Research Findings

Photo 1. Durian fruit. Photo by the authors.

Polyhalite Improves Physiochemical and Organoleptic Properties of Durian When Applied After Flowering and During Fruit Development

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Abstract

Secondary macronutrients play a major role in durian fruit yield and quality. The treatment in this study withdrew nitrogen (N) and phosphorus (P) input, increased the rate of magnesium (Mg), calcium (Ca) and sulfur (S) input, whilst maintaining potassium (K) input through the application of polyhalite during D101 durian fruit development stage. There was a significant increase in thickness of the distal portion of durian husk (1.47 cm vs 1.63 cm) in the polyhalite treatment. However, there were no significant changes observed in durian fruit weight and other physical characteristics. Several characteristics of the arils were significantly increased in the treatment group, such as pH (6.15 vs 6.92) and firmness (0.088 N vs 0.169 N). In terms of nutritional quality, protein content in the polyhalite-treated arils increased from 6.36% to 7.52% whereas fat content increased significantly from 7.68% to 10.64%. Sensory attribute mean scores obtained from a consumer panel showed

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significant improvements in terms of flavor and sweetness of the arils in the polyhalite treatment group. However, a decrease in total soluble solids (°Brix) was recorded. In short, application of polyhalite resulted in improved quality of durian fruits. The results of the research did not discount the importance of primary macronutrients but rather emphasized the requirement to balance primary and secondary macronutrient input during fruit development.

Introduction

The Durio genus consists of almost 30 recognized species, including the internationally traded *Durio zibethinus* L., and is now widely cultivated in Thailand, Malaysia, and Indonesia due to the favorable climate (Brown, 1997). In Malaysia, many different planting materials exist, and their fruits differ in characteristics including the taste and aroma of the arils (Idris *et al.*, 2018). The D101 cultivar is fairly popular in Malaysia due to its more affordable price, while the D197 cultivar (*Musang* King) remains unrivaled in terms of demand, both locally and from China. The arils of D101 are yellow to yellowish-orange, taste fairly sweet, are creamy, and have a fair strength of aroma (Idris *et al.*, 2018).

One metric tonne of durian fruit removes 2.4 kg of nitrogen (N), 0.4 kg of phosphorus (P), 4.0 kg of potassium (K), 0.3 kg of calcium (Ca), and 0.5 kg of magnesium (Mg) (Jamil, 1968; Ng and Thamboo, 1967). The high potassium removal leads growers to apply high levels of K fertilizer, before and after anthesis. Potassium foliar spray has been shown to result in a higher flesh to fruit weight ratio and improved yellowness of arils (Punnachit *et al.*, 1992).

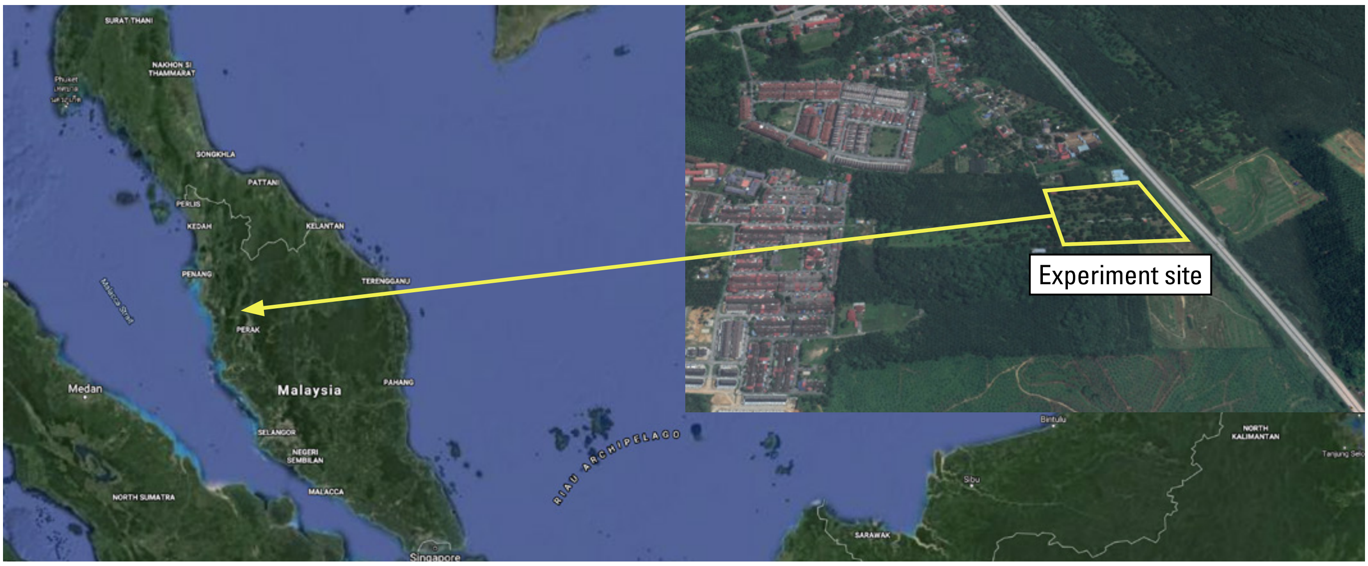
Although yield response is highly desirable, improvements in fruit quality are also crucial to secure higher profitability for farmers. Poor quality characteristics include uneven ripening which has always been associated with genetics, poor weather, and imbalanced nutrition. Uneven ripening tends to occur in D24 clones or under poor weather conditions. In terms of nutrients, lack of calcium input leads to an imbalanced Ca:Mg or Ca:K ratios, leading to poor ripening in durian. Although it is commonly believed that imbalanced nutrition, such as high application of N but lower secondary macronutrient applications, during the fruit development phase leads to poor fruit quality, scientific evidence is scarce.

Organically-grown durian is currently in high demand but production is difficult due to durian's high potassium requirement and the rarity of organic potassium fertilizers. Polyhalite ($K_2Ca_2Mg(SO_4)_4 \cdot 2(H_2O)$) is a mineral containing K, Mg, Ca and S (14% K_2O, 6% MgO, 17% CaO, and 45% SO_3). The mineral can be applied in its natural state directly to the field, without going through any industrial processing, hence it is certified for use in organic farming systems. The prolonged release of the nutrients, and its supply of four out of six macronutrients, were recently shown to improve crop yields in legumes and cereal crops (Melgar *et al.*, 2017; Liu, 2019; Li and Lu, 2019).

The effect of fertilizer on the yield of durian trees is always difficult to determine due to the influence of climate, flowering and the farmers pruning practices. The current study aims to evaluate the effect on the quality of durian fruit of application of polyhalite as a replacement for conventional high-K NPK 15-5-20 + 2MgO + 10S + TE applied after anthesis and during fruit development.

Materials and methods

The study was conducted from January 2020 to January 2021 at a durian farm in Tapah, Perak. Six durian trees of the D101 cultivar were selected for the study. The trees were planted in 2012-2013 on



Map 1. Location of the trial carried out at a durian farm in Tapah, Perak, Malaysia. *Source:* Google Maps.

Table 1. Nutrient input per durian tree after anthesis until harvest.

	Fertilizer	Rate	N	P_2O_5	K_2O	MgO	CaO	SO_3
		------------------			*kg^{-1} tree*			------------------
Control	NPK 15-5-20-2	3.5	0.53	0.18	0.70	0.07	Foliar	0.88
Treatment	Polyhalite	5.0	0.00	0.00	0.70	0.30	0.85	2.25

recent alluvium with excellent drainage and were selected based on uniformity of growth and size.

An NPK 15-5-20-2 + 10S + TE fertilizer was applied at a rate of 3.5 kg $tree^{-1}$ divided into two applications, after fruit set and during fruit development, as a control (farmer's practice). This was in combination with a calcium and boron foliar spray during fruit development. In the treatment plot, polyhalite was applied as an alternative at a rate of 5 kg $tree^{-1}$ as shown in Table 1.

Anthesis and fruit drop occurred mid-August 2020 and 10 January 2021, respectively. The number of fruits produced per tree ranged from 30 to 40 for the December 2020-February 2021 harvest season, with no pruning conducted. Flowering and fruit set remained low due to higher-than-average rainfall from August to December 2020. Fruits were allowed to ripen on the tree and drop naturally. Six durians free from physiological defects and pest damage, ranging from 1.65-2.05 kg, were selected randomly from treatment and control trees (three each). The durians were collected on the morning of 10 January 2021.

Total soluble solids

Total soluble solids of samples were determined using a hand-held digital refractometer (PAL-3, ATAGO, Japan). Calibration of the refractometer was done by dripping distilled water onto the prism. The distilled water was wiped off before the samples were analyzed. Durian pulp was blended and diluted with distilled water (1:10). Approximately 2 to 3 drops of the sample were placed onto the prism of the refractometer (Onyekwelu, 2017). The Brix value (% Brix) of the sample was shown on the digital screen. Total soluble solids of samples were expressed as % Brix multiplied by the dilution factor, and triplicates for each sample were obtained.

Measurement of moisture content

The moisture content of each durian sample was measured by using a moisture analyzer (MX-50, A&D, Japan). "Quick mode" operation was selected as the measurement method, and the drying temperature for the program was set at 160°C.

pH determination

pH was determined using a pH meter (FP20, Mettler Toledo, USA). Calibration was conducted using buffer solutions of pH 4.0, 7.0, and 10.0. Next, the electrode of the pH meter was dipped into the sample to obtain the pH reading. When the pH meter beeped, the finalized pH of the sample was shown on the digital screen. All samples in both treatments were run in triplicate and the results were presented as mean ± standard deviation.

Photo 2. Six durian trees of the D101 cultivar were selected for the study on a durian farm in Tapah, Perak, Malaysia. Photo by the authors.

Photo 3. Flowering durian tree. Photo by the authors.

Photo 4. Durian aril color was recorded. Photo by the authors.

Titratable acidity (TA)

According to the Association of Official Analytical Chemists method (AOAC, 2010), titratable acidity was determined using titration. NaOH (0.1 N) was used as a titrant. To prepare 0.1 N of sodium hydroxide, 4 g of NaOH was dissolved in 1 L of distilled water. The solution was then filled into the burette. Ten grams of sample was poured into a volumetric flask and diluted to 250 mL with the purpose of allowing the endpoint of titration to be easily detected. One hundred mL of the diluted sample was transferred into a conical flask and titration was conducted by titrating NaOH into the sample until the endpoint was reached, whereby a distinct color change of the sample was observed. The titratable acidity of the samples was expressed as % malic acid, since malic acid is the major compound in durian. The titratable acidity was calculated using the formula shown below.

$$\text{TA (\%)} = \frac{Normality\ of\ base \times volume\ of\ base\ (mL) \times miliequivalent\ of\ malic\ acid \times 100}{volume\ of\ sample\ (mL)}$$

$$= \frac{0.1\ N\ NaOH \times volume\ of\ base \times 0.067 \times 100}{10\ g\ sample}$$

Color analysis

Evaluation of color of durian arils was measured using a colorimeter (CM-600D, Konica Minolta, Japan) according to Niu *et al.*, 2008. The black and white plates were used to calibrate the colorimeter, followed by zero calibration. After the standard calibration of the colorimeter, the color of each sample was measured. Color measurement was obtained, and CIE-Lab parameters were expressed as L* (lightness intensity), a* (+ redness, – greenness), and b* (+ yellowness, – blueness) values. All samples in both treatments were run in triplicate and the results were presented as mean ± standard deviation.

Texture analysis

The texture of each sample was analyzed by subjecting the sample to a puncture test performed by a texture analyzer (TA.XT Plus, Stable Micro Systems, UK). The firmness of the durians was analyzed freshly, right after the fruits were opened. The durian sample was placed in a plastic tube with a diameter of 2 cm and height of 4 cm. A cylindrical probe with a diameter of 5 mm was used. The equipment was set for a puncture test performed at a constant velocity of 100 mm min^{-1} until the probe reached 25 mm of the sample's depth according to Holzwarth *et al.*, 2013. The sample texture was recorded as the maximum force (N) at the breaking point of the sample and expressed as firmness.

Protein determination

Protein content determination was carried out using Kjeldahl and titration method which referred to AOAC 984.13 (AOAC, 2010) that involved three steps: digestion, distillation, and titration. The protein content of all samples was determined in triplicate. First, 2 g of powdered sample was added into the cleaned Kjeldahl flask with 0.8 g of $CuSO_4$ and 7 g of K_2SO_4, followed by 25 mL of 98% concentrated sulfuric acid (H_2SO_4), then all six flasks were transferred to the speed digester for digestion. During digestion, the flasks were heated for one hour until clear green mixtures were obtained, then the flasks were cooled to room temperature. The cooled digested mixtures were then transferred to the distillation unit and digestion was conducted for five minutes, with the end tube of the distillation unit connected to a conical flask with 50 mL of boric acid and three drops of methyl orange indicator. When distillation was completed, the boric acid mixture was then titrated with 0.25 M of H_2SO_4 until the mixture turned from blue to pink (Maisarah *et al.*, 2014). The volume of acid used was recorded and used in the protein content calculation, by using the formula shown:

$$\%N = ([V(1)-V(B1)] \times F \times c \times f \times M(N))/(m \times 1000) \times 100\%$$

$$\%\ Protein = \%N \times PF$$

Where:

V (1) = volume of acid (H_2SO_4) used (mL)

V (B1) = volume of blank (mL)

F = molar reaction factor (1 = HCl, 2 = H_2SO_4)

c = concentration of acid (mol L^{-1})

f = factor of titrant (acid)

M(N) = molecular weight of N (14.007 g mol^{-1})

m = sample weight (g)

PF = protein factor (6.25)

%N = % weight of N

%P = % weight of protein

Fat determination

Fat content determination using Soxtherm method was performed for all samples according to AOAC standard as per Bagchi *et al.* (2016). Soxtherm fat analyzer (Gerhardt, SOX 6-place) was used

Table 2. Weight characteristics of the durian samples.

Sample	Weight of husk	Weight of aril and seed	Weight of aril	Weight of seed
	---%	---	---	---
Control	66.30 ± 3.16[a]	33.70 ± 3.16[a]	22.88 ± 1.53[a]	10.81 ± 1.64[a]
Polyhalite	65.70 ± 3.57[a]	34.30 ± 3.57[a]	24.70 ± 1.88[a]	9.61 ± 2.05[a]

Values in the table represent the mean ± standard deviation of three biological replications. Means within each column with different letters are significantly ($p < 0.05$) different.

in this analysis. Firstly, the extraction beakers with three pieces of boiling stones were dried at 105˚C for one hour, then cooled in the desiccator for one hour, the weight of each cooled extraction beaker with boiling stones was then determined and recorded as M1. Then 5 g of powdered samples were weighed and recorded as M0, then wrapped with filter paper. The wrapped samples were inserted into thimbles and covered with cotton wool, and placed into the labelled extraction. Hence, 90 mL of petroleum ether was added into each extraction beaker, then the beakers were connected to the fat analyzer and the analysis program was conducted. When the extraction was completed, the extraction beakers were dried at 105˚C for one hour, and the weight after drying was recorded as M2. The fat content was determined using the formula shown below:

$$\% \text{ Fat} = (M2 - M1)/M0 \times 100\%$$

Where:

M0 = weight of samples (g)

M1 = weight of extraction beakers and boiling stones before extraction (g)

M2 = weight of extraction beakers and boiling stones after extraction (g)

All the measurements were performed in triplicate. The data was analyzed with independent samples T-test and generated by software IBM SPSS Statistics 25 (SPSS Inc., Chicago, Illinois, USA). The significance level was pre-set at $\alpha = 0.10$ and $\alpha = 0.05$.

Sensory evaluation

Sensory evaluation was conducted in accordance with the procedure described by Olivera and Salvadori (2006). A panel of eight semi-trained individuals from Universiti Tunku Abdul Rahman were recruited and required to evaluate the acceptability of each durian sample in terms of yellowness, attractiveness of aril in terms of color and shape, flavor, sweetness, aroma, less watery pulp and texture on a typical 9-point hedonic scale. The 9-point hedonic scale was used by having 9 scaling tests ranging from 9 = like extremely, 5 = neither like nor dislike and 1= dislike extremely.

Results and discussion

Higher than average rainfall was recorded from September 2020 to January 2021 directly resulting in poorer yields of durian. Approximately two weeks before anthesis, irrigation was withheld but heavy rainfall continued. High rainfall after anthesis causes flowers to drop, resulting in poor pollination, and subsequently in poorer fruit set. Accompanied by strong winds, higher fruit abscission could occur. The trees in this experiment yielded approximately 30 fruits tree^{-1} only, and no fruit pruning was conducted.

Polyhalite application and the withdrawal of N and P input after anthesis showed an increase in weight percentage of arils and decreases in husk and seed weight (Table 2). The same treatment also non-significantly increased the average fruit roundness and sphericity, while significantly increasing shell thickness in the distal portion of the fruit (Table 3). Reductions of N applications during the fruit development stage is generally associated with higher yields, improved quality and good fruit shape (Datepumee *et al.*, 2019).

Characteristics of the arils (Total soluble solid, moisture content, pH, and titratable acidity)

TSS gives an estimate of sugar content which included other components such as organic acids, amino acids, or pectin (Martínez *et al.*, 2013). Sucrose was the predominant sugar in durian. Durian also contains glucose, fructose, and maltose (Aziz and Jalil, 2019). This study recorded that both control and polyhalite-treated

Table 3. Physical characteristics of the durian samples.

Sample	Roundness	Sphericity	Shell thickness	
			Distal	Middle
			------------cm	------------
Control	0.86 ± 0.26[a]	0.87 ± 0.29[a]	1.47 ± 0.07[a]	1.18 ± 0.13[a]
Polyhalite	0.86 ± 0.31[a]	0.88 ± 0.49[a]	1.63 ± 0.06[b*]	1.17 ± 0.10[a]

Values in the table represent the mean ± standard deviation of three biological replications. Means within each column with different letters are significantly different.
(*) denotes $p < 0.05$.

Table 4. Characteristics of the arils (Part 1).

Sample	TSS	Moisture content	pH	Titratable acidity
	°*Brix*	%		%
Control	29.0 ± 1.0^a	49.75 ± 0.69^a	6.15 ± 0.52^a	0.256 ± 0.13^a
Polyhalite	27.0 ± 1.7^a	48.43 ± 1.56^a	6.92 ± 0.15^b	0.256 ± 0.00^a

Values in the table represent the mean ± standard deviation of three biological replications. Means within each column with different letters are significantly ($p < 0.10$) different.

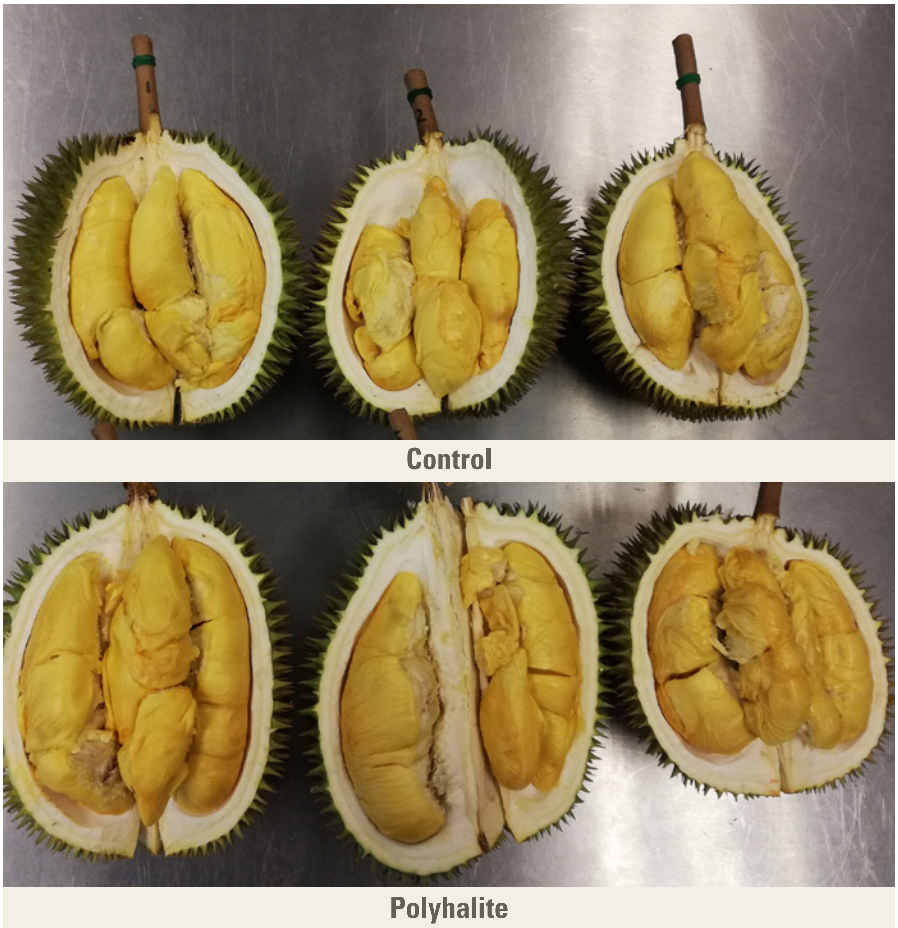


Photo 5. Arils from the durian fruit from the control plots (top) were yellower than those from fruit taken from the polyhalite treated plots. Photo by the authors.

(27.0-29.0 °Brix), with no significant ($p > 0.05$) difference among the samples (Table 4). The moisture content of both samples ranged from 48.43 to 49.75% and showed no significant difference. Moreover, the titratable acidity of both samples showed no significant differences (~0.256%). However, the durian pulp pH of the control and the polyhalite-treatment showed a significant difference at $p < 0.10$. This demonstrated that polyhalite-treated durian pulp has a higher pH, nearer to neutral and less acidic, compared to control durian pulp. The pH is commonly used to determine the quality and freshness of durian. Durian with a low pH can be categorized as acidic and might not be appropriate for consumption. However, durian with a high pH, or alkaline, might promote the growth of spoilage microorganisms (Tan *et al.*, 2018).

Characteristics of the arils (color and firmness)

Based on the results shown in Table 5, durian pulp, either control or polyhalite-treated, was lighter in color, indicated by a high L* value (79.05-80.52) and a low a* value (redness 11.42-12.49). There were no significant differences ($p > 0.05$) among the samples, either in the control or treated durian. However, the control has higher yellowness b* value (45.60) which is significantly different ($p < 0.10$) compared to the treated sample (42.91). Although the yellowness of the polyhalite-treated arils was a slightly lower intensity when measured by the colorimeter, the sensory evaluation panel determined the yellowness to be higher in the polyhalite-treated durian compared to the control (Table 7).

Table 5. Characteristics of the arils (Part 2).

Sample	Color			Firmness (N)
	L*	a*	b*	
Control	80.52 ± 1.72^a	11.42 ± 2.41^a	45.60 ± 0.67^b	0.088 ± 0.008^a
Polyhalite	79.05 ± 0.18^a	12.49 ± 0.69^a	42.91 ± 1.93^a	0.169 ± 0.041^{b*}

Color measurements expressed using CIE-Lab color space: L* (lightness intensity), a* (+ redness, – greenness), and b* (+ yellowness, – blueness). All values represent the mean ± standard deviation of three biological replications. Means within each column with different letters are significantly ($p < 0.10$) different. (*) denotes $p < 0.05$.

Table 6. Nutritional composition of the durian arils.

Sample	Protein	Fat content
	---------------------------%---------------------------	
Control	6.36 ± 1.31^{a}	7.68 ± 1.03^{a}
Polyhalite	7.52 ± 0.70^{a}	10.64 ± 0.53^{b*}

Values in the table represent the mean ± standard deviation (n = 6). Means within each column with different letters are significantly ($p < 0.10$) different. (*) denotes $p < 0.05$.

The firmness test showed the polyhalite-treated durian arils were significantly firmer (p < 0.05) than the control durians. According to Szczesniak (2002), texture is a multifaceted sensory property consisting of a combination of multiple sensory characteristics and perceptions linked to mechanical properties (hardness, chewiness, crunchiness, etc.), geometric properties (shape, size, etc.), and product composition (fat and water contents).

Nutritional composition of the durian arils

Based on the result of this study (Table 6), polyhalite-treated durians were found to be significantly richer (p < 0.05) in fat content than the control (10.64% vs 7.68%). However, all durians contained a moderate amount of protein (6.36-7.52%) with no significant differences.

Sensory quality of the arils

The results of the hedonic scaling test for durian arils are listed in Table 7 and Table 8. Polyhalite application non-significantly increased the attractiveness (color) score, attractiveness (shape) score, aroma score, texture score, and reduced the watery pulp texture according to consumers. However, there were significant differences for flavor (p < 0.10) and sweetness (p < 0.10) between the control and polyhalite-treated durian pulps. Sweet and fruity aromas correlate strongly with most esters and an aldehyde compound respectively (Voon *et al.*, 2007). However, flavor compounds were not quantified in this study.

Most of the panelists commented that the polyhalite-treated durian pulps had a stronger onion-sulphur aroma and flavor compared to the control. There could be close correlations between the mean scores of liking for the flavor and aroma characteristics of the polyhalite-treated durians. The mean score of liking for texture of the polyhalite-treated durian pulps was higher compared to the control, which was correlated to the enhanced firmness exhibited by the treated durian pulps. However, there were no significant differences between these two samples for the texture attribute.

Conclusion

Polyhalite application at the rate of 5 kg tree^{-1} to the D101 cultivar on the durian farm in Tapah, Perak, could potentially increase weight percentage of arils and decreases in husk and seed weight. Furthermore, it showed better physicochemical and organoleptic properties of the durian arils in terms of color, flavor, sweetness, aroma and texture. Therefore, polyhalite has shown positive and promising results on the overall quality of durian and can be a possible alternative to conventional high potassium NPK 15-5-20-2 + 10S +TE applied after flowering and during fruit development.

Table 7. Sensory attribute mean scores of the arils (Part 1).

Sample	Sensory attributes		
	Attractiveness		Flavor
	Color	Shape	
Control	7.14 ± 1.07^{a}	6.86 ± 1.21^{a}	6.29 ± 1.98^{a}
Polyhalite	7.50 ± 1.07^{a}	7.00 ± 1.60^{a}	8.00 ± 0.76^{b}

Values in the table represent the mean ± standard deviation (n = 6). Means within each column with different letters are significantly ($p < 0.10$) different.

Table 8. Sensory attribute mean scores of the arils (Part 2).

Sample	Sensory attributes			
	Sweetness	Aroma	Watery pulp	Texture
Control	6.14 ± 1.77^{a}	7.00 ± 1.15^{a}	6.14 ± 1.77^{a}	6.14 ± 1.07^{a}
Polyhalite	7.38 ± 0.74^{b}	7.25 ± 1.16^{a}	6.38 ± 1.51^{a}	7.00 ± 1.31^{a}

Values in the table represent the mean ± standard deviation (n = 8). Means within each column with different letters are significantly ($p < 0.10$) different.

Acknowledgements

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The paper "Polyhalite improves Physiochemical and Organoleptic Properties of Durian When Applied After Flowering and During Fruit Development" also appears on the IPI website.