Pertanika J. Trop. Agric. Sci. 46 (2): 517 - 528 (2023)

PERTANIKA JOURNALS

TROPICAL AGRICULTURAL SCIENCE

Journal homepage: http://www.pertanika.upm.edu.my/

Locule Position and Thawing Duration Affect Postharvest Quality of Freshly Cryo-Frozen Musang King Durian Fruit

Shahidah Md Nor[1], Phebe Ding[2]* and Tan Jit Chun[3]

[1]Department of Technology and Natural Resources, Faculty of Applied Science and Technology, Universiti Tun Hussein Onn Malaysia, Hab Pendidikan Tinggi Pagoh, KM 1, Jalan Panchor, 84600 Muar, Johor, Malaysia
[2]Department of Crop Science, Faculty of Agriculture, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia
[3]Green Mile Gain Ltd., Level 54, Hopewell Centre, 183 Queen's Road East, Hong Kong

ABSTRACT

This study examined the effect of locule position and thawing duration on the physicochemical and nutritional characteristics of intact cryo-frozen Musang King durian fruit. Cryo-frozen durian that had 5 locules was thawed for 2 and 18 hr, and the fruitlets of each locule were analysed for colour (L*, a*, b*, C*, and h°), firmness, soluble solids concentration (SSC), titratable acidity (TA), pH, ascorbic acid (AA), total phenolic content, total flavonoid content, 1,1-diphenyl-2-picrylhydrazyl, 2,2′-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid and ferric reducing antioxidant power assay (FRAP). Results show that L* and a* of pulp colour, firmness, SSC, pH, TA, AA, and FRAP of cryo-frozen durian fruit were affected by a significant interaction between locule position and thawing duration. It implies the postharvest quality of intact cryo-frozen durian fruitlet distinct from each other due to their locule position and thawing duration.

Keywords: Colour, cryogenic, eating quality, fruitlet, nutritional quality

ARTICLE INFO

Article history:
Received: 30 October 2022
Accepted: 14 December 2022
Published: 12 April 2023

DOI: https://doi.org/10.47836/pjtas.46.2.09

E-mail addresses:
shahidahmn@uthm.edu.my (Shahidah Md Nor)
phebe@upm.edu.my (Phebe Ding)
jcjitan@gmail.com (Tan Jit Chun)
* Corresponding author

INTRODUCTION

Durian (*Durio zibethinus*) fruit, especially clones like Musang King and Black Thorn, is popular among durian connoisseurs due to their unique mouthfeel and pulp colour. As a result, the planting acreage of durian has increased to 72,391 ha with a total production of 210,874 MT/year (Md Nor, Ding, Sakimin, et al., 2022). Currently, Musang King durian has been exported

ISSN: 1511-3701
e-ISSN: 2231-8542

to countries such as China, Singapore, Taiwan, Australia, and European countries (Razali et al., 2020). Musang King durian fruit is very perishable, with easily dehisce husk within 12 hr of harvest under harsh and poor handling environments. The fruit must be frozen using a cryogenic technique where liquid nitrogen of -110 to -90°C is used to freeze the intact fruit for at least one hour before storage and shipping under -20 to -18°C (Ding, 2018). As a result, the postharvest life of intact cryo-frozen Musang King durian fruit is longer than fresh fruit; thus, the fruit can be exported to long-distance markets using sea referral.

Since the husk of intact cryo-frozen durian is strong and cannot be dehisced, the fruit must be thawed before serving. Thawing can be as simple as leaving the intact cryo-frozen durian at room temperature or using electromagnetic radiation to generate heat within the fruit (Wu et al., 2021). During thawing, the ice crystals of water molecules in the frozen fruit will change from solid to liquid, an important deterioration phenomenon to the fruit quality as cell structure collapses and nutrients are lost. Thus, thawing duration may affect cell structure and nutrients. The information on the thawing duration of durian fruit quality is very scarce. Although some studies on cryo-frozen durian have been reported, their focus was not on the effect of thawing duration on fruit quality. Razali et al. (2022) thawed intact cryo-frozen Musang King durian fruit for 0, 12, 24, and 36 hr to compare the effectiveness of conventional and cryo-freezing on the fruit and concluded that cryo-freezing was better in preserving durian fruit. The Japanese group of researchers revealed that thawing conventional-frozen (keeping fruit in a -20°C freezer) Thai durian neither using iced water (~0°C) nor hot water (~90°C) affects fruit eating quality (Tagubase et al., 2016). There are no standard operating procedures to thaw the cryo-frozen durian fruit: some vendors advise thawing the fruit overnight, but most do thaw for 2 hr. Nevertheless, the effect of thawing duration on fruitlets eating quality of Musang King durian fruit is not known.

Apart from thawing, it is believed that fruit locule may affect the eating quality of durian fruitlets. Generally, a durian has three to seven locules, where fruitlets are formed from the flower ovary after successful pollination (Ketsa et al., 2020). Fruit such as pineapple has been evident that the parts (basal, medium, top) of a fruit affected flesh firmness, with the basal part showing lower firmness than the medial and top parts (Joomwong & Sornsrivichai, 2005). The central part of white-fleshed dragon fruit (*Hylocereus undatus*) contained higher soluble solids than other parts of the fruit; thus, the fruit core tastes sweeter than the pulp near the peel (Nomura et al., 2015). The pulp dry matter at the stem end of Hass avocado was higher than above the seed, and the dry matter gradient decreased from the outside (peel) to the core (seed) of the fruit, indicating the distribution of moisture content varied in different parts of a fruit (Phetsomphou, 2000). For durian, the information on the locule effect on fruit-

eating quality is almost nil. The information may enhance the knowledge of fruit quality from different locules of durian fruit.

Thus, the present study was conducted to study the effect of locule position and thawing duration on the postharvest quality of cryo-frozen Musang King durian.

MATERIALS AND METHODS

Fruit Samples

The fresh Musang King durian of export grade (having 5 locules and a weight of approximately 2 kg per fruit) was cryo-frozen using liquid nitrogen for 60 min at -110°C within 5 hr of harvesting. The freshly cryo-frozen fruits were packed in a polystyrene box with an ice gel pad and stored at -20°C overnight while waiting for transport to send to the laboratory. The frozen fruit arrived at the laboratory within 3 hr from Top Fruits Sdn. Bhd., Batu Pahat, Malaysia. Upon arrival, the fruits were removed from the polystyrene box and allowed to thaw at room temperature (25 ± 2°C) for 2 and 18 hr. After the thawing duration, the fruits were opened with the help of a chopping knife. Randomly, one of the dehisced locules was assigned as locule number 1 (L1), the following locules from the right of the L1 were assigned as locule number 2 (L2), locule number 3 (L3), locule number 4 (L4), and locule number 5 (L5), respectively. The L5 was to the left of L1. Each locule of durian fruit consisted of five to seven fruitlets. Analyses were immediately conducted once the fruitlets were removed from each locule.

Physico-Chemical Analysis

The durian pulp physio-chemical properties of each fruitlet, such as colour (L*, a*, b*, C*, and h°), firmness, soluble solids concentration (SSC), pH, titratable acidity (TA), and ascorbic acid contents (AA) were analysed (Md Nor et al., 2021). The colour and firmness were measured when the pulp was attached to the seed. The Durian pulp colour of each fruitlet was taken using a colourimeter (CR-400, Minolta Corp., Japan) that was calibrated with a standard white tile before measuring. Three random points of each fruitlet were taken and presented in lightness/darkness (L*), redness/greenness (a*), yellowness/blueness (b*), chroma (C*), and hue angle (h°) according to International Commission on Illumination CIELAB. The firmness was measured using Instron Universal Testing Machine (5543P5995, Instron Corp., USA) fitted with a 6-mm diameter cylindrical probe and a 5-kg load cell. Each durian fruitlet was penetrated with a probe to a depth of 3 mm at a crosshead speed of 20 mm/min. The reading was recorded in Newton (N) using the Instron Merlin Software version M12-13664-EN. For SSC determination, 10 g durian pulp was homogenised with 20 ml distilled water prior to cotton filtration. Two to three drops of the filtrate were placed on a digital hand-held pocket refractometer (ATAGO™ RX-5000α, Japan), and the reading was calculated and presented as %SSC. The remaining filtrate prepared for SSC analysis was used for pH and TA analysis. pH was measured using an electrode of a pH

meter, and TA was measured by acid-base titration (Ding & Raja, 2021). Titration was performed using 10 ml filtrate added with 2 drops of phenolphthalein against 0.1 N sodium hydroxide (NaOH) until a light pink solution appeared for at least 15 s, and results were expressed as a percentage of malic acid. The dye method was applied according to Zainal et al. (2019) with modifications for AA determination. One gram of pulp was first homogenised with 25 ml 2% cold metaphosphoric acid (HPO_3), followed by a second filtering step using cotton. The filtrate was made up of 25 ml solution, and 10 ml filtrate was then titrated with standardised dye solution until a permanent pink colour appeared. The result was expressed as mg/100 g of fresh weight (FW).

Antioxidant Analysis

Prior to antioxidant analysis, 0.50 g of durian pulp was extracted with 1.50 ml (75% methanol) (Merck, Germany) using a Wise Clean ultrasonic water bath (Wise Laboratory Instrument, Germany) at 35°C for 30 min. Then, the sample was centrifuged at 16,100 × *g* for 10 min. The supernatant was collected and further analysed for total phenolic content (TPC), total flavonoid content (TFC), 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay, and 2,2′-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) radical scavenging assay analysis.

TPC was determined using 0.2 M Folin-Ciocalteau phenol reagent (SIGMA Chemical Co., USA) according to Ding and Choon (2021) with slight modification. A diluted extract of 200 µl was mixed with 25 µl Folin-Ciocalteu reagent for 4 min. Consequently, 20 µl 6% (w/v) sodium bicarbonate solution was added to the mixture and incubated in the dark for 30 min. Finally, the absorbance of the reaction mixture was measured at 750 nm using a spectrophotometer (Thermo Scientific, Multiskan™ Go Microplate Spectrophotometer, Finland). The result was extrapolated using a gallic acid standard curve, and the value was expressed as milligrams of gallic acid equivalents (GAE) in 100 g extract (mg GAE/100 g extract).

TFC was quantified using the aluminium trichloride method modified by Rebaya et al. (2015). A volume of 125 µl extract was added to 75 µl 5% sodium nitrite ($NaNO_2$) (SIGMA Chemical Co., USA). The mixture was allowed to mix for 6 min before adding 150 µl aluminium trichloride (10% $AlCl_3$) (Merck, Germany). Later, the mixture was incubated for 2 hr at room temperature with continuous shaking. Then, 750 µl 1 M NaOH (Merck, Germany) and 1,475 µl distilled water were added into the mixture and incubated for 15 min until a pink-peach colour solution formed. The absorbance was measured at 510 nm. Quercetin was standard, and the result was expressed as quercetin equivalents (QE) in mg/100 g FW.

The 2,2-diphenyl-1-picryl-hydrazyl-hydrate (DPPH) radical scavenging assay was modified according to the procedure described by Ding and Choon (2021). The solution of 0.2 mM DPPH (Merck, Germany) was prepared in methanol. A total

volume of 20 µl fruit extract was added to 180 µl DPPH and incubated in the dark for 30 min at 25°C. Discolouration of DPPH was measured against a blank at 517 nm. Trolox solution was used as the reference standard, and DPPH free radical scavenging activity results were expressed as µmol Trolox equivalent (TE)/100 g FW.

The 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) assay was adapted from the method of Ding and Choon (2021) with some modifications. Firstly, 0.7 mM ABTS salt (Merck, Germany) and 0.24 mM potassium persulfate ($K_2S_2O_8$) (Merck, Germany). were mixed and incubated in the dark for overnight to form a stock solution. Then, 5 ml stock solution was mixed with 100% methanol (MeOH) (Merck, Germany) to form a 25 ml working solution. Fruit extract with volume 10 µl was added to 150 µl ABTS working solution and let to react in the dark within 6 min at room temperature. The $ABTS^{\bullet+}$ radical discolouration was measured at 734 nm. Trolox solution was used as a reference, and results were expressed as µmol Trolox equivalent (TE)/100 g FW.

The FRAP assay was prepared and modified according to the procedure applied by Ding and Choon (2021) using 2,4,6-tripyridyl-S-triazine (TPTZ) (Merck, Germany). The essay was prepared by mixing 25 ml acetate buffer (pH 3.6), 2.5 ml TPTZ solution (10 mM), and 2.5 ml ferric chloride hexahydrate ($FeCl_3 \cdot 6H_2O$) (20 mM) solution (Merck, Germany), warmed in the dark at 37°C just before conducting the analysis. Then, 25 µl of the sample solution was mixed with 175 µl FRAP essay and incubated for 10 min in the dark at 25°C. Absorbance was measured at 562 nm. Trolox was standard, and results were expressed in µmol Trolox equivalent (TE)/100 g FW.

Statistical Analysis

The experiments were conducted using a completely randomised design with a factorial arrangement of treatments (2 thawing duration × 5 locule) with 3 biological replications and 3 technical replicates. Statistical analysis was performed by SAS software (SAS Institute, USA). Data were analysed using analysis of variance (ANOVA), and means separation was determined by Tukey's post hoc tests at $p < 0.05$.

RESULTS AND DISCUSSION

Effects of Locule Position and Thawing Duration on Eating Quality of Cryo-Frozen Musang King Durian

The main effects of locule position and thawing duration and their interaction on the colour of durian pulp are presented in Table 1. The colour of L* and a* of durian pulp was affected significantly by the interaction between the locule position × thawing duration, while another colour parameter was not affected by the interaction. From Table 1, the L* (lightness) and a* (red/green coordinate) values of durian pulp varied among locules and changed with thawing duration, with fruit thawing for 18 hr having darker colour (lower L* and

higher a* values) than those thawing for 2 hr. The b* (yellow/blue coordinate), C* (colour chromaticity), and h^{o} (hue angle) of durian pulp colour was not affected by the interaction but affected by locules position (Table 1). During the thawing of conventional-frozen (using -20°C) Thai durian fruit using hot water, it was found that the fruit pulp was darker in colour than iced-water thawing (Tagubase et al., 2016). The temperature could affect thawed durian fruit's L* and a* values. The temperature of Musang King durian fruit thawed for 18 hr has elevated and higher than those thawed for 2 hr, thus causing darker pulp colour in fruit pulp thawed for 18 hr.

Table 1
The main and interaction effects of locule position and thawing duration on pulp colour (L, a*, b*, C*, and h^{o}) of intact cryo-frozen Musang King durian fruit*

Factors	L*	a*	b*	C*	h^{o}
The main effect of locule position					
L1	76.55^{a}	0.13^{c}	42.58^{b}	42.58^{b}	88.28
L2	71.24^{b}	1.05^{a}	48.07^{ab}	48.07^{ab}	88.59
L3	72.82^{b}	1.02^{ab}	47.62^{ab}	47.62^{ab}	88.95
L4	72.53^{b}	1.12^{a}	49.83^{a}	52.10^{a}	88.68
L5	72.04^{b}	0.49^{bc}	49.13^{ab}	49.83^{ab}	89.04
Levels of significance	**	**	*	*	ns
The main effect of thawing duration (hr)					
2	74.70^{a}	0.64^{b}	47.63	47.69	89.02
18	70.97^{b}	0.89^{a}	47.26	47.26	88.40
Levels of significance	**	*	ns	ns	ns
Interaction effect of locule position and thawing duration					
2 hr of thawing					
L1	76.31^{a}	0.10^{c}	41.45	41.41	86.72
L2	75.20^{ab}	0.70^{ab}	48.19	48.11	88.80
L3	74.21^{ab}	1.15^{a}	48.09	48.02	88.61
L4	74.80^{ab}	0.79^{ab}	52.10	52.11	89.11
L5	72.82^{b}	0.46^{bc}	48.30	48.30	88.62
18 hr of thawing					
L1	74.72^{a}	0.16^{c}	43.70	43.70	89.81
L2	67.22^{c}	1.40^{a}	47.95	47.95	88.33
L3	71.44^{b}	0.89^{ab}	47.14	47.14	89.23
L4	70.26^{b}	1.45^{a}	47.57	47.56	88.25
L5	71.21^{b}	0.52^{bc}	49.95	49.95	89.41
Levels of significance	*	*	ns	ns	ns

Note. Means (n = 3) followed by the same letter in the same column within factors are not significantly different at $p < 0.05$ according to Tukey's post hoc tests
ns, *, ** = Non-significant or significant at $p \leq 0.05$ or $p \leq 0.01$, respectively

Table 2 shows pulp firmness, SSC, pH, TA, and AA of cryo-frozen Musang King durian was affected by a significant interaction between locule position × thawing duration. Regardless of thawing duration, the firmness, SSC, pH, TA, and AA of durian fruitlets differed among locules (Table 2). For the eating quality of durian fruitlets, firmness, pH, TA, and AA of 18 hr-thawed fruitlets was lower than 2 hr-thawed while SSC of cryo-frozen durian fruit increased with thawing duration. Thawing conventional-frozen Thai durian using 90°C hot water at a high temperature but shorter

Table 2
The main and interaction effects of locule position and thawing duration on pulp firmness, soluble solids concentration, pH, titratable acidity, and ascorbic acid of intact cryo-frozen Musang King durian fruit

Factors	Firmness (N)	Soluble solids concentration (%SSC)	pH	Titratable acidity (%malic acid)	Ascorbic acid (mg/100 g)
The main effect of locule position					
L1	1.51^{b}	29.95^{a}	6.79^{c}	0.07^{a}	7.52^{b}
L2	1.53^{b}	27.22^{b}	7.22^{ab}	0.04^{b}	6.41^{b}
L3	1.96^{ab}	26.40^{b}	7.10^{b}	0.04^{b}	6.15^{b}
L4	1.97^{ab}	27.00^{b}	7.28^{a}	0.03^{c}	7.09^{b}
L5	2.51^{a}	21.95^{c}	7.32^{a}	0.04^{b}	10.34^{a}
Levels of significance	*	**	**	**	**
The main effect of thawing duration (hr)					
2	2.53^{a}	25.12^{b}	7.55^{a}	0.05^{a}	8.65^{a}
18	1.26^{b}	27.89^{a}	6.73^{b}	0.03^{b}	6.36^{b}
Levels of significance	**	**	**	**	**
Interaction effect of locule position and thawing duration					
2 hr of thawing					
L1	1.35^{c}	28.20^{a}	6.18^{e}	0.10^{a}	6.84^{b}
L2	2.13^{bc}	25.90^{b}	6.87^{c}	0.05^{b}	6.50^{b}
L3	2.92^{ab}	25.20^{b}	6.60^{d}	0.04^{c}	4.62^{c}
L4	2.62^{ab}	25.90^{b}	6.93^{b}	0.03^{d}	4.62^{c}
L5	3.64^{a}	20.40^{c}	7.08^{a}	0.05^{b}	9.23^{a}
18 hr of thawing					
L 1	1.68^{a}	31.70^{a}	7.40^{b}	0.04^{a}	8.21^{bc}
L 2	0.94^{b}	28.53^{b}	7.57^{ab}	0.02^{c}	6.33^{c}
L 3	0.99^{ab}	27.60^{b}	7.59^{ab}	0.03^{b}	7.69^{bc}
L 4	1.32^{ab}	28.10^{b}	7.63^{a}	0.02^{c}	9.57^{ab}
L 5	1.34^{ab}	23.50^{c}	7.57^{ab}	0.02^{c}	11.45^{a}
Levels of significance	*	*	**	**	*

Note. Means (n = 3) followed by the same letter in the same column within factors are not significantly different at $p < 0.05$ according to Tukey's post hoc tests
*, ** = Significant at $p \leq 0.05$ or $p \leq 0.01$, respectively

thawing duration caused higher moisture content to fruitlets compared to ice-water thawing with a longer period (Tagubase et al., 2016). At the same time, thawing methods did not affect other eating qualities of durian, such as texture profile (hardness, cohesiveness, and adhesiveness), SSC, pH, organic acids, and sugar contents.

In terms of durian fruitlet firmness, fruit thawing for 2 hr has a firmer texture than those thawing for 18 hr (Table 2). Firmer fruit is more acceptable than softer fruit since it gives a fresh perception to consumers (Md Nor & Ding, 2020). The softening of durian pulp in prolonged thawing duration may be due to the melting of crystalised water that breakdown the cell's structure. The greater SSC value in fruit thawed for 18 hr compared to 2 hr (Table 2) may indicate that starch has been actively converted to simple sugar as enzyme activity increases with temperature as the thawing process progresses. Additionally, the lower pH values in fruit thawed for 18 hr shows that durian pulp is acidic and exhibits a greater hydrogen dissociation rate than 2 hr-thawed fruit. TA reflects titratable organic acids content, and the lower TA in 18 hr-thawed fruit may be due to the utilisation of organic acids during metabolic respiration as a respiratory substrate or carbon skeleton (Md Nor, Ding, Abas, et al., 2022) during the thawing of durian fruit at room temperature. Lower AA in durian fruit thawed for 18 hr, signifying more degradation of AA has occurred during longer thawing duration compared to 2 hr thawing (Table 2). AA is water soluble and a powerful antioxidant that prevents or reduces the damage caused by reactive oxygen species in fruit (Khaliq et al., 2015). Oxidative damage could have taken place during longer thawing duration and utilise the natural AA in the fruit as a detoxification compound to fight against reactive oxygen species (Table 2).

Effects of Locule Position and Thawing Duration on Nutritional Quality of Cryo-Frozen Musang King Durian

Bioactive compounds such as phenolic and flavonoid, as part of the nutritional quality of fruit, were quantified as TPC and TFC in this study. At the same time, the oxidant systems of cryo-frozen durian were evaluated based on radical scavenging activity (DPPH and ABTS) and one assay based on the reducing potential of antioxidants (FRAP) (Table 3). The presence of bioactive compounds with antioxidant activity in a fruit indicates it is packed with nutrients that can combat oxidative stress-induced degenerative illnesses (Ding & Choon, 2021). This study's findings revealed no significant interaction between locule position × thawing time on the nutritional quality of cryo-frozen durian fruit except FRAP (Table 3). It indicates that regardless of thawing duration, every locule fruitlet in a cryo-frozen durian fruit has the same amount of nutritional quality except FRAP.

The pulp colour (L* and a*) of durian fruitlet that underwent longer thawing duration was darker and redder than those thawing for a shorter period (Table 1). The pulp darkening could be due to an enzymatic

browning reaction and degradation of natural pigment. This study has quantified that cryo-frozen durian contains polyphenol compounds as valued by TPC (Table 3). During thawing, cell decompartmentalisation may occur, permitting a reaction between enzymes and polyphenol compounds, consequently leading to browning (Wei

Table 3
The main and interaction effects of locule position and thawing duration on total phenolic content, total flavonoid content, DPPH, and ABTS a FRAP of intact cryo-frozen Musang King durian fruit

Factors	Total phenolic content (mg GAE/100 g)	Total flavonoid content (mg QE/100 g)	DPPH (μmol TE/100 g)	ABTS (μmol TE/100 g)	FRAP (μmol TE/100 g)
The main effect of locule position					
L1	16.54	0.50^{ab}	22.79	8.69	62.11
L2	12.76	0.54^{ab}	31.48	7.90	63.21
L3	15.75	0.77^{a}	28.07	7.15	68.63
L4	14.30	0.29^{b}	26.33	8.89	59.43
L5	15.86	0.42^{ab}	28.07	8.09	62.70
Levels of significance	ns	*	ns	ns	ns
The main effect of thawing duration (hr)					
2	17.09	0.48	30.45	8.38	73.55^{a}
18	12.99	0.53	26.61	7.91	52.88^{b}
Levels of significance	ns	ns	ns	ns	**
Interaction effect of locule position and thawing duration					
2 hr of thawing					
L1	15.97	0.56	19.54	9.66	58.22^{a}
L2	14.00	0.41	39.47	8.83	55.96^{a}
L3	21.37	0.70	30.52	7.59	59.29^{a}
L4	15.58	0.28	28.55	8.42	42.53^{b}
L5	18.54	0.46	34.14	7.39	48.40^{ab}
18 hr of thawing					
L1	17.11	0.45	26.05	7.71	65.99^{b}
L2	11.51	0.67	23.49	6.97	70.47^{ab}
L3	10.12	0.84	37.41	6.71	77.98^{a}
L4	13.02	0.30	24.10	9.36	76.32^{a}
L5	13.17	0.38	34.14	8.79	77.01^{a}
Levels of significance	ns	ns	ns	ns	*

Note. Means (n = 3) followed by the same letter in the same column within factors are not significantly different at $p < 0.05$ according to Tukey's post hoc tests
GAE = Gallic acid equivalent; QE = Quercetin equivalent; TE = Trolox equivalent; DPPH = 1,1-diphenyl-2-picryl-hydrazyl; ABTS = 2-2'-azino-bis(3-ethylbenzothiozoline-6-sulfonic acid); FRAP = Ferric reducing antioxidant power
ns, *, ** = Non-significant or significant at $p \leq 0.05$ or $p \leq 0.01$, respectively

et al., 2022). Furthermore, a carotenoid responsible for the intense yellowish colour of durian pulp (Tan et al., 2020) is heat labile and susceptible to degradation (Gheonea et al., 2020). Temperature equilibration between frozen fruit (-20°C) and room (25°C) could have degraded the carotenoid and thus manifested in a darker colour, especially when the thawing duration was prolonged.

CONCLUSION

Results from this study indicated that the locule position and thawing duration significantly interact with the postharvest quality of cryo-frozen Musang King durian fruit. Unfortunately, the locule position of durian fruit was assigned randomly. Thus, it could not corroborate the cause of variation in each locule towards the postharvest quality of durian fruit. However, the finding of this study indicates that the sampling methods employed in collecting data on an intact durian should consider the locule effect. Since the thawing duration of cryo-frozen durian affects the colour of durian pulp, thus vendors must provide proper advice or instruction to consumers in enjoying the intact cryo-frozen durian fruit.

ACKNOWLEDGEMENTS

The authors acknowledged the grant given by Green Mile Gain Limited (Vote: 6380067), Hong Kong, for funding this project. The authors also thank the Top Fruits Sdn. Bhd., Malaysia, for providing the intact cryo-frozen Musang King durian fruit.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

REFERENCES

Ding, P. (2018, September 26). Cryogenic freezing technology: Twisting M'sian durians' fate. *The Borneo Post*. https://www.theborneopost.com/2018/09/26/cryogenic-freezing-technology-twisting-msian-durians-fate/#:~:text=Dr%20Ding%20said%20presently%2C%20local,taste%2C%20flesh%20colour%20and%20texture

Ding, P., & Choon, S. Y. (2021). Effects of storage temperature on postharvest quality of Malaysian grown fig (*Ficus carica* L.) cv. Ipoh Blue Giant. *Mindanao Journal of Science and Technology*, *19*(2), 91-106.

Ding, P., & Raja M. R. N. (2021). Hydro-cooling as means to retain fresh sweet corn ears quality. *Sains Malaysiana*, *50*(12), 3593-3602. https://doi.org/10.17576/jsm-2021-5012-11

Gheonea, I., Aprodu, I., Enachi, E., Horincar, G., Bolea, A. C., Bahrim, G. E., Rapeanu, G., & Stanciuc, N. (2020). Investigations on thermostability of carotenoids from tomato peels in oils using a kinetic approach. *Journal of Food Processing and Preservation*, *44*(1), e14303. https://doi.org/10.1111/jfpp.14303

Joomwong, A., & Sornsrivichai, J. (2005). Morphological characteristics, chemical composition and sensory quality of pineapple fruit in different season. *Chiang Mai University Journal of Natural Science*, *4*(2), 149-164.

Ketsa, S., Wisutiamonkul, A., Palapol, Y., & Paull, E. R. (2020). The durian: Botany, horticulture, and utilization. In I. Warrington (Ed.), *Horticultural reviews* (Vol. 47, pp. 125-211). John Wiley & Sons, Inc. https://doi.org/10.1002/9781119625407.ch4

Khaliq, G., Muda Mohamed, M., Ali, A., Ding, P., & Ghazali, H. (2015). Effect of gum arabic coating combined with calcium chloride on physico-chemical and qualitative properties of mango (*Mangifera indica* L.) fruit during low temperature storage. *Scientia Horticulturae*, *190*, 187–194. https://doi.org/10.1016/J.SCIENTA.2015.04.020

Md Nor, S., & Ding, P. (2020). Trends and advances in edible biopolymer coating for tropical fruit: A review. *Food Research International*, *134*, 109208. https://doi.org/10.1016/j.foodres.2020.109208

Md Nor, S., Ding, P., Sakimin, S., Ismail, A., & Abas, F. (2022). Passion fruit - A potential crop for exploration in Malaysia: A review. *Pertanika Journal of Tropical Agricultural Science*, *45*(3), 761–780. https://doi.org/10.47836/pjtas.45.3.14

Md Nor, S., Ding, P., Abas, F., & Mediani, A. (2022). ^{1}H NMR reveals dynamic changes of primary metabolites in purple passion fruit (*Passiflora edulis* Sims) juice during maturation and ripening. *Agriculture*, *12*(2), 156. https://doi.org/10.3390/agriculture12020156

Md Nor, S., Siti, N. F. M. H., & Ding, P. (2021). Effects of temperature and storage duration on keeping quality of Malaysian grown passion fruit (*Passiflora edulis* Sims f. *flavicarpa* Deg.). *Acta Horticulturae*, *1327*, 557-562. https://doi.org/10.17660/actahortic.2021.1327.73

Nomura, K., Ide, M., & Yonemoto, Y. (2015). Changes in sugars and acids in pitaya (*Hylocereus undatus)* fruit during development. *Journal of Horticultural Science and Biotechnology*, *80*(6), 711-715. https://doi.org/10.1080/14620316.2005.11512003

Phetsomphou, V. (2000). *Evaluation of various methods for dry matter content and firmness of 'Hass' avocados* [Unpublished Bachelor dissertation]. Massey University.

Razali, N., Rosly, N., Hamzah, F., Abdullah, S., & Hussin, W. (2020). Optimum storage temperature of mature drop durian (*Durio zibethinus* cv. Musang King). *International Journal of Agriculture, Forestry and Plantation*, *10*(9), 267-273.

Razali, N., Wan Ibrahim, W. M. Safari, S., Rosly, N. K., Hamzah, F. A., & Wan Husin, W. M. R. I. (2022). Cryogenic freezing preserves the quality of whole durian fruit for the export market. *Food Research*, *6*(3), 360-364. https://doi.org/10.26656/fr.2017.6(3).428

Rebaya, A., Belghith, S., Baghdikian, B., Leddet, V., Mabrouki, F., Olivier, E., Cherif, J., & Ayadi, M. (2015). Total phenolic, total flavonoid, tannin content, and antioxidant capacity of *Halimium halimifolium* (Cistaceae). *Journal of Applied Pharmaceutical Science*, *5*(1), 52-57. https://doi.org/10.7324/JAPS.2015.50110

Tagubase, J. L., Ueno, S., Yoshie, Y., & Araki, T. (2016). Effect of freezing and thawing on the quality of durian (*Durio zibethinus* Murray) pulp. *Transactions of the Japan Society of Refrigerating and Air Conditioning Engineers*, *33*(3), 267-272. https://doi.org/10.11322/tjsrae.16-17NR_OA

Tan, X. Y., Misran, A., Daim, L. D. J., Ding, P., & Dek, M. S. P. (2020). Effect of freezing on minimally processed durian for long term storage. *Scientia Horticulturae*, *264*, 109170. https://doi.org/10.1016/J.SCIENTA.2019.109170

Wei, D., Yang, J., Xiang, Y., Meng, L., Pan, Y., & Zhang, Z. (2022). Attenuation of postharvest browning in rambutan fruit by melatonin is associated with inhibition of phenolics oxidation and reinforcement of antioxidative process. *Frontiers in Nutrition*, *9*, 905006. https://doi.org/10.3389/fnut.2022.905006

Wu, J., Zhang, M., Bhandari, B., & Yang, C.-H. (2021). Drip loss control technology of frozen fruit and vegetables during thawing: A review.

International Agrophyscis, *35*(3), 235-250. https://doi.org/10.31545/intagr/142289

Zainal, B., Ding, P., Safinar, I., & Saari, N. (2019). Physico-chemical and microstructural characteristics during postharvest storage of hydrocooled rockmelon (*Cucumis melo* L. *reticulatus* cv. Glamour). *Postharvest Biology and Technology*, *152*, 89-99. https://doi.org/10.1016/j.postharvbio.2019.03.001