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Potassium Management for Corn Growth, Yield and Sweetness Under Sabah Sandy Soil

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ABSTRACT

A study was conducted to determine the effect of potassium (K) with organic fertilizers on the growth, yield and sweetness of reddish waxy corn. The treatments were: (T1) standard fertilizer rate of 60 kg ha^{-1} K_2O without organic fertilizer (control); (T2) 30 kg ha^{-1} K with organic fertilizer; (T3) 90 kg ha^{-1} K with organic fertilizer and (T4) 120 kg ha^{-1} K with organic fertilizer. Organic fertilizer used was 1.5 t ha^{-1} Bokashi and 20 t ha^{-1} chicken manure biochar (CMB). The planted corn received 120 kg ha^{-1} N and 60 kg ha^{-1} P_2O_5. The experimental design was Completely Randomized Design (CRD) with six replications. Stem girth, number of leaves, the height of the first cob, fresh weight of the first cob, 100 grains weight, cob girth, cob length and sweetness (Brix scale, %) data were analyzed using ANOVA (Analysis of Variance) at 5% significant levels. The Least Significant Different (LSD) was used to compare the means for significantly different results. Significant differences in growth were obtained at ($p<0.05$) in waxy corn for the number of leaves, the height of the first cob, length of cob, and girth between the control and all treatments. However, there is no significant difference for the sweetness of waxy corn for all treatments. Mean total for growth parameters; the number of leaves, stem girth and height of the first cob from soil surfaces and mean total for yield parameters; cob girth, length of cob, fresh weight of cob, 100 grains weight and the number of kernels was significantly higher for all treatments of T2, T3 and T4 compared to control the treatment of T1. The study showed no significant difference in the sweetness of waxy corn with increasing potassium application, resulting in increased total soluble content. Similar studies for a different rate of organic fertilizers and soil analysis can be done to ascertain further the effects on growth, yield, and sweetness parameters of reddish waxy corn with selected soil properties.

Keywords:
Potassium; corn; biochar; bokashi; chicken manure; sandy soil

1. Introduction

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Corn (*Zea mays* L.) or Indian corn are cultivated widely [1], and ranked third, after wheat and rice for global production of cereal crops. Malaysia is a tropical country located in the Equator, with hot and humid climate and land mass of over 336,745 km^2 [2]. In Malaysia, by 2015, about 21,112 hectares were allocated to grow crops such as corn, groundnut, cassava, sweet potatoes and aroids [3]. Hence, in year 2015, corn production recorded at 99,640 metric tons, with Selangor, Johor and Sarawak as the main corn producer in Malaysia [4].

Corn variety types include *Zea mays* var *amylaceae* (floury corn), *Zea mays* var *tunicata* (pod corn) or *Zea mays* var *ceratina* (waxy corn) [1]. Waxy corn differs from regular corn based on the starch formation in its structure. The composition in waxy corn is mostly amylopectin, whereas the other types of non-waxy corn have 25% amylose and 75% amylopectin in their composition. Several studies showed that the application of potassium with the rate of 60 and 90 kg ha^{-1} significantly produced bigger cobs and an increase in 100-grain weight [5], a more significant number of leaves that aids in the photosynthesis process and resulted in a substantial increase in total soluble solid content [6].

Sabah is a state in Malaysia surrounded by a coastal area of about 1,800 km long. The coastal zones are mainly flat with low elevation (m.a.s.l.). As such, these natural landscapes are affected with seawater intrusion, giving rise to one main soil fertility issue that is known as soil salinization. In parts of east and west coastline of Sabah, the BRIS (Beach Ridges Interspersed with Swales) soil landscape is noted. These areas are cultivated with paddy as the main livelihood activity. However, due to salinity, water sources and inefficient drainage condition, agriculture activity mainly paddy farming have been halted, directly affecting the socioeconomic of the community. BRIS soils are marginal soil, and about 40,400 hectares (Sabah) from 200,000 hectares recorded in Malaysia. Due to inherent low fertility (>80% sandy), about 119,273 hectares within Malaysia [2], [4] have been classified as idle land.

Waxy corn is a value-added crop; thus it is one possible option to be grown under BRIS soils, other than watermelon, cucumber, papaya, and banana. Literature study on the area noted that, waxy corn was planted mainly in hilly areas of the west coast (north) of Sabah in Kampung Menggaris Dua, Kota Marudu [7]. According to local community, waxy corn had starchy textures, ranging from white, yellow to reddish and easier to plant because it required less maintenance and fertilizer than sweet corn. Nevertheless, there is no significant study yet as evidence that waxy corn required less maintenance because waxy corn, mainly reddish waxy corn, considered a local breed with unidentified origins in Malaysia.

It was suggested that BRIS soil fertility has opportunities to be improved with organic fertilizers such as compost. Pasture plants respond to the treatment with phosphorus (P), potassium (K), calcium (Ca), copper (Cu), sulphur (S), boron (B), molybdenum (Mo) and magnesium (Mg) when planted in the BRIS soils [2], and Lah et al. [8] showed that organic fertilizer such as compost aids the increase of cation exchange capacity (CEC) thus, improving the soil fertility.

In the Tuaran area, activities to improve BRIS soil fertility by using organic amendments from chicken manure were applied by local farmers. When using organic amendments to increase the fertility of the sandy soil and using silver shine to mulch the soil, preventing weed growth, retain moisture and avoid fertilizer leaching, farmers managed to improve the soil fertility and successfully planted crops such as cucumber, papaya, pumpkin, and hybrid corn and banana.

Potassium (K) promotes translocations of sugar in plants, especially fruit or vegetable plants and it is assessed by total soluble solid (TSS) content. Sugar as assimilates is translocated from sources to sink in a plant, as potassium application increased. A study showed that K influences the sweetness of papaya by increasing the TSS content [6].

Therefore, this study objectives are, (1) to assess the growth and yield parameters of waxy corn and, (2) to determine the sweetness of waxy corn by using different rates of potassium (K) in combination with organic amendments (chicken manure biochar + bokashi).

2. Methodology

2.1 Location, Treatments and Experimental Design

This study was conducted under an insect-proof net house located in the Faculty of Sustainable Agriculture, Universiti Malaysia Sabah, Sg. Batang, Sandakan (5°55′ N, 118° 02′ E). Table 1 shows the four (4) treatments for the experiment. The treatments were in combination of potassium (K) fertilizer with bokashi and chicken manure biochar in six (6) replications arranged in Completely Randomized Design (CRD) set-up. A total of 24 experimental units were subjected for data collection and analyses.

Table 1
NPK Fertilizer, Bokashi and Chicken Manure Biochar treatments (in-combination)

Treatment	Potassium fertilizer (kg ha^{-1})	Chicken manure biochar (ton ha^{-1})	Bokashi (ton ha^{-1})
T1 (Control)	60	-	-
T2	30	20	1.5
T3	90	20	1.5
T4	120	20	1.5

Urea, Triple Super Phosphate (TSP) and Muriate of Potash (MOP) were used for nitrogen (N), phosphorus (P), and potassium (K). For organic fertilizers, chicken manure biochar and bokashi were used.

The rate for straight fertilizers application was 120 kg ha^{-1} N: 60 kg ha^{-1} P_2O_5: 60 kg ha^{-1} K_2O as control, whereas the potassium rate used varied from 60 kg ha^{-1}, 90 kg ha^{-1} and 120 kg ha^{-1}. For chicken manure biochar and bokashi, the use rate was constant at 20 tons ha^{-1} and 1.5 tons ha^{-1}, respectively.

2.2 Preparation of Planting Materials

The reddish-yellow glutinous corn (seed) was obtained from the local farm in Kg. Menggaris, Kota Marudu, Sabah. The cold room was used at a set temperature of 5°C and 50% relative humidity (RH) to maintain the viability of the seeds.

A germination test was conducted to determine the viability of the seeds, and subsequently unfilled and damaged seeds were discarded. The seed were soaked (in water) for 24 hours, collected and used as sowing materials. Upon seed germination, they were transplanted into a pot.

The pots were washed from any dirt and pot bottom-holes were covered with gravel (small stones) to counter soil draining out of the pots when plant watering was conducted. Inspection for deformities of the pots, such as visible cracks and minor holes, were also conducted to avoid excessive water seepage and soil draining out during the study. All pots were labelled according to the experimental layout.

2.3 Soil Preparation

Part of the Sabah coastline soil is generally classified as BRIS soils. BRIS soils are a group of sandy, siliceous, isohyperthermic, and moderately to well-drained soil. Rhu Tapai Series are part of BRIS soils were used as planting media in this experiment. This selection of soil series correlates with the local farmers' soil condition. Soils for experiment were collected from Kg. Tembalang, Tuaran. For each pot, approximately 13 kg of soil were required, thus about 500 kg where soil was collected from the site. The soil was air-dried under the insect-proof net house by thin-laying the soil. The soil was sieved through a 2 mm sieve. Gravel (small stones) were used to cover the bottom of the pot to prevent soil from draining out during watering.

2.4 Growth, Yield and Total Soluble Solid Analyses

Stem girth (in cm) and the number of leaves were collected weekly from planting until harvesting. The number of leaves were measured by counting the total number of visible leaf collars [9]. The corn plant height was measured from the ground surface to the tip of the tassel of the corn at maturity [9]. The height of the first cob was measured from the soil surface to the base of the ear using a measuring tape [9].

At harvesting, the yield parameters measured were the length of cobs, corn girth, fresh weight of cobs without husk, 100 grains, and grain per cob [10].

Sugar content are the primary soluble solids in fruit juice. Soluble solids concentration (SSC%) were determined using a handheld refractometer. The refractometer usage is one the standard practice, besides hydrometer. The former measures the refractive index, which indicates how much a light beam are "bent" when it passes through the (corn) fruit juice. The total soluble solid of glutinous corn was measured using the refractometer to obtain the Brix refractive index as stated conducted by [11]. One degree Brix ($1^{o}\,B_x$) is 1 gram of sucrose in 100 grams of aqueous solution and represents the strength of the solution, stated as percentage by mass. If the solution contains dissolved solids other than pure sucrose, then the °Bx only approximates the dissolved solid content. The index correlates to the sugar content of an aqueous solution (i.e. corn fruit juice).

2.5 Statistical Analysis

The data collected from this study were analysed using SAS v9.4 Statistic Software and one way-ANOVA test for growth, yield, and sweetness parameters. Besides that, Least Significant Different (LSD) test was conducted to test for significant differences between the means obtained for the various treatments.

3. Results and Discussion

3.1 Girth of Stem

The progression in stem girth over time (weeks of planting) are shown in Figure 1. The mean stem girth increased with time, starting from week one until week four for treatment T2, T3 and T4, and constant until week eight. For the control treatment one (T1), the mean of stem girth increased with time until week five and then was constant until week eight. The mean girth stem for potassium (K) rate of T2, T3 and T4 combined with chicken manure biochar and bokashi was consistently higher than T1 with no organic fertilizers.

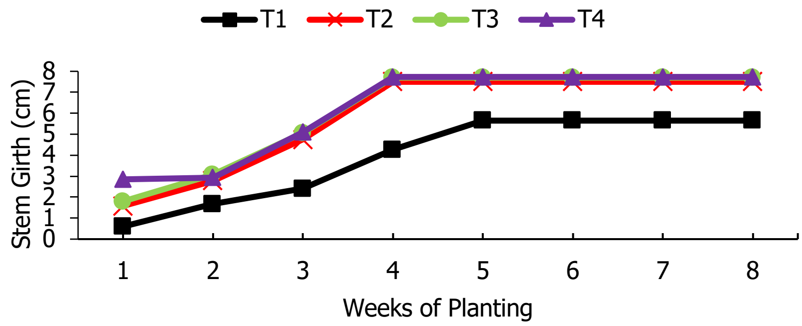

Fig. 1. Stem girth (cm) of reddish waxy corn variety

The effect of K rates combined with chicken manure biochar and bokashi on the girth of stem at eight weeks after planting, shown in Figure 2. Stem girths were significantly different between the fertilizer treatments based on the Analysis of Variance (ANOVA) (p=0.0001). The highest mean stem girth (6.18 cm) of waxy corn resulted from T4, which was 120 kg ha^{-1} Muriate of Potash (MOP) + 20 tons ha^{-1} chicken manure biochar + 1.5 tons ha^{-1} bokashi. The lowest mean stem girth (3.94 cm) resulted from control treatment of treatment one (T1) which was 60 kg ha^{-1} Muriate of Potash (MOP) only. There was a significantly lower mean for the control, T1, than any other treatments with a 56.85% decrease in stem girth than T4. Treatment two (T2) and treatment three (T3) showed a slight difference in girth, just as between treatment three (T3) and treatment four (T4).

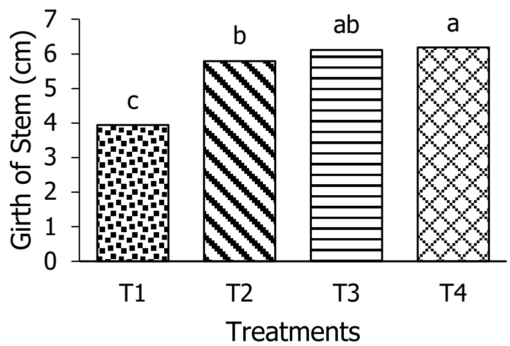

Fig. 2. Stem girth (cm) of reddish waxy corn variety for different potassium rates at week eight. Note: mean values with the same letter are not significantly different at 5% probability

According to the previous studies, the most considerable girth was recorded at 60 kg ha^{-1} and 90 kg ha^{-1}. Stem girth increased at a higher level of K application under optimum fertilizer rate, which may be due to the cell expansion that enhanced the plant sturdiness [5], [12]. Increase in stem girth support the plant to stand upright and withstand wind damage, especially for tall plants like corn.

Other studies reported different results with an increase in the application of potassium, resulting in detrimental influence that reduces the stem girth. However, the negative effect might be associated with high nitrogen levels in the soil. During the flowering stage, Kumar et al. [6] recorded that, higher amount of nitrogen decreased the stem diameter and plant height.

3.2 Height of Cob

The effect of K rates in combination with chicken manure biochar and bokashi on the height of the first cob after planting, shown in Figure 3. The height of the first cob was significantly different between the fertilizer treatments (p=0.0015). The highest mean of cob height (156.86 cm) of waxy corn resulted from T3, the 90 kg ha^{-1} Muriate of Potash (MOP) + 20 tons ha^{-1} chicken manure biochar + 1.5 tons ha^{-1} bokashi. The lowest mean of cob height (101.4 cm) was for the control (T1), applied with 60 kg ha^{-1} Muriate of Potash (MOP). No significant difference between control (T1) and T2, T3 and T4, with percentage increases compared to T1 at 39.12%, 55.09% and 50.15%, respectively.

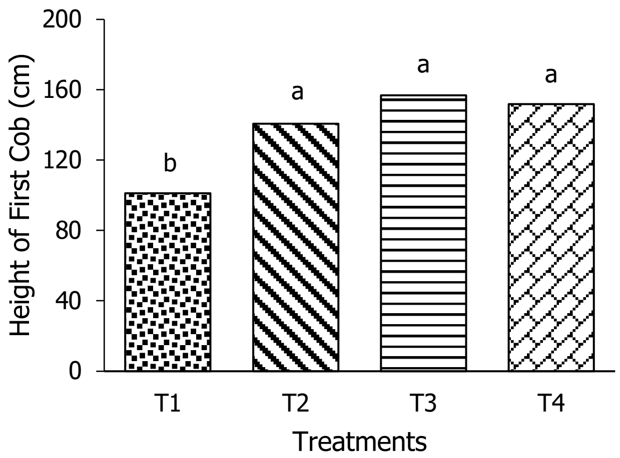

Fig. 3. Height of the first cob (cm) of reddish waxy corn variety for different potassium rates at week eight. Note: means values with the same letter are not significantly different at 5% probability

Nielsen [13] stated that elongation of the stalk occurs primarily by cell expansion and influenced by light (and shade relationships), day-time length and temperatures. Reduced aeration, leads to heat accumulation inside the insect-proof house can contribute to increase in mean temperature, stimulating gibberellin hormones, causing cells to expand [14]. Longer internodes will increase plant height and enhance the chances of lodging or stalk breaking. According to Ali et al. [15] stated that taller plants were generally later flowering than the shorter plant in the sweet corn variety.

Previous studies showed that application of potassium at 60 kg ha^{-1} resulted in the lowest mean height of the first cob compared to other treatments with a higher potassium application [12], [16]. Potassium application aids in promoting assimilation and the translocation of assimilates from source to sink [6]. Decreased potassium application results in lower promotion of assimilation, thus shorten the height of the first cobs.

3.3 Number of Leaves

The progression in the number of leaves over time is shown in Figure 4. The mean number of leaves increased with time, starting from week one until week five for T2, T3 and T4 and becoming constant until week eight. For control treatment T1, the mean number of leaves increased with time until week six and became constant until week eight. The mean number of leaves for potassium rates of T2, T3 and T4 combined with chicken manure biochar and bokashi was higher than T1 without organic fertilizers. In week five, the number of leaves for T1 and T2 showed the highest with 12 leaves.

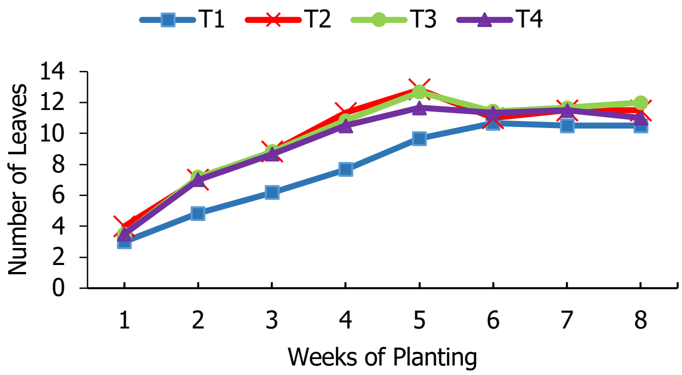

Fig. 4. Number of leaves of reddish waxy corn variety for different potassium rates

At the growing point of corn plants, it is typical for the leaves' number to decrease with time as the lower leaves that emerged early undergo senescence or torn away from the stem. This decreasing number was due to the stalk expansion or roots that begin to develop, allowing new leaves to emerge at the upper parts of the plants [17], [18]. Previous studies showed that potassium concentration affect the number of new leaves in *Guzmania Lingulata* L. or cherry plants [19]. However, other studies suggested that higher levels of potassium will produce a higher number of leaves with a larger surface area [6].

3.4 Length of Cob (cm)

There was a significant difference in the length of cob between the fertilizer treatments (p=0.0001). T3 resulted in the longest cob even though the mean values showed no significant difference with T2 and T4 fertilizer application with only 3.49% and 0.08% percentage differences, respectively. T1 had the lowest length of cob (5.92 cm), which was significantly lower than other treatments (Figure 5).

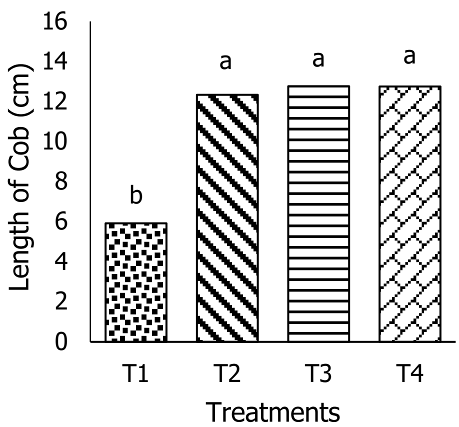

Fig. 5. Length of cob (cm) of reddish waxy corn variety for different potassium harvest rates. Note: means values with the same letter are not significantly different at 5% probability

In corn (cob) development, for ovules to fertilize, a process for cells to differentiate and divide must occur. At any moment in time between ear initiation and pollination, ovule formation differs along the length of the developing corn ear. Ovules near the base of the ear develop first, and newer ovules will continue to form as development progresses toward the tip of the ear. Abendroth et al. [20] stated that, the exact time (phase) progress from ovules into cob, are subjected to environmental condition such as drought stress and mean temperature during the formation of the ovule.

3.5 Girth of Cob

The effect of potassium rates in combination with chicken manure biochar and bokashi on the mean girth of cob after planting is shown in Figure 6. Mean cob girth was significantly different (p=0.0001) between treatments. The highest mean cob girth (12.53 cm) of waxy corn resulted from T3, 90 kg ha^{-1} Muriate of Potash (MOP) + 20 tons ha^{-1} chicken manure biochar + 1.5 tons ha^{-1} bokashi. The lowest mean cob girth (7.71 cm) resulted from the control (T1), 60 kg ha^{-1} Muriate of Potash (MOP). The percentage difference between the lowest and the highest mean cob girth was between T1 and T3 with a value of 62.52%.

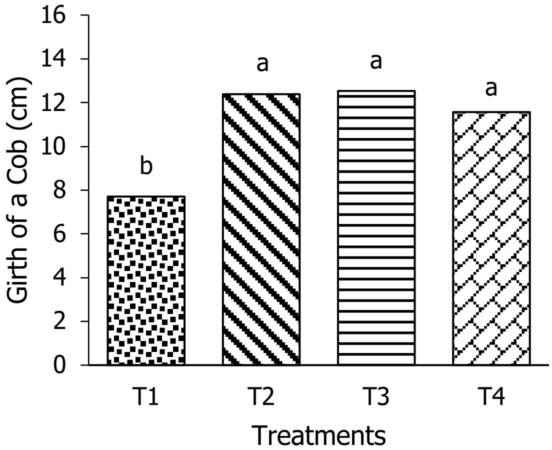

Fig. 6. Girth of cob (cm) of reddish waxy corn variety for different potassium rates at week ten. Note: means values with the same letter are not significantly different at 5% probability

Potassium (K) uptake by plants influences metabolic and enzyme activity [10]. A previous study resulted in more significant production of cobs with increment in length and girth when 60 kg ha^{-1} and 90 kg ha^{-1} [5] were used in corn production, and similar findings were recorded from this study. Another study reported that the size of the cobs might be adversely affected by the changes in water pressure, which was due to insufficient water supply during the formation of kernel and cob stages [21]. Therefore, it was essential to maintain a sufficient water supply to the crop, especially during the critical stages of crop development.

3.6 Fresh Weight of Cob Without Husk (g) and Weight of 100 Grains (g)

Significant differences between treatments for the fresh weight of cob without husk and weight of 100 grains (p=0.0001 and p=0.0328, respectively) were recorded. The percentage difference of mean fresh weight of cob without husk for T2 compared with T3 and T4 was 0.09% and 3.90%, respectively (Figure 7). For the weight of 100 grains, the percentage differences between the most significant mean of T2 with T3 and T4 was 4.63% and 1.31 %, respectively (Figure 8). Control (T1) resulted in the most negligible weight for both fresh cob without husk (17.12 g) and 100 grains (15.23 g).

An increase in potassium (K) application, indirectly improved corn's growth, and physiological characteristics, which resulted in a high yield with minimum water usage. It has been reported from a previous study that potassium increases fruit yield by plants leading to optimum vegetative growth; this indicated that potassium promoted assimilates translocation to the yield components of plants [6].

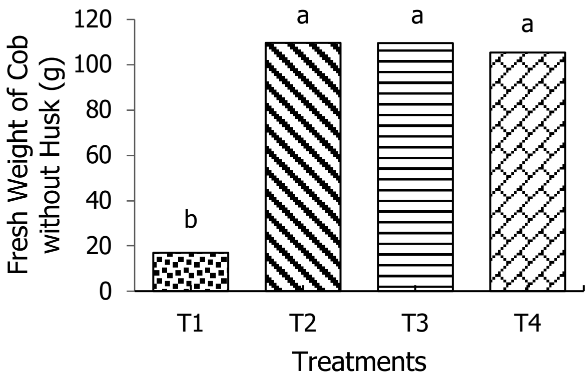

Fig. 7. Mean fresh weight of cob without husk (g) of reddish waxy corn variety for different potassium rates at week ten. Note: Means values with the same letter are not significantly different at 5% probability

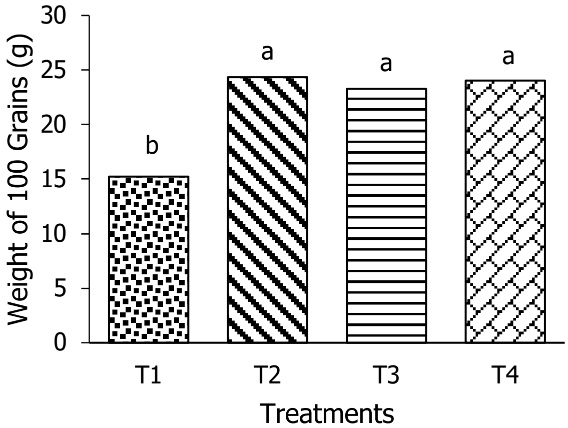

Fig. 8. Weight of 100 grains of reddish waxy corn variety for different potassium rates at week ten. Note: means values with the same letter are not significantly different at 5% probability

In this study, 60 kg ha^{-1} K for waxy corn growth resulted in the lowest growth and yield parameters which may be due to the nutrient being unavailable in soil. BRIS soil collected for study experiment were sandy (82 – 99% sand particles), low mineral nutrients (Ca, Mg, K and others) and low cation exchange capacity (CEC) of 9.53 meq/100) as stated by Peng et al. [2], can be a limiting factor for nutrient retention and uptake. Therefore, addition of organic fertilizers often increase water holding capacity of soils, subsequently improve CEC that increase nutrient retention. A similar findings were stated by Lah et al. [8], Hao and Chang [22] and Hao et al. [23]. Besides that, increase in crop yield leads to increase in crop residue, directly increase soil organic matter (SOM), that returned to the soil. After few cycles of corn production, SOM increase, so does the microbial population that further promotes soil carbon-to-nitrogen (C:N) ratio. The overall process of these chain reaction in soil nutrient retention and uptake are sometimes referred to as soil-crop residual effect. Thus, these phenomena support sustainable production of waxy corn under sandy soil with heavier cob-yield.

3.7 The Sweetness of Reddish Waxy Corn

No significant difference between the potassium fertilizer treatments on the sweetness of waxy corn (Table 2). Total soluble solids (TSS) content of waxy corn was the highest for T4 and lowest for T1 among treatments. The percentage difference in T2, T3 and T4 compared to T1 was 29.68%, 24.63% and 2.54%, respectively.

Table 2
Sweetness of reddish waxy corn variety for different potassium rates at week ten. Note: means values with the same letter are not significantly different at 5% probability

Treatments	Mean
T4	11.023a
T3	10.594a
T2	8.716a
T1	8.5a

Potassium (K) promotes sugar translocation in plants. Previous study showed that increased potassium application increased substantially in the total soluble solid content of papaya [6]. The juice content of many fruits increases as fruit matures on the tree [24]; thus, it is crucial to harvest the waxy corn at the correct time, which is at its physiological maturity. This stage of physiological maturity occurs earlier than the general harvesting maturity for these plants. A higher Brix reading, indicative of elevated total soluble solids (TTS), reflects enhanced sweetness and sensory attributes in waxy corn.

4. Conclusion

Based on this study, application of 90 kg ha^{-1} MOP (source of K) + organic fertilizers (T3) recorded the highest mean values for the number of leaves, the height of the first cob, and length of cob and girth of cob. Despite that, fresh weight without husk were about 5% lower than other treatment with lower K input. Despite that, Brix index clearly shows the sweetness (TSS content) of corn from T4 as the highest (at 11%). However, if the purpose of corn production is to obtain the highest fresh weight and 100 grains, it is sufficient to use 30 kg ha^{-1} of MOP (T2) with organic fertilizers. This practice in return, yield lower TSS content at 8.7%. Thus, this study noted that, potassium (K) promotes translocations of sugar in waxy corn. The alternative hypothesis for the growth and yield parameter in the first objective of this study was accepted. In contrast, the null hypothesis in the second objective was accepted for the sweetness of reddish waxy corn.

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