

Research Article

Effects of Polyhalite and Doses Application After Anthesis on Yield, Quality and Postharvest Storage Shelf Life of MD2 Pineapples (*Ananas comosus*)

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Potassium fertilisation plays an important role in improving pineapple fruit weight and quality. Potassium chloride (KCl)-based compound fertilizer instead of potassium sulphate (K_2SO_4) is often used in the pineapple cultivation due to its cheaper cost. A naturally formed mineral fertiliser mined in the U.K. known as polyhalite is one of the K_2SO_4 -based fertiliser suitable for use in pineapple cultivation, besides supplying other macronutrients, which include magnesium (Mg), calcium (Ca) and sulphur (S). This study aimed to evaluate the effects of polyhalite application after anthesis on yield, quality and postharvest storage shelf life of MD2 pineapples. Results showed that the average fruit weight increased by 12.8% with polyhalite dosage with significant increase recorded at the dose of 660 kg/ha. N, K, Mg, Ca and B levels in D leaf increased with polyhalite application. Pineapples treated with 660 kg/ha had slightly higher total soluble solids (11.30%), crude fibre content (28.50%), titratable acidity (13.30%) and sensory profile of overall acceptability (1.90%) compared with the control (without polyhalite application) at Day 13 of storage period. Thus, it can be concluded that polyhalite has the potential to serve as fertiliser source supplying K and secondary macronutrients such as Ca, Mg and S to enhance yield, quality and shelf life of pineapples grown in Malaysia.

Keywords: crude fibre; macronutrients; mineral fertiliser; potassium; sensory test; weight loss

1. Introduction

Pineapple (*Ananas comosus*) is one of the most cultivated fruits in Malaysia [1]. It is nonseasonal and takes more than 15 months to harvest. Among all the pineapple varieties, MD2 pineapple, also known as “Gold” pineapple or “Honey Gold” pineapple, is a variety of pineapple that is prized for its sweetness, low acidity, juiciness and golden colour. Cultivation of MD2 is popular in many tropical regions and gained popularity due to its superior taste and texture quality and longer shelf life [2]. MD2 pineapples at 100% ripeness can

achieve higher total soluble solids (TSSs), vitamin C or ascorbic acid content and low acidity compared with MD2 pineapples at lower percentage of ripeness such as 50% ripeness [3, 4].

The pineapple has a large demand for plant nutrients. For this reason, appropriate and right practices of fertilisation always play a vital role in supporting plant growth, health and productivity in agriculture where fruit is destined for sale. Typical grower practices for pineapple fertilisation are using balanced fertilisers formulation containing nitrogen (N), phosphorus (P), potassium (K) and micro-nutrients such as magnesium (Mg) and iron (Fe) [5].

K is one of the nutritional basics in highest demand for pineapple development cycle, which increases pigments of fruits and enhances their colour or appearance. Furthermore, K fertilisation is crucial to obtain heavier fruits and higher yields with significant improvements in quality parameters such as TSSs, total titratable acidity (TA) and vitamin C content [6]. Substitution of KCl with potassium sulphate (K_2SO_4) applied up to 700 kg/ha, K_2O seemingly improved plant size and fruit yield, but could also be ascribed to lower Cl^- content in leaf tissues [7, 8]. K_2SO_4 reduces soil pH, which helps in improving the typical functioning of plant stomata, and enhancing nutrient uptake of K, Fe and many other elements [9]. Sulphur (S) fertilisation can help correct nutrient deficiencies, improve nutrient balance and contribute to stress tolerance. Although role of S in increasing yield remained unclear, these experiments could suggest potential depressive effects of overfertilisation with KCl. In agricultural settings, S deficiencies may occur in soils with low organic matter content, acidic pH, or limited S availability [10].

Naturally formed mineral fertiliser mined in the U.K. known as polyhalite is one of the K_2SO_4 -based fertilisers [11]. The fully soluble characteristic and unique slow nutrient release of this mineral fertiliser has the potential to supply four crucial macronutrients for the cultivation of pineapples as a novel agricultural fertiliser which improves food security through improving food stocks in terms of quantity and consistent quality [12, 13]. However, research on effect of polyhalite application on pineapples is scanty.

Some studies have exhibited that application of calcium (Ca) was shown to improve firmness of the pineapple fruit, reduce peroxidase activity and reduce internal browning up to a period of 4 weeks [14]. Mg fertilisation and foliar sprays generally improved crop yields, including fruit crops [15–18].

Therefore, in this study, we investigated the effect of various rates of polyhalite application after anthesis on the yield, quality and postharvest storage shelf life of MD2 pineapples. The outcome of this study can suggest an ideal approach for the pineapple growers to enhance their overall yield and postharvest storage quality by applying appropriate polyhalite dosage and nutrient formulation.

2. Materials and Methods

The study was carried out at a pineapple farm located in Linggi, Negeri Sembilan, Malaysia (GPS Coordinate: 2.4316, 101.9721) from July 2019 to December 2020. According to rainfall data from 2011 to 2020, the area had an average rainfall of 2113 mm and rain days of 103 per year. Monthly precipitation data are shown in Figure 1. MD2 pineapple suckers obtained from the Ministry of Agriculture, Malaysia, were planted at a density of 55,000 plants/ha in July 2019. The pineapples were planted on Malacca soil series (oxisol), which is a heavy clay soil with petroplinthite gravels and lateritic stones as reported by the soil analysis done by the farm owner. NPK 15-15-15 was applied 1 month after planting (MAP), 3 MAP and 7 MAP at the rate of 10 g/plant each time. NPK 12-12-17 + 2 MgO was applied at 11 MAP at

the rate of 20 g/plant. Subsequently, flower stimulation was conducted using Ethrel 5% and urea mixture to achieve flowering rate of > 95%. Polyhalite was applied after anthesis at 12 MAP at three rates, 0 g/plant, 6 g/plant (330 kg/ha) and 12 g/plant (660 kg/ha), hereafter referred to as Control, Treatment 1 (T1) and Treatment 2 (T2), respectively. The experiment was set up using a randomized complete block design (RCBD) with three replicates. There were 60 plants in each replication of each treatment. A sunshade net (50% shade) was used to cover the developing fruits to avoid sun scorch.

D-leaves of 10 plants per treatment were sampled before harvest and tested for N, P, K, Ca, Mg, S and boron (B) concentrations using the atomic absorption spectroscopy (AAS). D-leaves in pineapple cultivation refers to the tallest, youngest among the adult leaves and the most physiologically active, commonly used to assess the nutritional and growth conditions of the plant [19]. Furthermore, D-leaf length, width and dry weight were measured. The D-leaves were oven-dried at 65°C for 48 h before the dry weight was obtained.

Pineapples were harvested at maturity index 3 (quarter ripe fruit or 25% of fruit yellow in colour) in December 2020 for fruit physical characteristic measurements and laboratory analysis. A total of 270 fruits were measured for fruit circumference, length, and weight with 90 fruits per each treatment. Further measurement in terms of percentage of fruit proportion to crown weight was also determined.

Postharvest storage study was monitored and measured every 3 days on weight loss percentage basis at both room temperature ($25 \pm 2^\circ C$, 70%–80% relative humidity, RH) and chilling conditions with temperature set at $12 \pm 2^\circ C$, 70%–80% RH, until the fruits were not fit for consumption (fungus growth and slightly rotten). The results were expressed as percentage weight loss relative to the initial weight.

Fruit physical and biochemical quality including instrumental texture analysis on whole fruit and pulp, colour analysis, TSSs and TA were measured every 4-day interval throughout the storage period of 13 days. Evaluation of colour on pineapple pulp was measured by using a colorimeter (CM-600D, Konica Minolta, Japan) according to Niu et al. [20]. Texture was analysed by subjecting the samples to a puncture test as performed by texture analyser (TA.XT Plus, Stable Micro Systems, UK). The firmness of the pineapple fruit (before skin removal) and fresh pineapple pulp were analysed. Two fruits in each replication were penetrated using the 5 mm diameter cylindrical probe, at a speed of 50 mm min^{-1} on three points in the equatorial region of the whole piece of fruit and fruit pulp. The compression force measured at the maximum peak of the recorded force on the chart was expressed in Newtons (N). TSSs of the samples were determined by using a hand-held digital refractometer (PAL-3, ATAGO, Japan). Pineapple pulp in the equatorial region of the whole piece of fruit was blended to obtain juice samples. Approximately 2–3 drops of the sample were placed onto the prism of the refractometer [21]. The percentage of TSS of the sample was shown on the digital screen. TSS of samples was expressed as % and

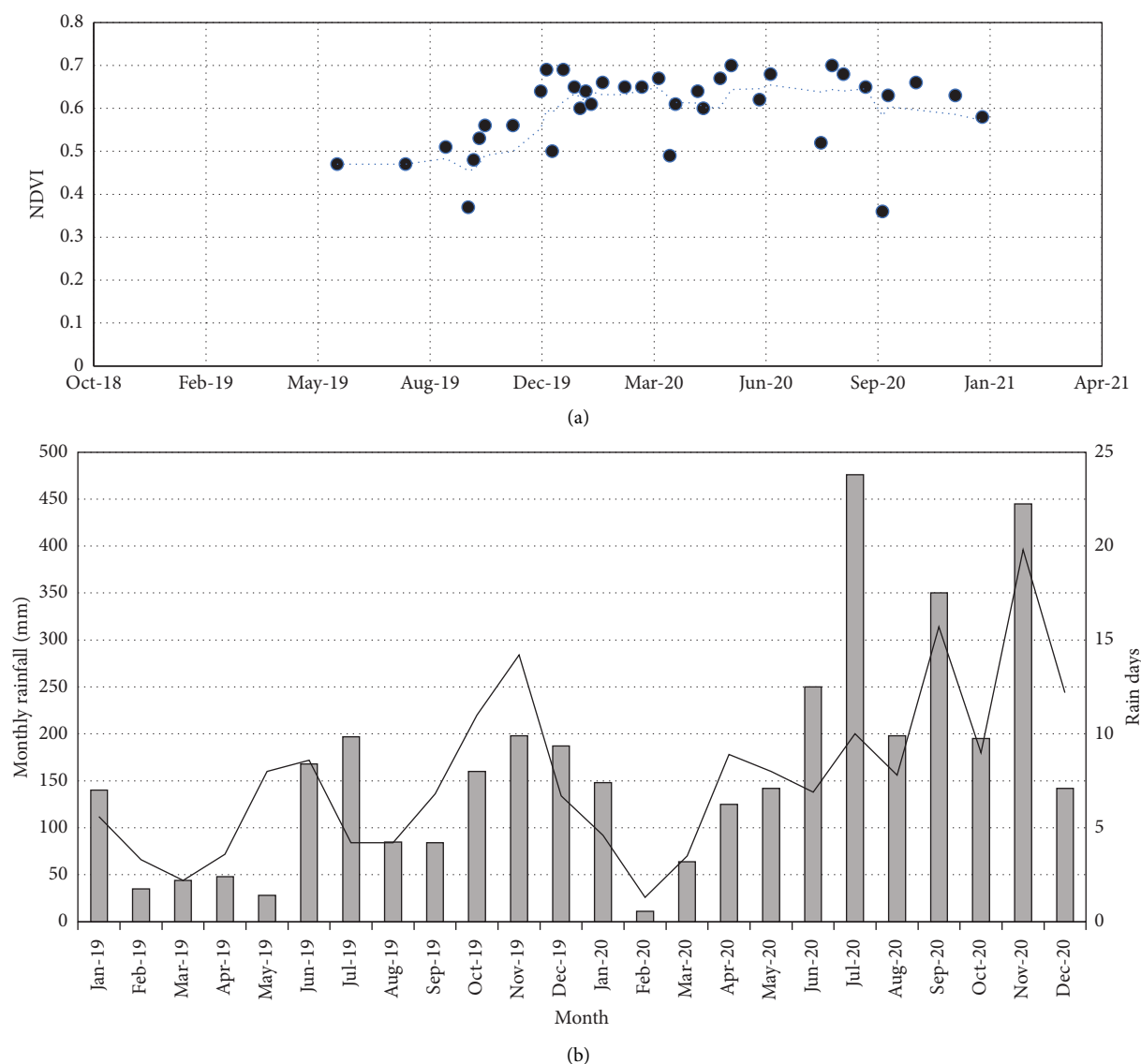


FIGURE 1: Normalized difference vegetation index (NDVI) values of the trial site analysed from satellite images from the sentinel satellites (a). Monthly rainfall (mm) represented by bar graph and number of rain days represented by line graph from January 2019 to December 2020 (b).

triplicates for each sample were obtained. According to the Association of Official Analytical Chemists, AOAC [22] method, TA was conducted by titration. Phenolphthalein (0.1%) was used as a pH indicator. The TA of the samples was expressed as % citric acid since citric acid is the major compound in pineapple.

Furthermore, crude fibre test, vitamin C test and sensory test were conducted for MD2 pineapples that were stored for Day 9. The fibre content of MD2 pineapples was determined using the standard AOAC method with reference to Issara and Rawdkuen [23]. Ascorbic acid was determined by using the 2,6 dichlorophenol-indophenol dye titration method [24]. Samples were prepared using 10 g of fruit pulp tissue, homogenized in 90 mL of 3.0% metaphosphoric acid (HPO_3) solution and the filtrate transferred into 100 mL volumetric flasks. The volume was made up to 100 mL using

3.0% HPO_3 . An aliquot of the sample (10 mL) was titrated against 2,6 dichlorophenol-indophenol dye until the light pink colour persisted for 15 s. The ascorbic acid content was expressed as mg per 100 g of the fresh fruit. Sensory evaluation was conducted in accordance with the procedure described by Olivera and Salvadori [25]. A panel of 30 untrained consumers includes students and researchers from the Universiti Tunku Abdul Rahman were recruited to evaluate the acceptability of each pineapple sample at the food sensory laboratory with individual test booths under white fluorescent lights. Each pineapple sample (approximately 3 cm × 3 cm × 3 cm) was chilled for 1 h at 4°C before disseminated among the panelists. The samples were served in plastic sample cups coded with three-digit random numbers. For every sensory evaluation procedure, the panelist was provided with drinking water for palate

cleansing. Each panelist was given a printed questionnaire to evaluate their degree of liking for each pineapple sample in terms of appearance (colour), aroma, texture, sweetness, juiciness and overall acceptability on a typical nine-point hedonic scale. Nine-point hedonic scale was used by having 9 scaling tests ranging from 9 = like extremely, 5 = neither like nor dislike and 1 = dislike extremely. The study was approved by the UTAR Scientific and Ethical Review Committee (ID no: U/SERC/113/2020).

All tests and analyses were performed in triplicate, and the data were reported as mean with standard deviation. The data was analysed using one-way analysis variance (ANOVA) and generated by software IBM SPSS Statistics 25 (SPSS Inc., Chicago, Illinois, USA). Least significant difference (LSD) test was applied in comparing if significant differences happened between the means at 95% confidence interval ($\alpha = 0.05$).

3. Results and Discussion

3.1. Yield, Fruit Size and D-Leaf. Results indicated that the application of polyhalite improved pineapple yield (Table 1). The average fruit weight increased with polyhalite dosage ($y = 0.1109x + 1.5395$, $R^2 = 0.99$) compared with the control. Significant increase of 12.8% was recorded for polyhalite application at the dose of 660 kg/ha compared with the control. In general, some of other studies have found that the use of K_2SO_4 as the K source in the pineapple nutritional program promoted superior results on pooled variables related to plant growth, compared with potassium chloride [7, 8, 26, 27]. With polyhalite application, fruits had longer length and width but resulted in larger aspect ratios. In another study on using polyhalite application on durian, it has shown that the withdrawal of N and P input after anthesis demonstrated an increase in weight percentage of durian arils and reduction in fruit seed and husk weight [28]. Polyhalite application also significantly improved D-leaf dry weight (10.76–12.16 g) at harvest. Even though some of the pineapple crowns look bigger than the whole fruit, the proportion of fruit body to crown of MD2 pineapples were not significantly different with the fruit ratio ranges from 85.28% to 89.68%.

D-leaves collected before harvest showed slight increases of all nutrients tested (six mineral compositions including N, K, Mg, Ca, S and B) except P in D-leaf after polyhalite application but there is no statistically significant increment as shown in Supporting Table 1. The data showed slight increase of 6%, 32%, 37%, 38%, 50% and 60% for B, N, K, Ca, S and Mg levels, respectively, in D-leaf samples of pineapples in T2 compared with control (without polyhalite application). These observations corroborated with the data from various authors concerning the amount of macronutrients accumulated by the pineapple plant from the soil. They found that there is a decreasing order of uptake for macronutrients: $K > N > Ca > Mg > S > P$ [29]. In the case of P, the results did not show an increase in concentration of P in leaves from plants treated with both T1 and T2 (with polyhalite application). This could be due to P would have been mobilised to the fruit, given with the larger pineapple sizes

and weight compared with the control. Understanding the fruit weight histogram is crucial to further determine optimum K_2O input and achieve maximum economic yield for producers (Figure 2). For example, exports to certain international markets require a consistent supply of smaller fruits but could be sold at premium pricing [30].

3.2. Postharvest Shelf Life Study. Weight loss is a parameter to evaluate the quality of fruit. Weight loss of treated and untreated MD2 pineapples increased over the storage period. There was a 1.6%–2.1% weight loss after 4 days of storage at chilled conditions (Figure 3). However, no significant difference in weight loss was observed between MD2 pineapples treated with T2 and untreated fruits. This demonstrated that K fertilization has little influence on the weight loss.

It demonstrated that the duration of postharvest storage life of MD2 pineapples at ambient conditions was 7 days shorter than the duration of postharvest storage life of MD2 pineapples stored at chilled conditions (21 days). The vapour pressure deficit, which is a function of temperature and RH is the driving force of water loss [31].

3.3. Colour Analysis. Colour is one of the most important visual attributes of MD2 pineapples. Colour measurement is the reflectance spectrum that has been proposed as a maturity index [32]. The L^* value representing the lightness of colour for treated and untreated MD2 pineapple pulp ranged 74.40–74.67 on the first day of storage. The L^* value gradually increased as the fruit ripened over the storage period as shown in Supporting Table 2. From this study, a delayed ripening was observed in T1-treated MD2 pineapples compared with control and T2. However, there was no significant difference of L^* values among the treatments.

The increase in lightness of MD2 pineapple peel during storage showed that the colour changed as ripening progressed. While the decrease in lightness of flesh during storage indicated that the colour changed from light yellow to deep yellow as ripening progressed. This lightness (L^*) and yellowness (b^*) of pineapples indicated a good visual appeal for consumer demand.

The a^* value representing the greenness to redness colour of treated and untreated MD2 pineapple pulp ranged 3.28–3.76 on the first day of storage. It was observed that the a^* value or the redness gradually increased as the fruit ripened during storage and peaked at Day 9 at chilled storage conditions. However, there was no significant difference of a^* values among the treatments.

The b^* value representing the blueness to yellowness colour of treated and untreated MD2 pineapple pulp ranged 34.57–37.57 on the first day of storage. It was observed that the b^* value or the yellowness gradually increased as the fruit ripened during storage and peaked at Day 9 during chilled storage conditions. However, there were no significant differences of b^* values among the treatments. This demonstrated that K fertilization at this rate has no significant effect on colour parameter. If the fruit of plants adequately fertilised with K, it will contain more pigments, enhancing its colour and appearance [8].

TABLE 1: Fruit and D-leaf measurements.

Treatment	Rate of polyhalite (kg/ha)	Fruit measurements				D-leaf measurements			
		Yield (mt/ha)	Weight (kg)	Length (cm)	Width (cm)	Aspect ratio	Fruit ratio (%)	Length (cm)	Dry weight (gm)
Control	0	89.90 ± 25.05 ^a	1.64 ± 0.46 ^a	16.51 ± 2.13 ^a	12.91 ± 1.13 ^a	1.28 ± 0.11 ^a	85.28 ± 3.99 ^a	102.70 ± 10.00 ^a	10.76 ± 1.51 ^a
T1	330	93.05 ± 27.41 ^a	1.69 ± 0.50 ^a	16.47 ± 2.55 ^a	12.97 ± 1.22 ^a	1.26 ± 0.13 ^a	89.68 ± 2.82 ^a	101.00 ± 11.90 ^a	11.08 ± 2.19 ^a
T2	660	101.60 ± 28.68 ^b	1.85 ± 0.52 ^b	17.14 ± 2.60 ^b	13.30 ± 1.24 ^b	1.34 ± 0.24 ^b	87.12 ± 2.33 ^a	106.80 ± 11.20 ^a	12.17 ± 0.93 ^b

Note: Measurement values are the means ± standard deviation. Different superscript letters indicate significant differences.

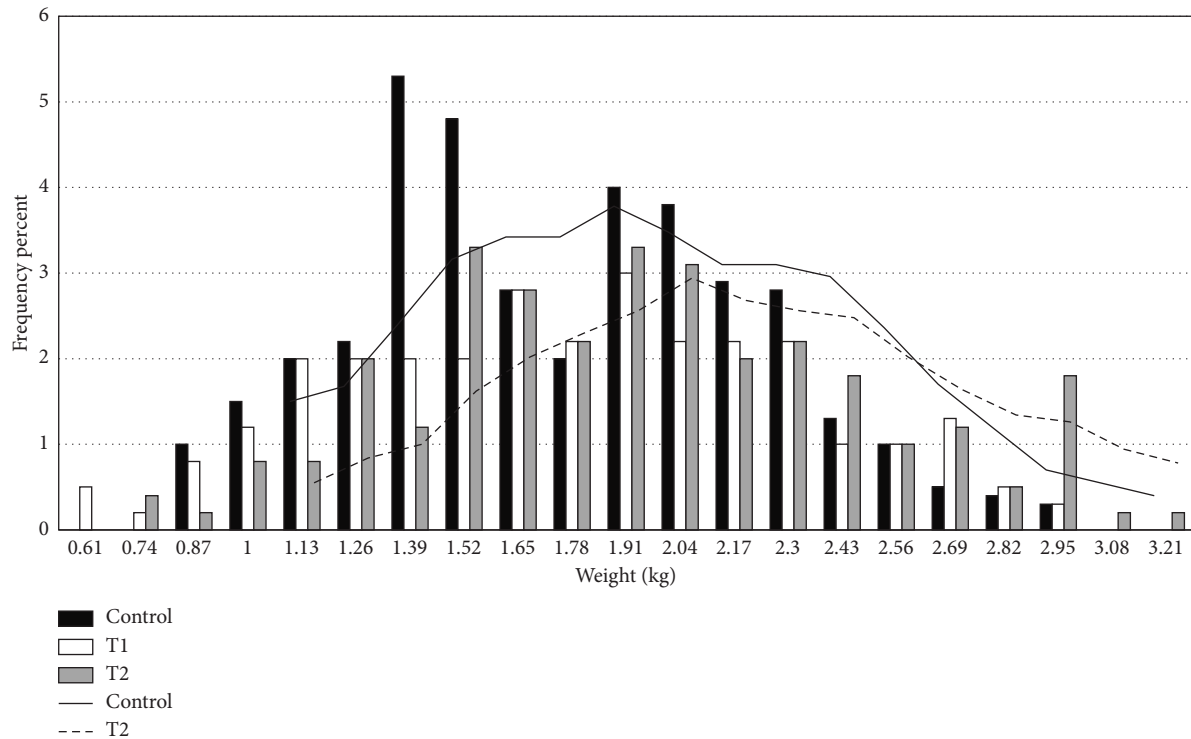


FIGURE 2: Fruit weight histogram for control, treatment 1 (T1) and treatment 2 (T2).

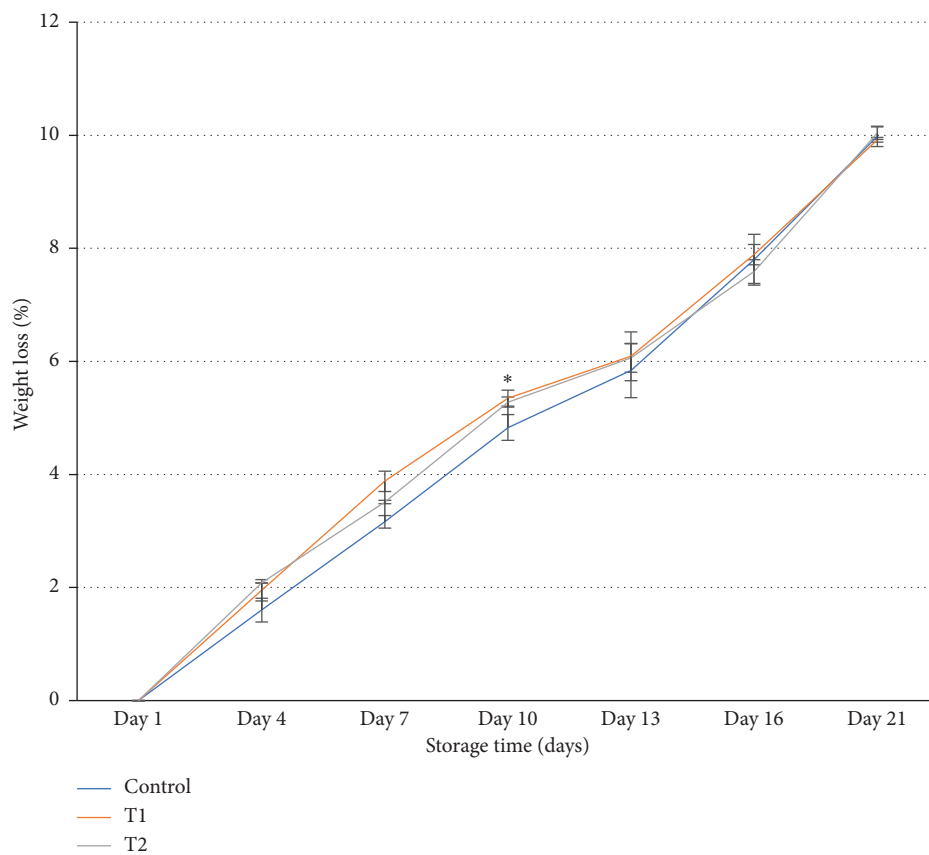


FIGURE 3: Weight loss of MD2 pineapple fruit during storage (12°C, 70%–80% RH). Each value is the mean of three replicates $\pm$ SD. The (*) indicate significance differences.

3.4. Texture Analysis. Firmness is related to water content and metabolic changes and it is one of the important factors that influence the consumers' acceptability of fruits [33]. Firmness of the MD2 pineapple fruits decreased significantly during storage, from 14.2 N to 11.9 N (Control), from 14.5 N to 12.1 N (T1) and from 15.5 N to 12.3 N (T2) after 13 days as shown in Supporting Figure 1. Normally, tissue firmness decreases during fruit ripening in storage [34]. From field observations, a delay of fruit ripening in the treatment plots was also recorded based on how rapid the first 150 fruits reached index 3.

The MD2 pineapple fruit pulps were soft. The firmness of pineapples for all treatments was not significantly different to each other. Total soluble acids and firmness decrease as MD2 pineapples ripen [3, 35]. Flesh firmness is the parameter of the greatest concern in pineapple fruit storage and marketing because flesh softening is associated with senescence and fruit injuries [36].

During Day 13 of storage, the pineapples from control or treated with polyhalite were seen with the internal fruit darkening and water-soaked conditions after the pineapple were cut into halves. Improved firmness has been reported through preharvest K_2SO_4 sprays whereas Ca hydroxide spray has been shown to decrease internal browning of Mauritius pineapples after cold storage of 4 weeks [37]. Owureku-Asare et al. [5] ascribed increase in the amounts of K can lead to a reduction in internal fruit darkening.

3.5. TSSs. Besides fruit firmness, the sugar content is another important quality attribute of MD2 pineapple fruits. TSSs content for MD2 pineapple fruits ranged from 11.42% to 15.43% as shown in Supporting Figure 2. The TSSs for control samples decreased from 14.28% to 12.16% after 13 days of storage. Besides that, the TSSs for T1 samples decreased from 15.43% to 13.05% after 13 days of storage. In contrast, the TSSs for T2 samples increased from 12.65% to 13.53% after 13 days of storage. An observed delay of fruit ripening in the treatment T2 could be the possible cause to the gradual increase of TSSs in T2-treated pineapple fruits (reference to results). Various studies found that a rise in TSSs content and vitamin C in the pineapple fruit are caused by a balanced nutrition with K in the pineapple plant [6, 38]. TSS is usually correlated with sweetness index than total sugars [27] and it is commonly used as an indicator of fruit maturity and quality [39]. However, the TSSs of all treatments at each interval of storage period were not significantly different. Pineapples with different varieties range between 10.8% and 17.5% with very little disparities [40].

3.6. TA. The TA of MD2 pineapple fruits ranged from 0.019% to 0.057%. In the present work, the TA value of all samples gradually increased from Day 1 to Day 5 of storage period (Figure 4). Later, the TA value gradually decreased from Day 5 to Day 9 of storage. Respiration

process could reduce the level of acidity in the pineapple fruits due to the utilization of citric acid as a substrate [40]. This trend of TA value changes, which initially had increased and declined during storage, is in agreement with Nilprapruck et al. [41].

TA value did not significantly ($p > 0.05$) show changes in different maturity stages of pineapple fruit during Day 5 of storage. However, TA values for control and T2 samples were significantly higher than T1 samples during Day 1 of storage. During Day 9 and Day 13 of storage, TA values for T2 samples were significantly higher than T1 samples. This showed some distinct features of T2 samples with higher TA upon ripening. K deficiency can decrease TA and increase the TSSs/TA ratio significantly [6]. The higher the fruit acidity, the higher the astringency and the longer the storage shelf life [5].

3.7. Vitamin C Analysis. In this study, vitamin C content or ascorbic acid in MD2 pineapple fruits were moderately high and ranged from 38.32 to 39.98 mg/100 g (Table 2). However, there was no significant difference of vitamin C content among the polyhalite-treated and untreated pineapple samples. There are several factors that affect the ascorbic acid content of pineapple such as the cultivar or variety, maturity indices, part of fruit, method of analysis and conditions of storage. It can range from 20 to 34.44 mg/100 g [42, 43].

3.8. Crude Fibre Analysis. Based on the result of this study (Table 2), polyhalite-treated T2 pineapples were found to be significantly higher ($p < 0.05$) in fibre content than control (2.67%) and T1 samples (3.03%). This could be caused by the effect of K supplementation in the fertiliser application which increased the fibre content of the pineapples [44].

3.9. Sensory Evaluation. Polyhalite application shown in T2 samples insignificantly increased appearance (colour), aroma and sweetness according to consumers (Figure 5). However, there were significant differences for texture, overall acceptability and juiciness between the control and polyhalite-treated pineapple pulps. Both control and T2 samples obtained significantly higher score in texture compared with T1 samples, while T2 samples had better juice content as compared with T1 samples.

Most panellists preferred T2 samples by giving the highest score for the overall acceptability, which was contributed by the attractive appearance/colour, sweet aroma, sweet taste, high juiciness and good bite texture. These results were also in agreement with the mean score of overall preference which was predominantly affected by the juiciness of MD2 pineapples [45].

Based on the data collected from this study, it showed that polyhalite application or with addition of K level has demonstrated an enhanced effect on fruit quality. Experimental studies have shown that increasing the amount of K increases the acidity and sugar content of fruit pulp and improves aroma and fruit firmness. Several advantages could

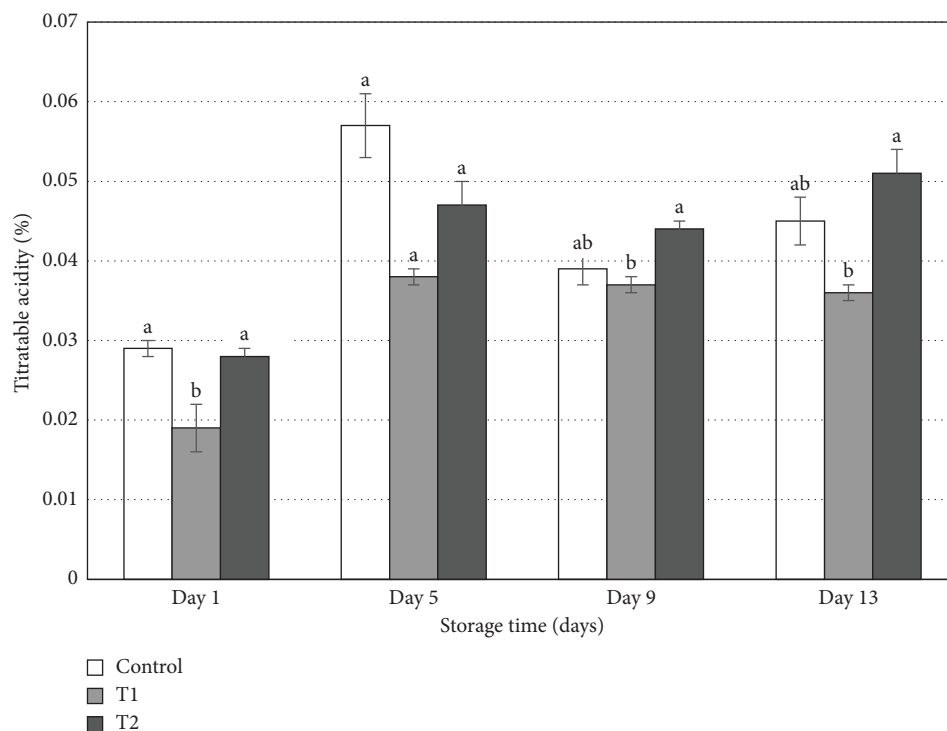


FIGURE 4: Titratable acidity of MD2 pineapple fruit during storage (12°C, 70%–80% RH). Each value is the mean of three replicates $\pm$ SD.

TABLE 2: Vitamin C and crude fibre content of MD2 pineapple fruit.

Treatment	Rate of polyhalite (kg/ha)	Vitamin C (mg/100 g)	Fibre content (%)
Control	0	38.32 $\pm$ 1.89 ^a	2.67 $\pm$ 0.31 ^a
T1	330	39.17 $\pm$ 1.79 ^a	3.03 $\pm$ 0.38 ^a
T2	660	39.98 $\pm$ 2.56 ^a	3.43 $\pm$ 0.31 ^b

Note: Measurement values are the means $\pm$ standard deviation. Different superscript letters indicate significant differences.

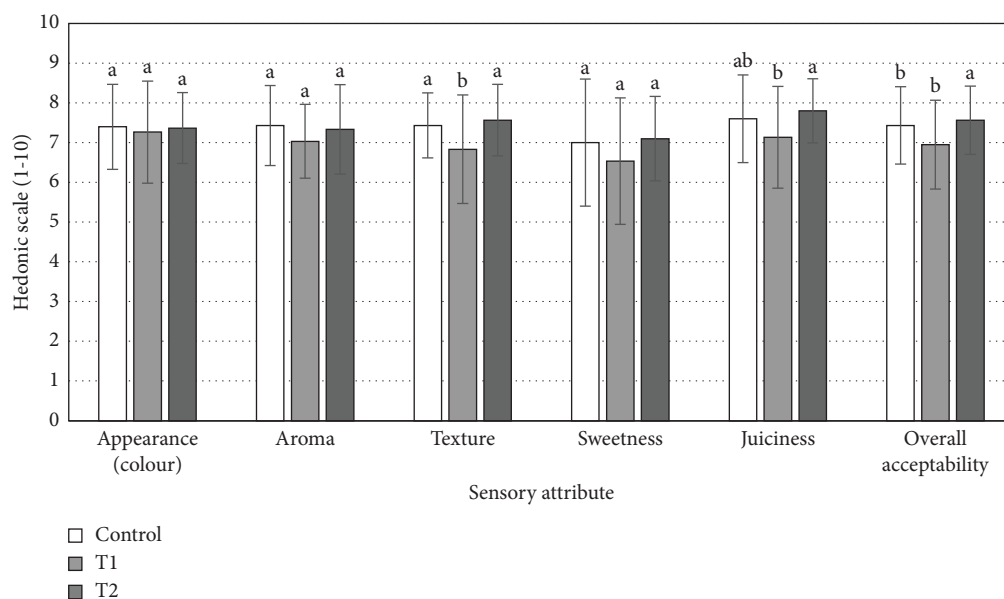


FIGURE 5: Sensory attribute mean scores of the pineapple pulp. Each value represents the mean $\pm$ standard deviation ($n = 30$). Means with different superscripts are significantly different.

also be clearly demonstrated by increasing levels of K, particularly to an increase in ascorbic acid content and enhancing the overall vitamin content of the fruit [46].

4. Conclusion

Results obtained have shown that average pineapple fruit weight significantly increased with polyhalite dosage. Furthermore, pineapples treated with 660 kg/ha had demonstrated higher TSSs, vitamin C and sensory profile. Thus, polyhalite, a naturally formed mineral mined in the UK has potential to serve as fertiliser source supplying K and secondary macronutrients such as Ca, Mg and S to enhance yield, quality and shelf life of pineapples grown in Malaysia.

Data Availability Statement

The data used to support the findings of this study are available from the corresponding author upon reasonable request.

Ethics Statement

Ethical approval by the UTAR Scientific and Ethical Review Committee (ID no: U/SERC/113/2020).

Conflicts of Interest

The authors declare no conflicts of interest.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. (*Supporting Information*)

S Table 1: D-leaf nutrient concentrations. S Table 2: Lightness (L^*), greenness to redness value (a^*) and blueness to yellowness (b^*) of MD2 pineapples pulp during storage (12°C , 70%–80% RH). S Figure 1: Firmness of MD2 pineapple fruit during storage (12°C , 70%–80% RH). S Figure 2: TSSs of MD2 pineapple fruit during storage (12°C , 70%–80% RH).

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