Bars are presented as Mean±SEM. Bars with different lowercase notations within the same storage days are significantly different (P>0.05) while bars with different uppercase notations within the same treatment are significantly different (P>0.05)

3.1.5 Visual observation

Table 1 shows the visual observation of non-impregnated jackfruits, calcium lactate, and sucrose impregnated samples throughout 10 days of storage in

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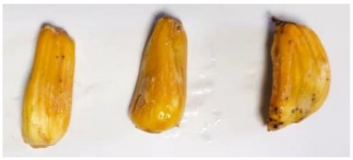
Table 1. Visual changes of control, calcium lactate and sucrose impregnated samples throughout the storage period

Day	Control	Calcium lactate	Sucrose
0	 • Sweet aroma • Firm texture • No presence of mould	 • Sweet aroma • Firm texture • No presence of mould	 • Sweet aroma • Firm texture • No presence of mould
2	 • Sweet aroma • Firm texture • No presence of mould	 • Sweet aroma • Firm texture • No presence of mould • Has wet surface	 • Sweet aroma • Firm texture • No presence of mould • Has wet surface
4	 • Sweet aroma • Firm texture • No presence of mould	 • Sweet aroma • Firm texture • No presence of mould • Has wet surface	 • Sweet aroma • Firm texture • No presence of mould • Has wet surface
6	 • Sour aroma • Mushy texture • Presence of mould	 • Bitter aroma (off odour) • Firm texture • No presence of mould • Has wet surface	 • Sweet aroma • Softer texture • No presence of mould • Has wet surface
8	 • Sour aroma • Mushy texture • Presence of mould	 • Bitter aroma (off odour) • Firm texture • No presence of mould • Has wet surface	 • Sweet aroma • Soft texture • No presence of mould • Has wet surface
10	 • Sour aroma • Mushy texture • Presence of mould	 • Sour aroma • Firm texture • No presence of mould • Has wet surface	 • Sweet aroma • Soft texture • No presence of mould • Has wet surface

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chilling condition. It can be seen that non-impregnated jackfruits started to appear mouldy as early as 6 days of storage. However, all impregnated jackfruits were still in good condition even on the 10th day of storage. However, the drip loss was detected in all impregnated samples throughout the storage period.

3.2 Chemical analysis

3.2.1 Changes in pH value

Our findings in Figure 5 shows that the increase in pH was observed in non-impregnated and all impregnated jackfruits. Throughout 10 days of storage time, the pH values of non-impregnated, calcium lactate and sucrose were increased gradually up to 5.19, 5.13 and 5.16 respectively. The significant increase in pH was found from the day 0 of non-impregnated jackfruits, calcium lactate, and sucrose impregnated jackfruits where the pH were initially recorded as pH 4.71, 4.76 and 4.88 respectively. The increase in pH during the storage period indicated that the acidity was decreased throughout the storage period (Chulaki *et al*., 2017).

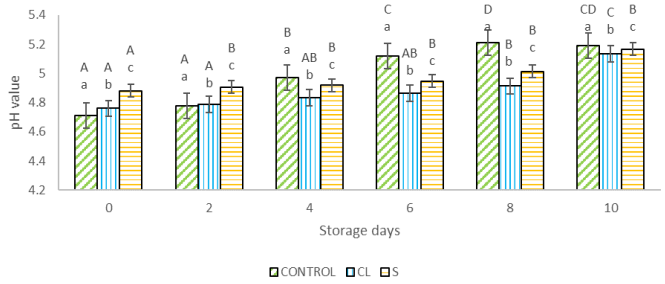

Figure 5. pH value of non-impregnated jackfruits, vacuum impregnated with 1.5 % calcium lactate and 20% sucrose during 10 days at 4°C. Bars are presented as Mean±SEM. Bars with different lowercase notations within the same storage days are significantly different (P>0.05) while bars with different uppercase notations within the same treatment are significantly different (P>0.05).

3.2.2 Reducing sugar content

Figure 6 shows the reducing sugar content in non-impregnated and impregnated jackfruits. Both calcium lactate and sucrose impregnated samples showed an increasing trend of reducing sugar content whereas the non-impregnated samples showed a significant decrease of reducing sugar from day 6 to day 10. Jackfruits impregnated with sucrose has the highest reducing sugar content (3.9 g/mL), followed by calcium lactate impregnated jackfruits (2.7 g/mL) and the lowest was found to be non-impregnated sample (1.8 g/mL) throughout 10 days of storage.

3.2.3 Total soluble solid content

Figure 7 shows that the initial value of total soluble solid recorded by non-impregnated jackfruit was 4.4°Bx. Throughout storage time, total soluble solid content in non-impregnated and all impregnated jackfruits were increasing gradually, with a significant decrease observed on day 2. At the end of storage, sucrose (8°Bx) impregnated jackfruits showed the highest total soluble solid content, followed by calcium lactate impregnated jackfruits (6.4°Bx) and non-impregnated jackfruits (5.0° Bx). Statistical analysis shows that the total soluble solids content for both impregnated leaves for all storage days are significantly different from non-impregnated jackfruits.

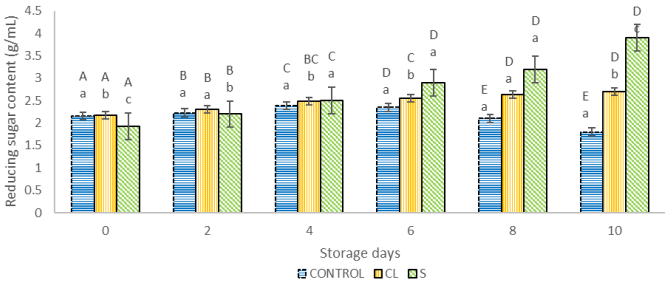

Figure 6. Reducing sugar content of non-impregnated jackfruits, vacuum impregnated with 1.5% calcium lactate and 20 % sucrose during 10 days at 4°C. Bars are presented as Mean±SEM. Bars with different lowercase notations within the same storage days are significantly different (P>0.05) while bars with different uppercase notations within the same treatment are significantly different (P>0.05).

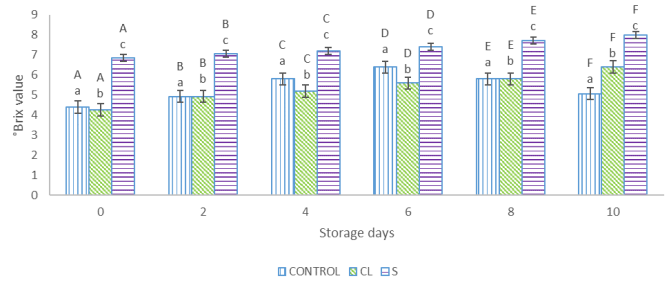

Figure 7. The total soluble solid content in non-impregnated jackfruits, vacuum impregnated with 1.5% calcium lactate and 20 % sucrose during 10 days at 4°C. Bars are presented as Mean±SEM. Bars with different lowercase notations within the same storage days are significantly different (P>0.05) while bars with different uppercase notations within the same treatment are significantly different (P>0.05).

3.2.4 Ascorbic acid content

Figure 8 shows that all 3 samples have decreasing trend of ascorbic acid content as the storage period increases. Ascorbic acid content in non-impregnated jackfruits (0.27 mg/100 g) is significantly lower as compared to the calcium lactate samples (0.59 mg/100 g) and sucrose impregnated samples (0.62 mg/100 g) after 10 days of storage.

3.3 Sensory evaluation

Sensory evaluation was conducted for a total of 14 samples which are day 0 to day 2 of control samples, day 0 to day 8 of calcium lactate impregnated samples and day 0 to day 10 of sucrose impregnated samples. A total

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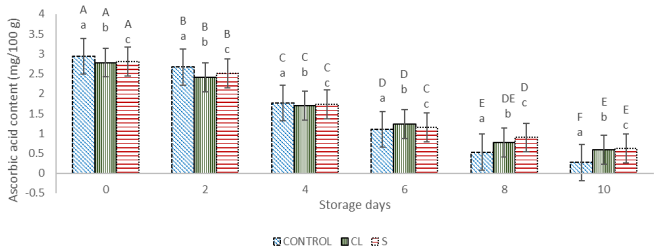

Figure 8. Ascorbic acid content in non-impregnated jackfruits, vacuum impregnated with 1.5% calcium lactate and 20% sucrose during 10 days at 4°C. Bars are presented as Mean±SEM. Bars with different lowercase notations within the same storage days are significantly different (P>0.05) while bars with different uppercase notations within the same treatment are significantly different (P>0.05).

of sixty panelists scored the samples based on their preference using a 7-point hedonic scale of liking. Colour is one of the most important attributes related to the appearance of the sample. All the samples were scored in the range of 5 to 6 in the sensory acceptability test as shown in Figure 9. In terms of aroma attribute, all 3 samples have a decreasing trend throughout storage while calcium lactate impregnated samples recorded the lowest score, and sucrose impregnated samples have the highest score. The flavour attribute displayed similar score as aroma attribute with samples impregnated with sucrose obtaining the highest score while the samples impregnated with calcium lactate obtaining the lowest score. The texture of the samples which is firmness and chewiness of the samples are correlated as depicted in

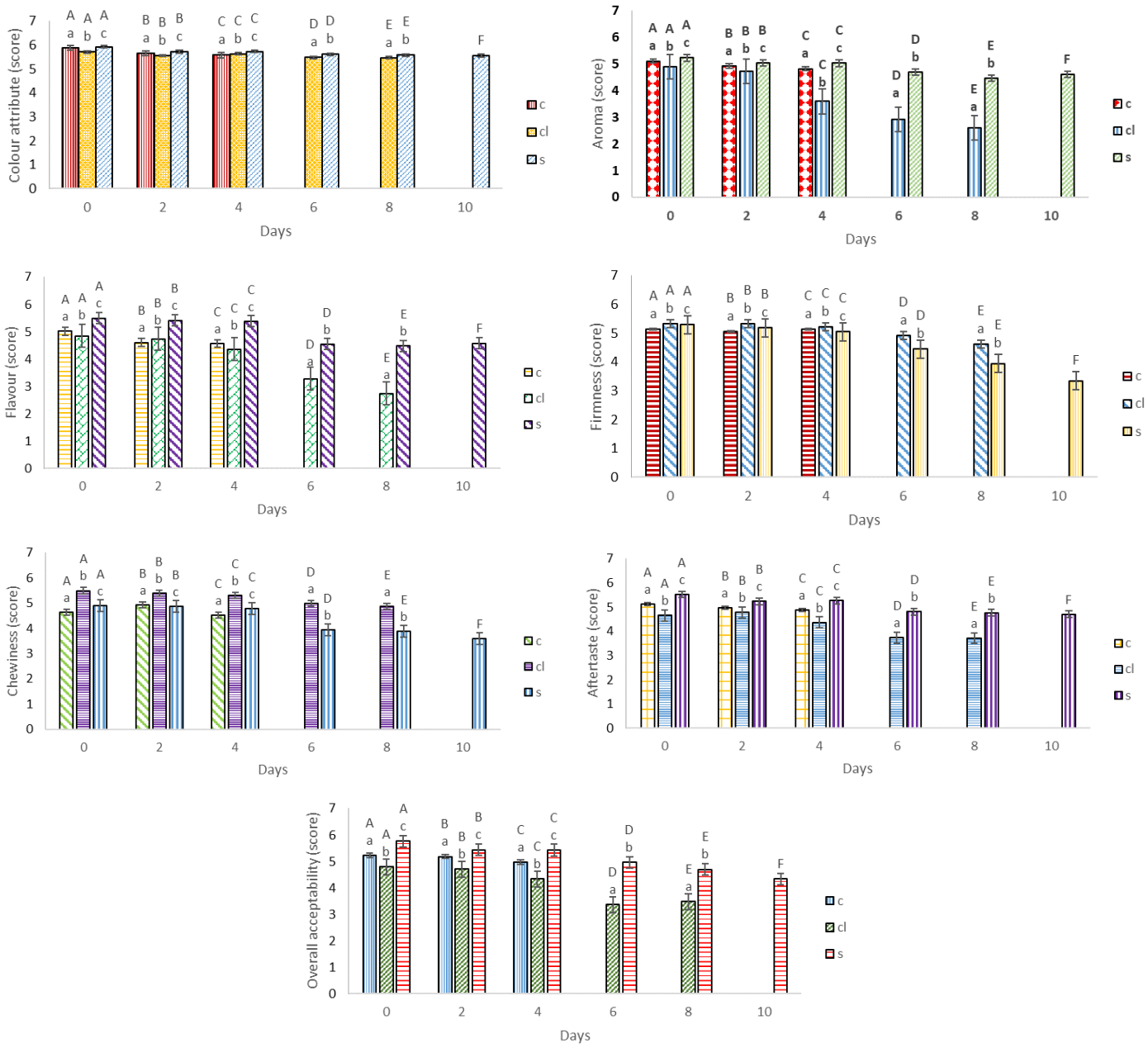

Figure 9. Effect of different impregnating solutions on colour attributes, aroma, flavour, firmness, chewiness, aftertaste and overall acceptability of non-impregnated, calcium lactate and sucrose impregnated jackfruits during storage at 4°C for 10 days. Bars are presented as Mean±SEM. Bars with different lowercase notations within the same storage days are significantly different (P>0.05) while bars with different uppercase notations within the same treatment are significantly different (P>0.05).

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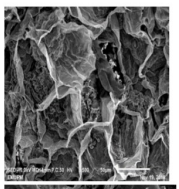
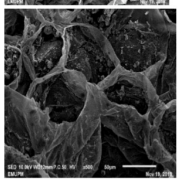
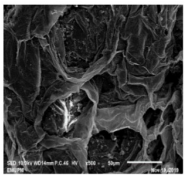
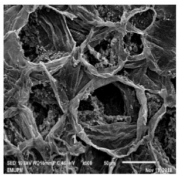
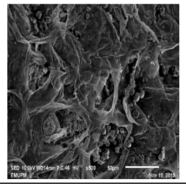
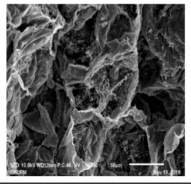
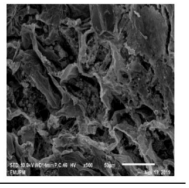
Figure 9. Calcium lactate impregnated samples appeared to have the highest firmness and chewiness scores when compared to other samples. In terms of aftertaste, calcium lactate impregnated samples showed the lowest score indicating the presence of slight bitter aftertaste while sucrose impregnated samples displayed the highest score indicating sweet or pleasant aftertaste. It has been shown that the overall acceptability of samples where sucrose impregnated samples scored the highest, followed by control samples and calcium lactate impregnated samples.

3.4 Scanning electron microscopy

Images from scanning electron microscopy (SEM) of jackfruit (day 0) and calcium lactate and sucrose impregnated samples at 0, 2 and 6 days of storage with the temperature set at 4±0.3°C are shown in Table 2. SEM images demonstrated that the cell walls of calcium lactate and sucrose impregnated exhibited a similar appearance to each other. After 6 days of storage, the cell walls of samples treated with calcium lactate maintained integrity and uniformity when compared to sucrose impregnated jackfruits. They suggested that the ionic bonds formed between pectic polymers and calcium maintained the cell wall strength. The stability and rigidity of the cell wall structure of calcium lactate impregnated samples were more significant when compared to sucrose impregnated samples.

Table 2. SEM images of control sample on day 0 and calcium lactate and sucrose impregnated samples on storage days 0, 2 and 6

Day	0	2	6
C		-	-
CL			
S			

4. Discussion

4.1 Weight gain and drip loss

The result clearly indicated that impregnation level is highly influenced by the viscosity of the medium (Tappi *et al*., 2016) (Figure 1). Calcium lactate had much lower viscosity (1.5%) when compared to sucrose (20%) which may cause it to seep out during the storage period, subsequently leading to drip loss of the samples due to the mechanism used in vacuum impregnation (Scholten and Peters, 2012).

4.2 Firmness

The firmness of samples impregnated with calcium lactate is significantly higher than the other samples (Figure 2). This may be due to the accumulation of calcium in the cell wall that induces the cross-linking of pectic polymers that increase the strength of the cell wall and cohesion (Shirzadeh *et al*., 2011). Awang *et al*. (2011) reported that calcium treatment either maintains or increases the firmness of infected fruit. The impregnation of sucrose depends on the vacuum pressure and relaxation time. However, this could lead to the alteration of the cell wall and middle lamella which causes the lowering of the fruit firmness (Phianmongkhol and Wirjantoro, 2016). This justifies the result where sucrose impregnated samples have the lowest firmness at the end of 10 days of storage.

4.3 Colour

Control sample has the lowest L* value as it develops browning more rapidly than treated samples (Ranasinghe *et al*., 2019) as shown in Figure 3. Ramli *et al*. (2017) reported that samples impregnated with calcium have the same trend as control samples in terms of L* value and calcium treatment does not prevent browning in the jackfruit pulps. The reduction in L* value is also affected by the solid uptake when the air in the fruit pores is replaced by an external solution during VI as it causes a homogenous refractive index in the sample, making the sample darker (Rongkom *et al*., 2015). Degradation of carotenoid contributes to browning in calcium impregnated samples and loss of fruit pigments during the vacuum impregnation of sucrose in samples may lead to a decrease in b* values (Phianmongkhol and Wirjantoro, 2016; Ramli *et al*., 2017). The increase in a* values indicates a dull visual appearance in the jackfruit pulps stored for a period of time (Ranasinghe *et al*., 2019). The increase in redness may be due to the solid uptake during the impregnation process of the samples (Chauhan *et al*., 2011). The justifications were observed similarly for both control and treated samples.

4.4 Visual observation

Table 1 shows the visual changes of control, calcium lactate and sucrose impregnated jackfruits. The results demonstrated that the calcium lactate and sucrose

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impregnated samples showed a similar appearance when compared to the initial sample, even after being stored for 10 days. Whereas for the control sample, the sour aroma, mushy texture and presence of moulds have been detected after 6 days. The calcium lactate exhibits a natural antimicrobial solution; thus, the shelf life of the calcium lactate impregnated samples was extended (Acedo *et al.,* 2013). Sucrose impregnated samples also have a longer shelf life due to the consumption of exogenous sucrose solution that serves as a substrate for metabolism prior to the exhaustion of storage sucrose in the plant tissue (Li *et al*., 2019). However, the total storage days of samples were fixed at 10 days due to the presence of a sour aroma in treated jackfruit samples on the 12th day.

4.5 Changes in pH, reducing sugar and total soluble solid content

Shirzadeh *et al.* (2011) also stated that calcium solution prevents the increase in acidity and has lower acidity values when compared to the control. However, the pH of fruit was stated to be unaffected when stored in sweetened sucrose solutions as hygroscopic properties in sugar tend to prevent changes in the organic acid content (Tua *et al*., 2018). The increase in the reduced sugar content is contributed by the gradual inversion of non-reducing sugar to reducing sugar (Shwetha and Ranganna, 2018). Samples impregnated with sucrose have the highest reducing sugar content throughout the storage period (Figure 6). This may be due to the external sucrose source impregnated into the samples. This addition of sugars also increases the total soluble solid content of samples (Magwaza and Opara, 2015). However, total soluble solid content tends not to be influenced and there are no significant changes in the samples after being treated with calcium (Shirzadeh *et al*., 2011; Awang *et al*., 2012).

4.6 Changes in ascorbic acid content

According to Dhaka *et al*. (2016), ascorbic acid content tends to decrease irrespective of treatments as the decomposition of vitamin C is influenced by the storage period as it follows the first order of kinetics. Not only that but it is also reported that the synergistic effect of the storage period and treatment showed no significant effect as the prolonged storage period decreases the ascorbic acid content in all treated samples (Yadav and Singh, 2012).

4.7 Sensory evaluation

Samples stored in chilled storage tend to retain their colour as cold temperature reduces the biological reactions and respiration in the fruits (Galvez *et al.*, 2019). Ripening also enhances carotenoid pigment and produces a more intense colour. However, the decrease in the colour score throughout storage may also be caused by browning or Maillard reaction during the storage period (Chauhan *et al*., 2011). Calcium lactate impregnated samples imparted bitter aroma mixed with sweetness aroma from the ripening of the pulps (Galvez *et al.*, 2019). The mixture of this aroma may have come out as off-odour as detected by the panellists. Samples impregnated with sucrose imparted a sweet aroma throughout the storage period. The flavour is closely related to the aroma produced by the samples. Calcium lactate impregnated samples were found to have a slight bitter taste which is not typical jackfruit taste. Sucrose treated samples showed a significantly higher score for taste and flavour (Chauhan *et al*., 2011).

Calcium lactate impregnated samples have the highest firmness and chewiness scores. Vasudeva *et al*. (2019) also reported that calcium-treated pulps retained the texture and obtained a higher acceptability score. Sucrose impregnated samples may have a lower score in firmness and in chewiness due to the changes in the cell wall structure and composition (Galvez *et al.*, 2019). Fruits with lower or no calcium content were preferred by consumers as they can detect bitterness or off-flavour in samples treated with calcium (Ngamchuachit *et al*., 2014). On the other hand, samples impregnated with sucrose do not produce a bitter or sweet aftertaste. In fact, it provides a pleasant consumption to the panellists (Rocha and Bolini, 2015). Samples impregnated with sucrose showed a significantly higher score for colour, aroma, flavour and aftertaste. Similar studies have also been reported by Chauhan *et al*. (2011) as samples treated with sucrose had significantly higher score values for taste and aroma. The poor sensory acceptance of calcium lactate impregnated samples may be due to a lack of sweetness in samples and an unpleasant aftertaste (Vasudeva *et al*., 2019).

4.8 Scanning electron microscopy

Calcium lactate treated samples were observed to contain calcium deposits on the surface of the cell wall and the structure of the cell wall was not destroyed during the treatment (Table 2). Samples impregnated with sucrose showed the deterioration of the cell wall which is associated with a high concentration that leads to the collapse of intercellular spaces. This could be due to stress and rupture of the cell wall that is commonly observed in fresh fruit samples treated with sucrose solutions (Yadav and Singh, 2012). Observation for control samples on day 2 and day 6 was not made available due to some technical errors during the handling of the samples.

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5. Conclusion

In conclusion, the effectiveness of VI in extending the shelf life, improving the storage stability and maintaining the food quality of fresh-cut jackfruit was revealed. It was obvious that vacuum impregnation with calcium lactate had much better structural stability and rigidity while the vacuum impregnated with sucrose samples had better overall acceptability. Both treated samples had a shelf life up to day 10 while control samples had a limited shelf life up to day 6. The calcium lactate impregnated samples were significantly firmer. On the other hand, sucrose impregnated samples showed significantly higher reducing sugar and total soluble solid content. Ascorbic acid content was reduced throughout the storage period for all samples. The rigidity of the calcium lactate impregnated samples was justified through the microscopic structure viewed under SEM. The sensory evaluation concluded that sucrose impregnated samples were preferred over calcium lactate impregnated samples as they showed higher scores for taste, aroma and overall acceptability up to day 10 of the storage period. This finding opens up a new possibility for the usage of VI on fruits and vegetables especially using calcium lactate and sucrose to enhance storage stability.

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