Application of Calcium Chloride Inhibits Physicochemical Changes of Fresh-Cut Tropical Fruit

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Abstract. This study evaluated the impact of calcium chloride application on the physicochemical properties of fresh-cut tropical fruits during storage. Specifically, calcium chloride was applied to fresh-cut mango, mangosteen, and rambutan, and their physical changes were monitored over a 9-day storage period. The purpose of this study was to investigate the influence of calcium chloride concentration and immersion time on inhibiting the physicochemical changes of fresh-cut tropical fruits. The acidity, vitamin C, moisture content, total solids, weight loss, texture, colour (L*a*b*), and browning index of coated and uncoated samples are determined during the storage process at 3, 6, and 9 days, respectively. Subsequently, the fresh-cut mangoes are prepared with seedless cuts, while mangosteen and rambutan are simply prepared by removing the fruit skin. The results showed that layered formulations have the potential to increase the shelf life and maintain the quality of fresh-cut mango and rambutan for 6 days and mangosteen for 9 days. The calcium chloride coating with a concentration of 1% and an immersion time of 10 minutes is most effective compared to other treatments.

1 Introduction

The consumption of tropical fruits to strengthen the body's immune system has increased significantly during the COVID-19 pandemic. Among these, mangosteen, mango, and rambutan are especially favored by consumers, not only for their appealing flavor but also for their functional health-promoting compounds. However, these fruits are highly perishable, often experiencing rapid spoilage and weight loss of around 20–50%. Consumer acceptance is frequently influenced by visible damage to the inedible parts, such as the peel, even though the edible portion may still be suitable for consumption.. Notably, the proportion of non-edible parts is relatively high compared to the edible fraction (63–75% in mangosteen, 22–29% in mango, and 52–57% in rambutan), thereby contributing to household organic waste.. This situation has led to a greater demand for minimally processed fruit products,

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commonly referred to as fresh-cut, which emphasise the “what you see is what you eat” principle.. The trend is further supported by consumer preferences for convenient, fresh, and high-quality products that require minimal preparation time.

Minimal processing refers to a series of preparatory and handling steps applied to fruits, including peeling, cutting, slicing, removing pith, washing, and packaging]. Fresh-cut products derived from this process offer several advantages, including providing consumers with diverse options, ensuring the desired quantity of freshness, simplifying quality assessment, reducing bulk volume, and lowering transportation costs. However, these products also have notable drawbacks, particularly their higher susceptibility to damage and shorter shelf life compared to intact fruits. The removal of the protective pericarp and the occurrence of tissue injury during minimal processing trigger physiological, pathological, and physicochemical alterations. Once fruits are peeled or cut, they typically exhibit elevated respiration and ethylene production, degradation of sensory attributes, accelerated ripening, and the generation of undesired metabolic compounds..

Calcium chloride is commonly applied to the surface of fresh-cut fruits as a postharvest treatment. Calcium has been reported to slow down respiration rates, delay senescence, extend shelf life, and enhance tissue firmness. Immersion in a calcium chloride solution promotes the binding of calcium to pectin in the fruit tissue, thereby strengthening the structural integrity of the cells. The higher the concentration of calcium chloride used, the greater the number of calcium–pectin bonds formed, which results in firmer fruit texture. When combined with cold storage, calcium chloride treatment has also been shown to maintain the overall quality of fresh-cut products. However, studies investigating its application on tropical fresh-cut fruits remain limited, particularly regarding the optimal concentration and immersion duration. Therefore, this research was designed to determine the effects of calcium chloride concentration and soaking time on reducing physicochemical changes during the storage of fresh-cut tropical fruits.

2 Research Methods

The fruits used in this study included mangosteen and mango, harvested at 105 days after flowering, and rambutan, harvested at 120 days after flowering. Only fruits that were fresh, defect-free, and uncontaminated were selected. The mangosteen, Harumanis mango, and Aceh rambutan were obtained from Panji Village, Sukasada Sub-district, Buleleng District, Bali Province, Indonesia. The experiment followed a completely randomized two-factor design. The first factor was calcium chloride concentration, with four levels (0.5%, 1.0%, 1.5%, and 2%), while the second factor was immersion duration, with three levels (10, 20, and 30 minutes). Control treatments were included for comparison, and each treatment was replicated three times. The study began with the characterization of intact tropical fruits, including harvest age, maturity stage, skin color, and visual texture. The Harumanis mangoes used as fresh-cut raw material were at the appropriate maturity stage, characterised by dark green skin with a dusty appearance, raised shoulders, curved stalks, rounded apices, a sweet aroma, yellow–orange flesh, less than 15% dirt, and a fruit weight ranging from 350 to 600 g. The selected mangosteen fruit exhibited a greenish-yellow skin with approximately 50% pink spotting, a round, slightly compressed shape, 5–8 flesh segments, fresh green sepals, and a weight of 130–180 g. The Aceh rambutan variety used was fully ripe, as indicated by an evenly red skin, a round to oval shape, long and flexible spines, translucent white flesh, and a weight of 20–30 g.

Prior to processing, all fruits were pre-cooled using the hydrocooling method and then drained. Minimal processing was carried out by peeling and removing the skin and seeds, with stripping performed using a stainless steel knife. The mangoes were cut into cubes measuring 4 × 4 × 1.5 cm (seedless), while the mangosteen was prepared as intact segments, and the rambutan was peeled with the seeds left intact. Each fruit sample was subsequently immersed in calcium chloride solutions of varying concentrations and soaking durations. After treatment, the fresh-cut fruits were drained, air-dried for 20 minutes, and packaged in plastic containers fitted with two ventilation holes (0.5 cm in diameter) on the lid. The packaged fruits were stored in a chiller at 7 ± 1 °C, with observations made on days 0, 3, 6, and 9. Parameters measured included pH, moisture content, total soluble solids, weight loss, texture, color (L*, a*, b*), and browning index. Collected data were analyzed using analysis of variance (ANOVA), and when significant differences were found, Duncan's Multiple Range Test was applied to determine treatment effects on mean values.

3 Results and Discussion

3.1 Degree of acidity (pH)

Acidity (pH) is a key parameter in determining the effectiveness of coating treatments. The concentration of calcium chloride, immersion duration, and their interaction were found to affect the pH of fresh-cut mango and rambutan on storage days 3, 6, and 9. In contrast, significant effects were observed only on day 3 in mangosteen and mango. During storage, mangoes generally showed an increasing trend in pH, mangosteens remained relatively stable, and rambutans exhibited a gradual decrease. The observed pH values ranged from 3.80 to 5.11 for mango, 2.95 to 3.50 for mangosteen, and 2.25 to 4.41 for rambutan. Variations in calcium concentration produced different responses across fruit types, with higher concentrations generally raising the pH of fresh-cut mango and rambutan. These changes are closely associated with fruit ripening, particularly the reduction in total acidity as organic acids are consumed in respiration. Prolonged immersion times also contributed to increased pH values. Overall, pH fluctuations are influenced by the total acid content, where higher acidity corresponds to lower pH. The decline in pH observed in mangosteen is likely due to the breakdown of sugars into organic acids, consistent with earlier findings that fruit acidity peaks during growth and development before declining throughout storage [1].

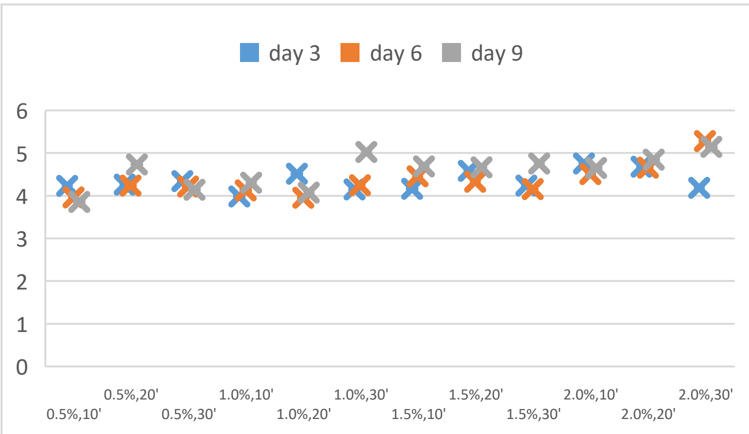

Fig. 1. pH of fresh-cut mango with concentration of calcium chloride (%) and immersion time (minutes) treatment.

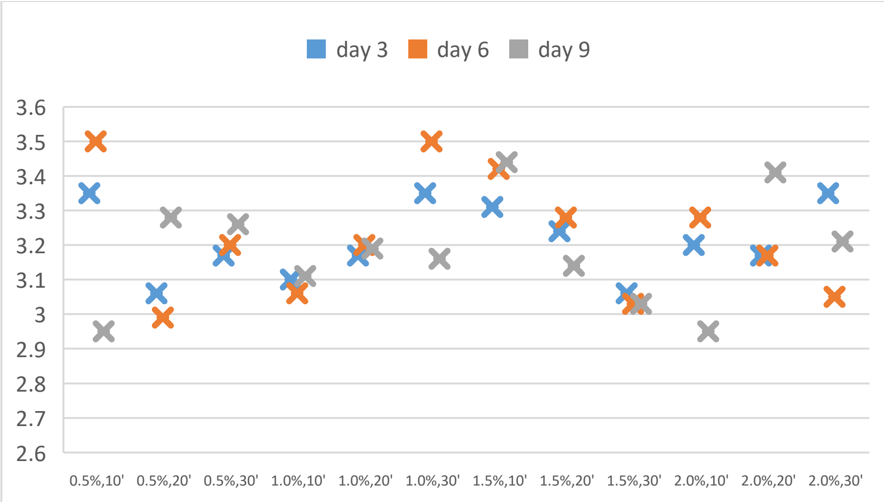

Fig. 2. pH of fresh-cut mangosteen with concentration of calcium chloride (%) and immersion time (minutes) treatment.

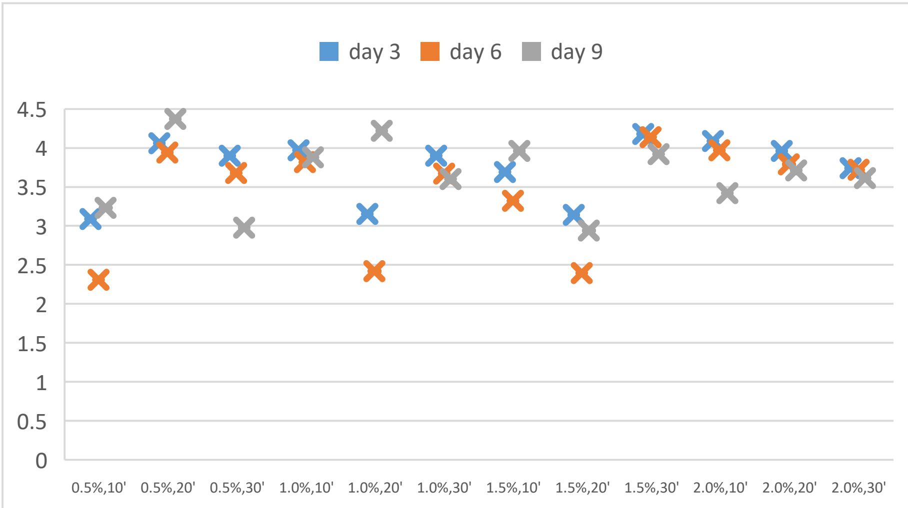

Fig. 3. pH of fresh-cut rambutan with concentration of calcium chloride (%) and immersion time (minutes) treatment.

3.2 Moisture content

Moisture content is a critical parameter influencing fruit quality, particularly its firmness and texture]. The results indicated that calcium chloride concentration, immersion time, and their interaction significantly affected the moisture content of fresh-cut mango on day 9, while for mangosteen and rambutan, the effects were observed on days 3, 6, and 9, respectively. Across treatments, the moisture content of fresh-cut mango ranged from 72.14% to 82.26%, mangosteen from 78.85% to 83.91%, and rambutan from 76.98% to 84.16%. The highest retention of moisture was recorded under the 1% calcium chloride treatment with a 10-minute immersion across all three fruit types, suggesting that calcium chloride application can effectively preserve water content during storage. This effect is linked to the role of calcium in strengthening cell structures and enhancing membrane stability, which increases cell

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turgor pressure and contributes to the firmness of the cell. Moreover, calcium ions form cross-links with the carbonyl groups of galacturonic acid, reinforcing pectin networks and retaining water within the tissue [2]. Consequently, calcium treatment helps maintain membrane integrity and tissue texture, thereby supporting higher moisture retention and prolonging the shelf life of fresh-cut tropical fruits.

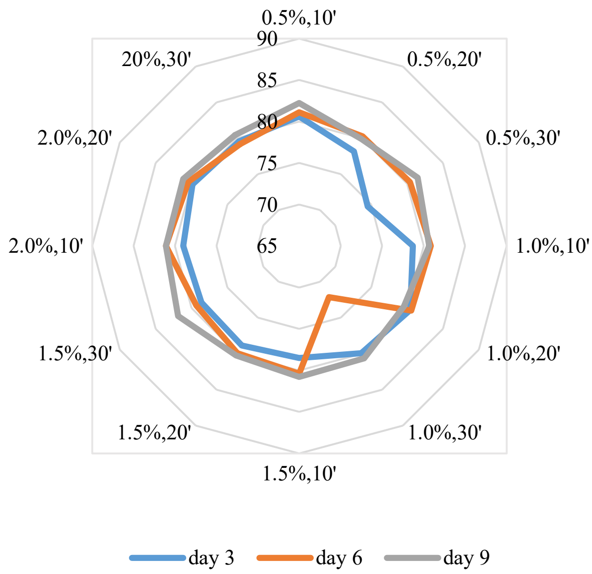

Fig. 4. Moisture content of fresh-cut mango with concentration of calcium chloride (%) and immersion time (minutes) treatment.

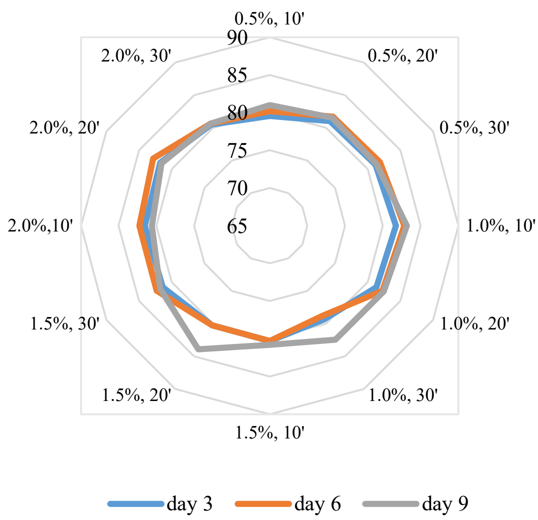

Fig. 5. Moisture content of fresh-cut mangosteen with concentration of calcium chloride (%) and immersion time (minutes) treatment.

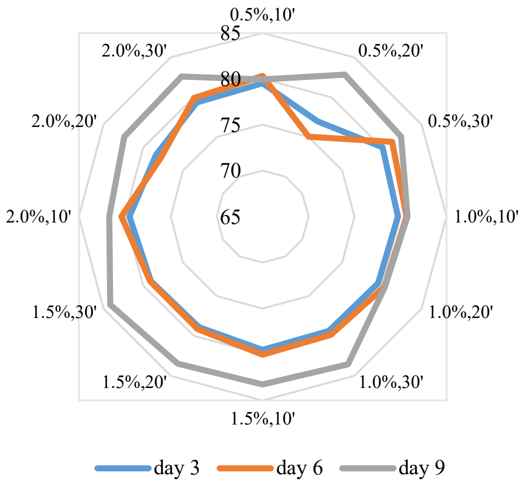

Fig. 6. Moisture content of fresh-cut rambutan with concentration of calcium chloride (%) and immersion time (minute) treatment.

3.3 Total dissolved solids

The concentration of calcium chloride, immersion duration, and their interaction significantly influenced the total soluble solids (TSS) of fresh-cut mango, mangosteen, and rambutan throughout storage (days 3, 6, and 9). TSS values ranged from 20.00–25.00 °Brix in mango, 21.00–25.30 °Brix in mangosteen, and 19.70–25.00 °Brix in rambutan. In all three fruit types, TSS generally increased until day 6 before declining, except in mango, which showed a continuous increase. Higher calcium chloride concentrations elevated TSS levels, likely due to the binding of calcium ions with pectic acid to form Ca-pectate, which suppresses respiration and slows the conversion of sugars into organic acids. In contrast, longer immersion times reduced TSS, as more soluble sugars diffused into the calcium chloride solution. According to [3], higher TSS can inhibit ascorbic acid degradation and protect against oxidation, thereby extending shelf life. Calcium treatments also enhance calcium accumulation in tissues, reducing respiration rates and delaying the conversion of starch into glucose [4]. The observed TSS dynamics—an initial increase during storage due to starch hydrolysis into glucose, followed by a decline—reflect the ongoing balance between sugar formation and utilization for respiration. As noted by [1], starch hydrolysis contributes to glucose accumulation, while the subsequent decrease results from glucose consumption as a respiratory substrate.

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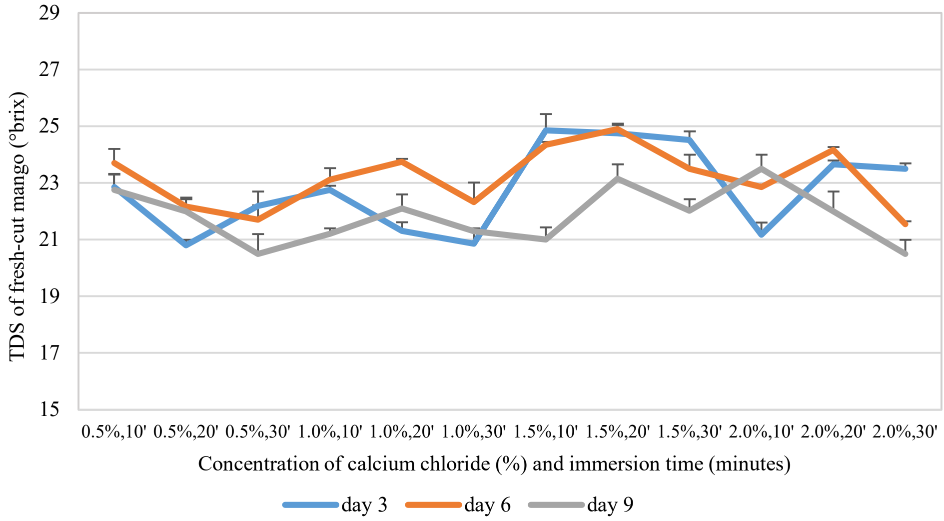

Fig. 7. Total disolved solids of fresh-cut mango with concentration of calcium chloride (%) and immersion time (minutes) treatment.

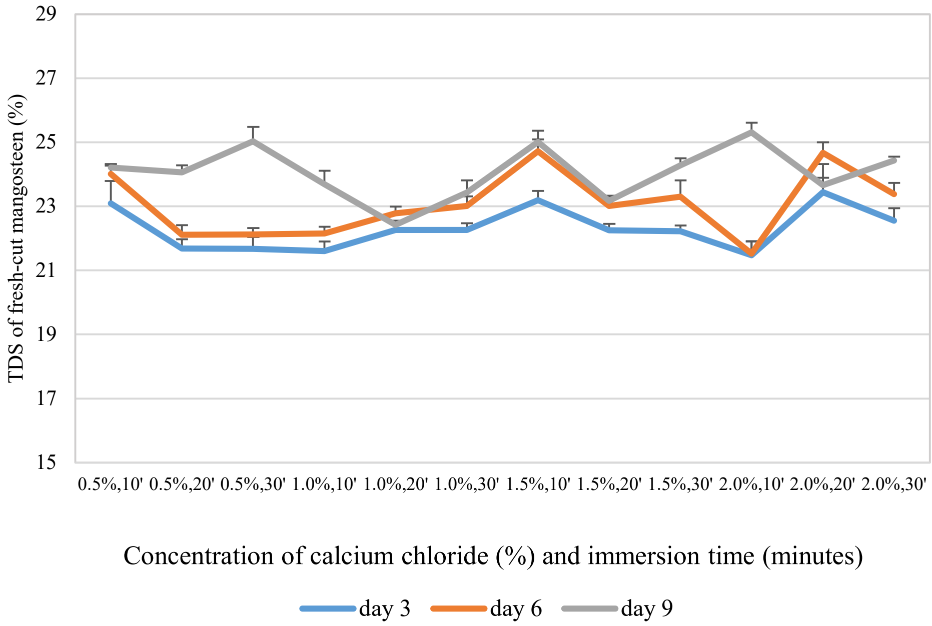

Fig. 8. Total disolved solids of fresh-cut mangoesteen with concentration of calcium chloride (%) and immersion time (minutes) treatment.

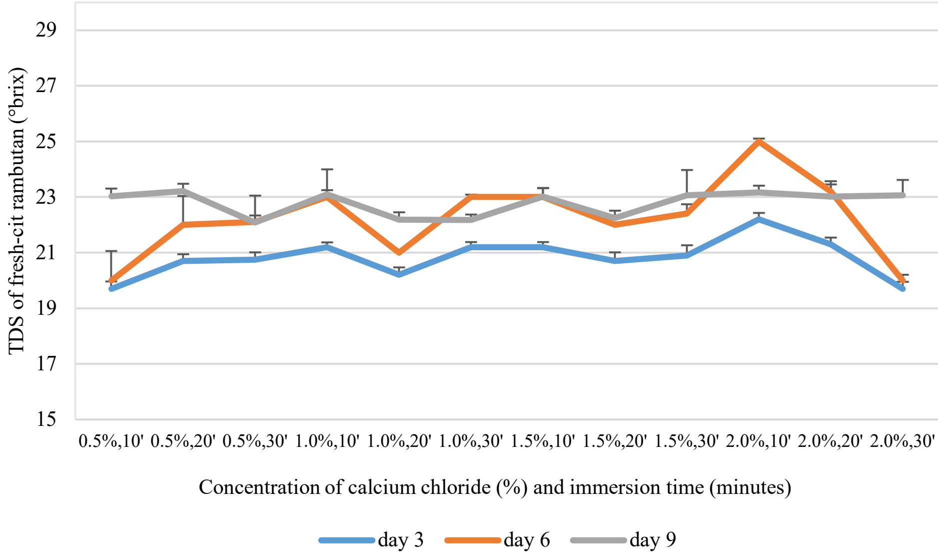

Fig. 9. Total dissolved solids of fresh-cut rambutan with concentration of calcium chloride (%) and immersion time (minutes) treatment.

3.4 Weight loss

Calcium chloride concentration, immersion duration, and their interaction significantly influenced the weight loss of fresh-cut mango, mangosteen, and rambutan during storage (days 3, 6, and 9). In general, weight loss increased until day 6 before declining on day 9, consistent with reports that storage duration strongly correlates with fruit weight and sugar content [4]. Weight reduction in fresh produce is largely attributed to water loss [5]. For mangosteen and rambutan, higher calcium chloride concentrations reduced weight loss, as calcium interacts with pectin in the cell wall to form Ca-pectate, thereby enhancing rigidity, lowering membrane permeability, and slowing respiration and transpiration rates. In contrast, applying higher calcium levels to fresh-cut mango resulted in greater weight loss, likely due to its larger exposed surface area and hydrophilic nature. As storage progresses, respiration and transpiration persist, leading to the depletion of water and organic matter. This aligns with the understanding that intact fruits maintain equilibrium with their environment, whereas fresh-cut products—lacking protective skin and cuticle layers—expose internal tissues and accelerate evaporation. Consequently, weight loss depends heavily on surface area and storage conditions [6]. Prolonged immersion times in calcium chloride solution also contributed to higher weight loss, possibly due to the leaching of soluble components during treatment [7].

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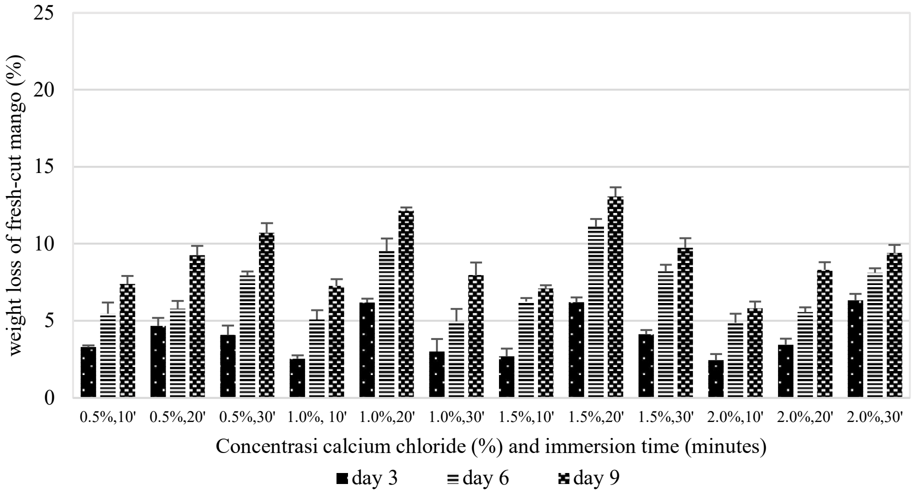

Fig. 10. Weight loss of fresh-cut mango with concentration of calcium chloride (%) and immersion time (minutes) treatment.

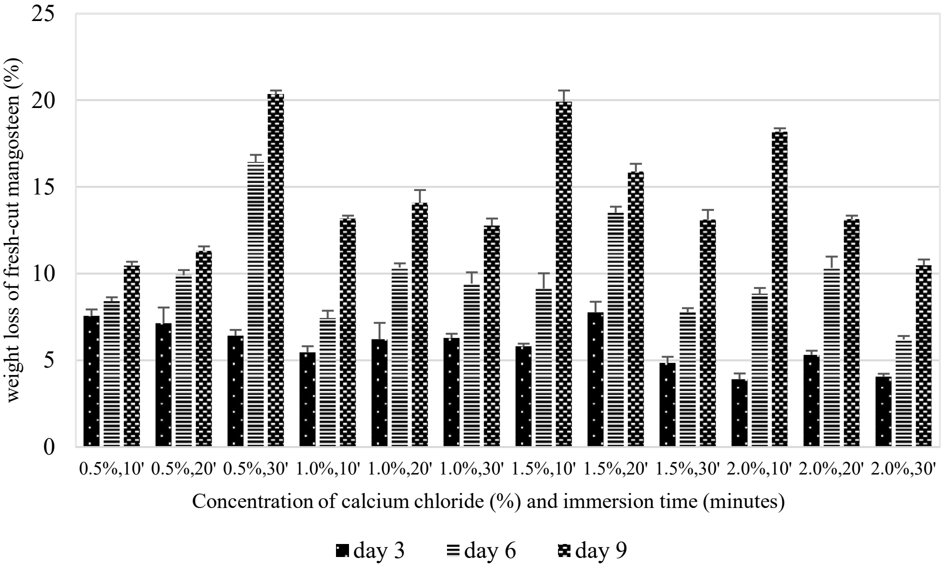

Fig. 11. Weight loss of fresh-cut mangosteen with concentration of calcium chloride (%) and immersion time (minutes) treatment.

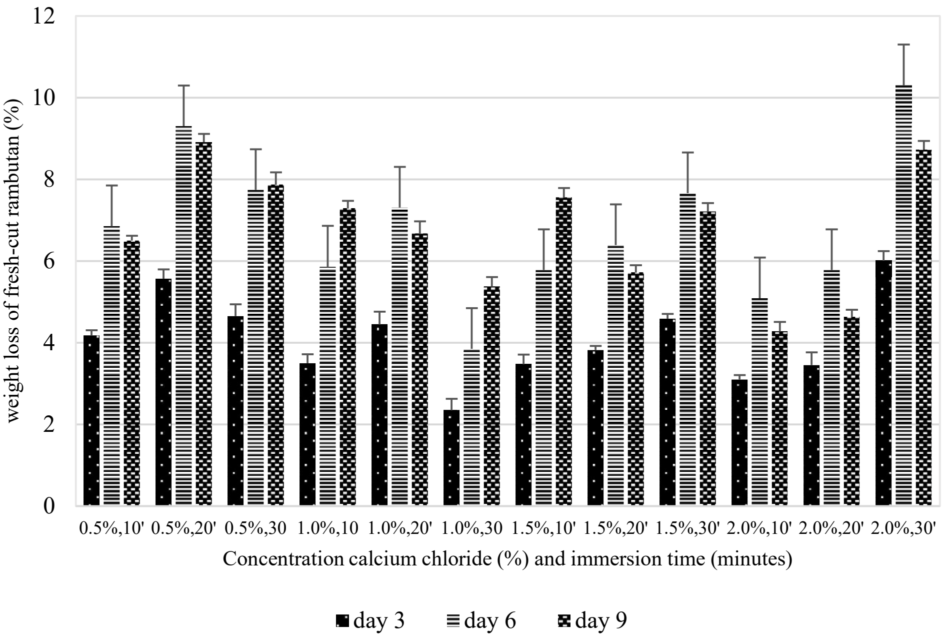

Fig. 12. Weight loss of fresh-cut rambutan with concentration of calcium chloride (%) and immersion time (minutes) treatment.

3.5 Texture

Texture is a critical quality attribute of fresh-cut fruits. The study showed that calcium chloride concentration, immersion duration, and their interaction significantly influenced the texture of fresh-cut mango, mangosteen, and rambutan during storage on days 3, 6, and 9, after which texture values declined. In mango, the cutting size of 4 × 4 × 1.5 cm exposed a large hydrophilic surface area, which reduced calcium adhesion and limited texture improvement. Rambutan exhibited only a short-term increase in firmness until day 3, likely due to its slippery surface that hinders calcium binding. In contrast, mangosteen showed increased firmness up to day 6, suggesting that calcium chloride was more effective in enhancing its texture compared to mango and rambutan. Longer immersion times allowed greater calcium penetration into tissues, thereby strengthening cell wall rigidity. Higher calcium concentrations also promoted the accumulation of calcium within fruit tissues, improving hardness through cross-linking between pectates and polysaccharides via divalent Ca^{2+} ions [8]. Such bonding helps delay softening by reinforcing the cell wall's structural integrity. Previous studies have similarly reported that calcium treatments enhanced fruit texture in tomatoes, apples, and strawberries [9]. The observed texture decline during storage is consistent with reports that cell wall degradation, particularly the breakdown of hemicellulose and pectin into soluble pectic acids, weakens cohesion between cells and results in softening. Pectin, a primary cell wall polysaccharide composed of homogalacturonan and rhamnogalacturonan, plays a central role in maintaining firmness [10]. Enzymatic activity, particularly from pectinolytic enzymes such as pectin methyl esterase and polygalacturonase, further accelerates softening by depolymerising pectin and altering the cell wall structure. Thus, calcium treatment mitigates fruit softening by

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maintaining pectin integrity and improving cell wall stability, ultimately helping preserve the texture of fresh-cut tropical fruits [25].

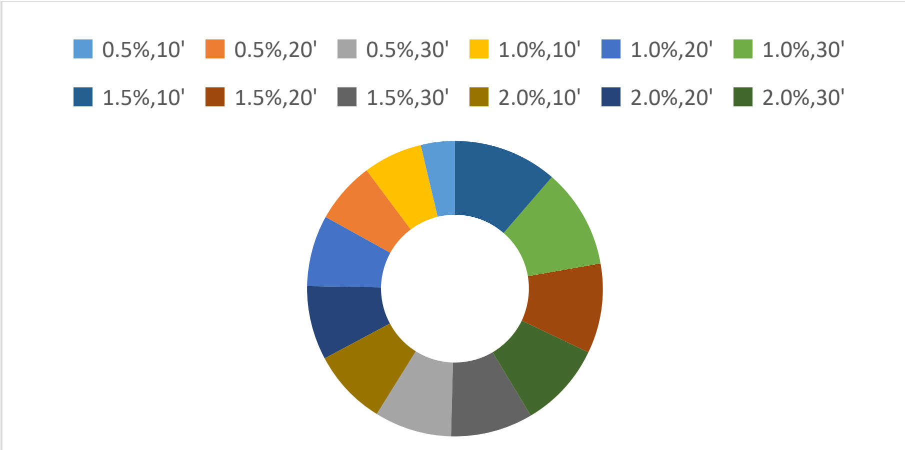

Fig. 13. Texture of fresh-cut mango with concentration calcium chloride (%) and immersion time (minutes) treatment.

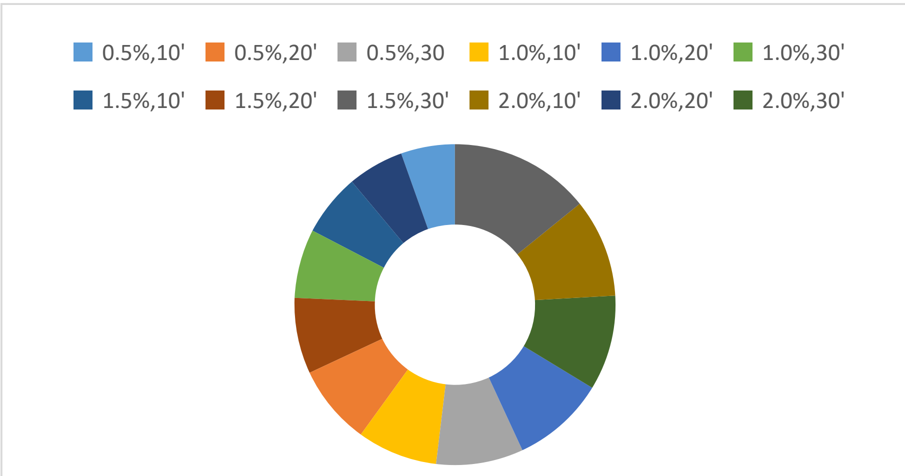

Fig. 14. Texture of fresh-cut mangoesteen with concentration calcium chloride (%) and immersion time (minutes) treatment.

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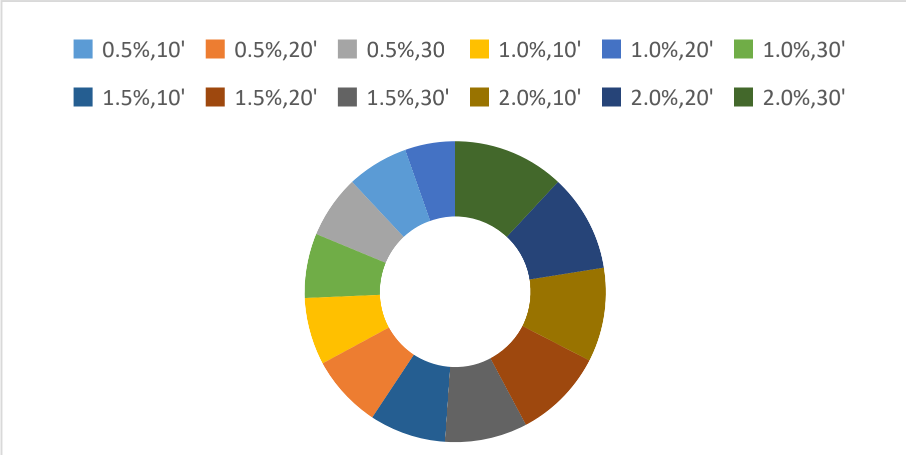

Fig. 15. Texture of fresh-cut rambutan with concentration of calcium chloride (%) and immersion time (minutes) treatment.

3.6 Color (L * a * b *)

Product appearance, particularly color, is a primary factor influencing consumer acceptance, often outweighing other attributes such as texture. Colour not only influences food selection but also shapes perceptions of sweetness and flavour intensity. The results indicated that calcium chloride concentration, immersion duration, and their interaction significantly affected the b-value of fresh-cut mango and the L-value of rambutan during storage on days 3, 6, and 9. Increasing the calcium chloride concentration generally enhanced the colour values of fresh-cut tropical fruits, while prolonged immersion reduced them. This effect was particularly evident in mango, which is highly hydrophilic, where extended immersion resulted in more pronounced colour differences.

In contrast, longer immersion times in mangosteen and rambutan resulted in their colour values aligning more closely with those of the untreated controls. Across storage, b values ranged from 72.19 to 43.82 for mango, 72.6 to 30.72 for mangosteen, and 42.36 to 33.19 for rambutan. These changes are attributed to biochemical processes, including the degradation of chlorophyll and carotenoids, browning reactions, and bleaching. Cutting also triggers signalling pathways that stimulate enzyme activity and phenolic compound production, thereby accelerating discolouration [11]. Without the protective skin, fresh-cut fruits are more vulnerable to dehydration, color loss, and tissue deterioration [12]. During storage, color intensity typically increased until day 6, followed by a decline, suggesting that calcium treatments delayed but did not fully prevent discoloration. Calcium has been reported to mitigate browning in apples and pears by stabilizing tissue structure. Furthermore, color shifts may also result from surface dehydration, with higher luminosity (L) linked to increased paleness, while reductions in L correspond to browning symptoms [13].

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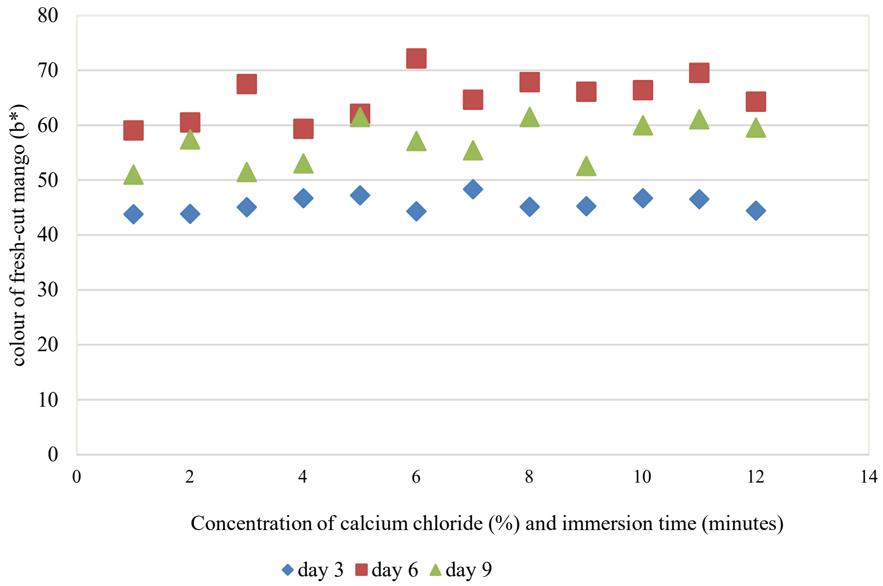

Fig. 16. Colour (b*) of fresh-cut mango with concentration calcium chloride (%) and immersion time (minutes) treatment.

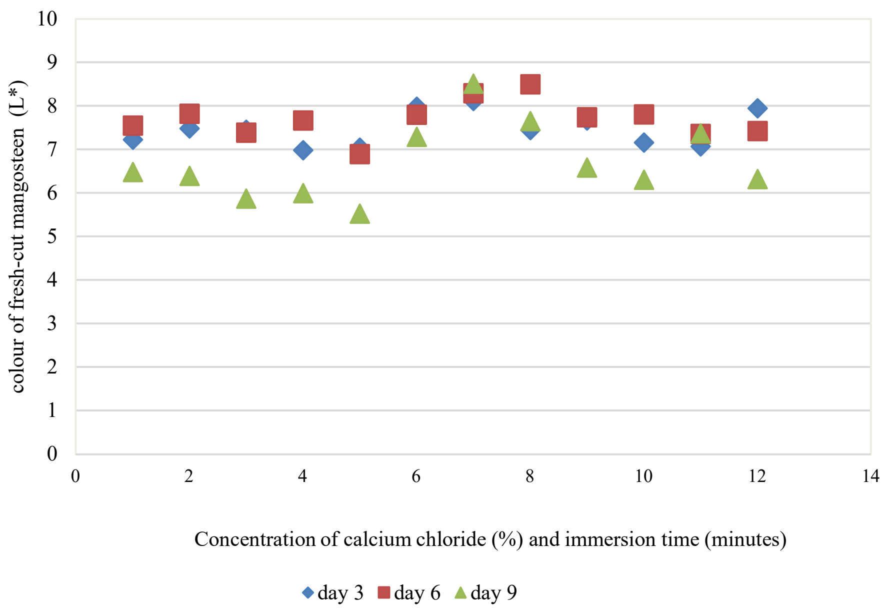

Fig. 17. Colour (L*) of fresh-cut mangosteen with concentration calcium chloride (%) and immersion time (minutes) treatment.

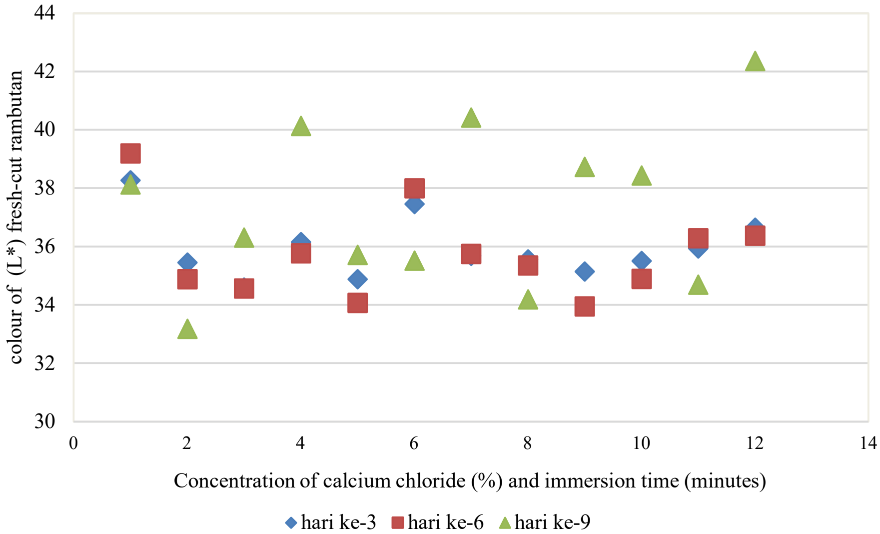

Fig. 18. Colour (L*) of fresh-cut rambutan with concentration of calcium chloride (%) and immersion time (minutes) treatment.

3.7 Browning index

Enzymatic browning is a major factor contributing to the decline in quality of fresh-cut fruits. This process primarily occurs through the oxidation of phenolic compounds by polyphenol oxidase (PPO), which produces quinones that polymerise into brown, reddish, or black melanins [13]. The study revealed that calcium chloride concentration, immersion duration, and their interaction significantly influenced the browning index of fresh-cut mango and rambutan during storage (days 3, 6, and 9). Increasing calcium chloride concentration reduced browning in mangosteen and rambutan, but this trend was not observed in mango, where the slicing process exposed a larger hydrophilic surface. Such mechanical damage disrupts the epidermal barrier and internal compartments, bringing enzymes into contact with their substrates and thereby accelerating browning [14]. Prolonged immersion times also decreased browning in mangosteen and rambutan, whereas in mango, the browning index increased. Many tropical fruits are rich in phenolic compounds, which undergo rapid browning after cutting, negatively impacting appearance, consumer acceptance, marketability, and nutritional quality [15]. During storage, the browning index of mango and rambutan increased up to day 6 before declining, while mangosteen showed a continuous decrease until day 9. Overall, mango exhibited the highest browning index compared to the other fruits. The increase is linked to the degradation of vitamin C, Maillard reactions, and the oxidation of anthraquinones. Because fresh-cut fruits consist of living tissues, enzymatic browning progresses throughout storage, reducing shelf life.. Wounding also stimulates the activity of enzymes such as phenylalanine ammonia-lyase (PAL), which promotes the synthesis of phenolics. Meanwhile, PPO oxidises these compounds, along with flavonoids and chlorogenic acid, into brown polymers, further intensifying tissue discolouration [15].

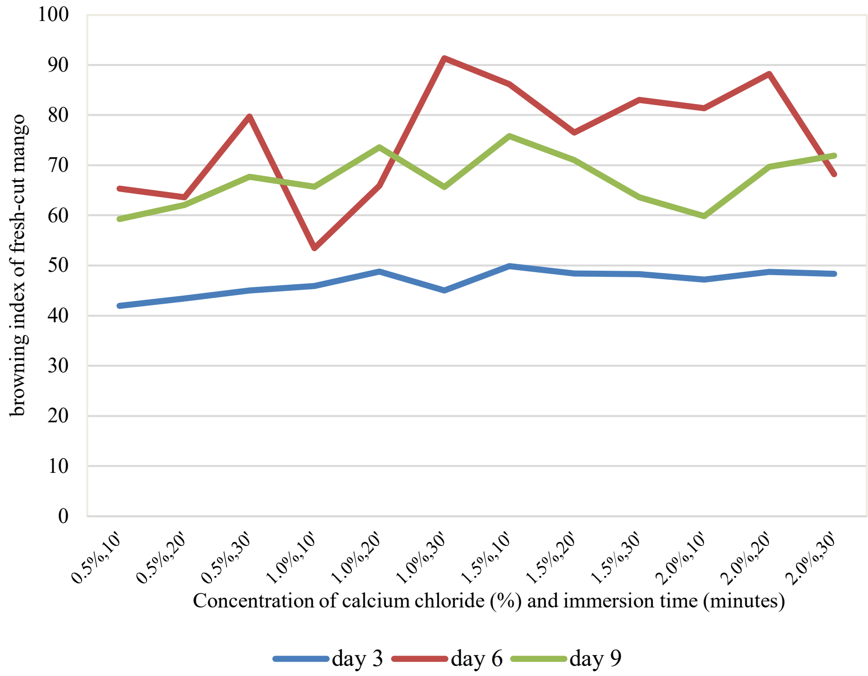

Fig. 19. Browning index of fresh-cut mango with concentration of calcium chloride (%) and immersion time (minutes) treatment.

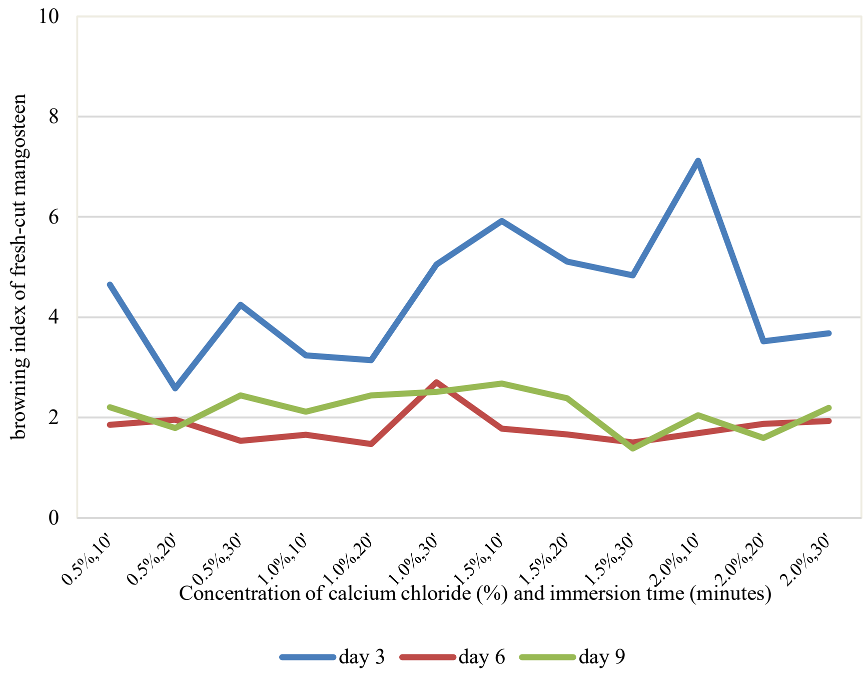

Fig. 20. Browning index of fresh-cut mangosteen with concentration of calcium chloride (%) and immersion time (minutes) treatment.

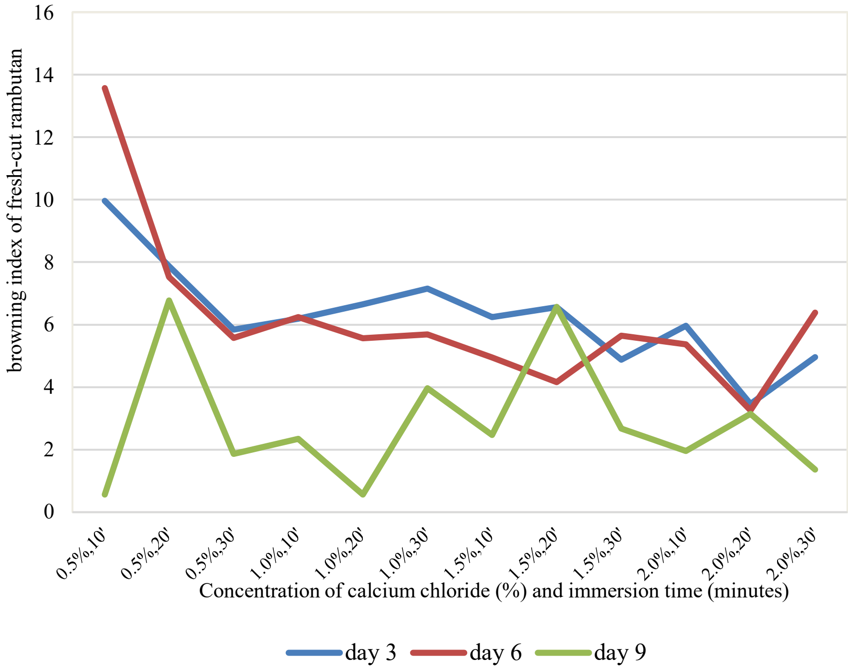

Fig. 21. Browning index of fresh-cut rambutan with concentration of calcium chloride (%) and immersion time (minutes) treatment.

4 Conclusion

The findings indicated that treatment with 1% calcium chloride for 10 minutes yielded the most effective results in preserving the quality of fresh-cut tropical fruits (mango, mangosteen, and rambutan) during a 9-day storage period. Under this treatment, the fruits maintained a favourable appearance, relatively high vitamin C levels, moisture content, and texture, while exhibiting reduced weight loss and a lower browning index. This formulation demonstrates strong potential for extending the shelf life of fresh-cut mango, rambutan, and mangosteen, maintaining their quality for up to 6 days and 9 days, respectively.

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