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Research Article
Storage Root Nutrient and Yield Enhancement in Sweet Potato Variety VitAto Using Empty Fruit Bunch Compost and Hexaconazole

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Abstract
Background: The effectiveness of oil palm Empty Fruit Bunch (EFB) compost and hexaconazole (HEX) growth regulator in increasing the storage root yield of sweet potato varietry. VitAto grown on sandy tin tailing soil was investigated. **Materials and Methods:** Four treatments were used namely, the recommended rate of inorganic fertilizer practice (control), EFB compost and the combination of EFB compost with 10 and 30 ppm HEX. The field experiment layout was a Randomized Complete Block Design (RCBD) with four replications. **Results:** At the maturity stage, the EFB compost with 30 ppm HEX treatment significantly increased the storage root number, fresh weight, dry mass production and harvest index by 125, 35.1, 16.9 and 15.2% higher than control treatment, respectively. At this stage also, this treatment significantly increased the storage root potassium (K) concentration (69.4%) and content (106.9%) higher than the control treatment, respectively. The result showed that the K nutrient was the main nutrient that can be efficiently supplied by EFB compost to the plant. Most nutrients, in particular K uptake were enhanced by the application of HEX. Both K nutrient and HEX at 30 ppm increased the yield primarily through an increase in the storage root number. The higher storage root number and greater proportion of assimilate translocation to the storage root contributed to an increase in the fresh weight and subsequent dry mass production. **Conclusion:** The combination treatment of EFB compost with 30 ppm HEX was better than other treatments in term of increasing the storage root nutrient concentrations, contents and most of yield parameters. The combination of EFB compost and PGR could be considered as an alternative practice to the application of inorganic fertilizer in VitAto cultivation on sandy soil.

Key words: VitAto, sweet potato, EFB compost, hexaconazole, storage root yield, potassium (K), sandy soil

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Sweet potato or scientifically known as *Ipomoea batatas* (L.) Lam. ranks 7th most important food crop after wheat, rice, maize, Irish potato, barley and cassava worldwide[1]. In Malaysia, VitAto variety introduced by MARDI in 2007 is an orange-fleshed sweet potato that is high in β-carotene content and antioxidant compounds such as vitamin C, E and anthocyanin[2].

VitAto is widely grown on sandy soil in East coast states of Peninsular Malaysia. Yield has been generally low under this condition. The market price for storage roots are usually based on size and currently marketed as grades A, B and C for large, medium and small storage roots, respectively[3]. VitAto storage roots obtained by farmers are mostly from grades B and C and only a limited few from grade A. This low yield consequently contributes to a low income obtained by farmers.

Empty Fruit Bunches (EFB) is one of the waste or by-product derived from Fresh Fruit Bunch (FFB) after palm oil extraction process in the mill[4]. In 2014, the availability of EFB was abundant with the production volume reached 21 million tons in Malaysia[5]. The use of organic fertilizer or compost was not uncommon in sweet potato cultivation as reported in several studies[6-8]. However, there is a lack of information or fundamental aspect on how EFB can affect or influence sweet potato storage root yield and quality. The previous study of EFB on sweet potato was focused on the use as the mulching material, parameters studied were on the leaf growth and storage root yield[9].

Hexaconazole (HEX) belongs to the group of fungicide called triazole compounds. These compounds are extremely effective at very low concentrations[10]. The use of HEX as a plant growth regulator has been shown to increase several physiological aspects of yield on root crops such as tuber root, fresh weight, dry mass production, increased in tuber number and length, pigment content, starch, protein and antioxidant of carrot[11], sweet potato[12] and white radish[13]. Other triazole compounds such as paclobutrazol were used in floral induction of mango in Malaysia[14]. However, HEX was used mostly as a fungicide but never as a growth regulator on any crops in Malaysia.

Therefore, the objectives of this study were to investigate the effects of EFB compost, the combination of EFB compost with HEX on storage root yield components and nutrient concentrations and contents of VitAto in a comparison to the recommended inorganic fertilizer practice currently adopted by most VitAto farmers.

MATERIALS AND METHODS

Experimental site: The field experiment was conducted at MARDI Rawang station, Selangor (N3°16'17.89", E101°30'52.19") from March-July, 2013. The soil type was sandy tin tailing with 90.8% sand, 4.5% silt and 4.7% clay[15]. The monthly means for selected climatic factors were 24.1-28.6°C for temperature, 3.0-7.1 mm for rainfall and 76.2-83.4% for relative humidity during the experimental period as shown in Table 1.

Planting materials, treatments and experimental design: VitAto stem cuttings obtained from MARDI Rawang station were used as planting materials. There were four treatments used in this study. The control treatment was the standard recommended fertilizer practice for the cultivation of VitAto on sandy soil[16]. The second treatment consisted of EFB compost (F-EFB) with Nitrogen (N), Phosphorus (P) and Potassium (K) nutrient contents equivalent to the inorganic fertilizer nutrient content in the control treatment. The other two treatments consisted of the EFB compost with 10 (third treatment) or 30 ppm HEX (fourth treatment) designated as F-EFB+10 ppm and F-EFB+30 ppm HEX, respectively. The experimental design was a Randomized Complete Block Design (RCBD) replicated four times. The EFB compost used was aGricare® Premium Compost (Myagri Eco-Biosciences Sdn. Bhd., Selangor, Malaysia) while the fungicide Anmi4.8SC (Advansia Sdn. Bhd., Selangor, Malaysia) was used as plant growth regulator with HEX as the main active ingredient. The formulation of this plant growth regulator was based on previous studies[11,12,17]. These three treatments; EFB compost with 10 and 30 ppm HEX were used based on their potential to give high yield as indicated on findings of earlier preliminary study. The inorganic fertilizers for control and EFB compost were applied at 7, 28 and 35 days after planting (DAP) based on the VitAto production manual[16]. The application of HEX using drenching method was given at 20, 40 and 60 DAP.

Table 1: Selected climatic factors during the experimental period (February to June, 2013)

Year/month	Temperature (°C) Minimum	Temperature (°C) Maximum	Rainfall (mm)	Mean relative humidity (%)
February	24.1	28.1	3.3	83.4
March	25.7	28.2	3.3	79.8
April	25.7	28.4	6.3	82.5
May	25.5	28.6	7.1	80.7
June	25.7	28.5	3.0	76.2

Source: Data were obtained from the Malaysian Meteorological Department in Kepong Station

Growth analysis procedure: The destructive growth analysis method by Hunt[18] coupled with the sequential growth analysis technique for systematic sampling of plant samples by harvest was employed[19]. One plant sample per replicate from each treatment was harvested with a total of four samples per treatment at each harvest. The storage root samples were obtained at 30, 55, 77 and 99 DAP corresponding to the storage root initiation, early and middle bulking and maturity growth stages, respectively. The sample was used to measure yield components of storage root. All samples were oven dried at 72°C for 48 h for dry mass determination and harvest index. Dried storage root samples obtained from the final harvest (99 DAP) were also used for nutrient analysis.

Storage root yield components: The yield parameters measured consisted of storage root and pencil size root numbers, fresh weight, storage root dry mass and harvest index. The classification of storage root was based on Wilson and Lowe[20] where, root diameter greater than 15 mm refer to the storage root and root between 5-15 mm refer to the pencil root. The pencil root was not considered as part of the yield but its diameter range was used to determine smaller storage root known as pencil size root. The difference in physical characteristics between both roots were identified and distinguished before the actual measurement and separation was carried out (Fig. 1). In addition, the storage root dry mass production and value of harvest index at the maturity stage were also used as yield component parameters. The storage root dry mass production was the sum of storage root and pencil size root. Harvest index was the ratio of storage root dry mass per total plant dry mass.

Storage root nutrients analysis: Nitrogen concentration analysis was based on Elementar Analysensysteme GmbH[21] using vario MACRO cube CHNS elemental analyzer (Elementar Analysensysteme GmbH, Hanau, Germany). The P and K concentrations analysis were based on Campbell and Plank[22]

Fig. 1(a-d): Classification on type of roots, (a) Fibrous root, (b) Pencil root, (c) Pencil size root and (d) Storage root using ICP-OES, Optima 7300 DV (Perkin Elmer, Massachusetts, United states). The storage root nutrient content was computed by multiplying the value of nutrient concentration with the storage root dry mass.

Statistical analysis: The data was analyzed using one way analysis of variance (ANOVA) followed by Tukey's pairwise comparisons for separation of means. The relationship between variables was determined using Pearson correlation. The $p \leq 0.05$ were used to determine levels of significance.

RESULTS AND DISCUSSION

Yield components

General trend: The storage root number and fresh weight were continuously increased from the storage root initiation to maturity stages (Fig. 2a, b). The pencil size root number and fresh weight were generally increased from the storage root initiation to the early bulking stage (55 DAP) before declining thereafter (Fig. 2c, d). At the early bulking stage, the storage root number for F-EFB was 200% significantly higher than the control while at the mid bulking (77 DAP) through maturity stages, both F-EFB and F-EFB+30 ppm HEX were 167% and 125% significantly higher than the control treatment, respectively. The storage root fresh weight for F-EFB+10 ppm and F-EFB+30 ppm HEX were 87 and 35% significantly higher than control at the mid bulking (77 DAP) and maturity stages, respectively. However, there were no significant differences between treatments at the earlier growth stages.

The pencil size root number was not significantly affected by treatment application throughout the entire growing period, however, at the mid bulking stage (77 DAP), the pencil size root for the control was higher than other treatments. At the early bulking stage (55 DAP), the pencil size root fresh weight for the F-EFB treatment was significantly higher than the control and at the mid bulking stage (77 DAP), the F-EFB+10 ppm was significantly higher than F-EFB+30 ppm while at the maturity stage, the control treatment was significantly higher than F-EFB+10 ppm HEX. The storage root dry mass production and harvest index for F-EFB+30 ppm HEX were 17 and 16% significantly higher than control at the maturity stage, respectively (Fig. 3a, b).

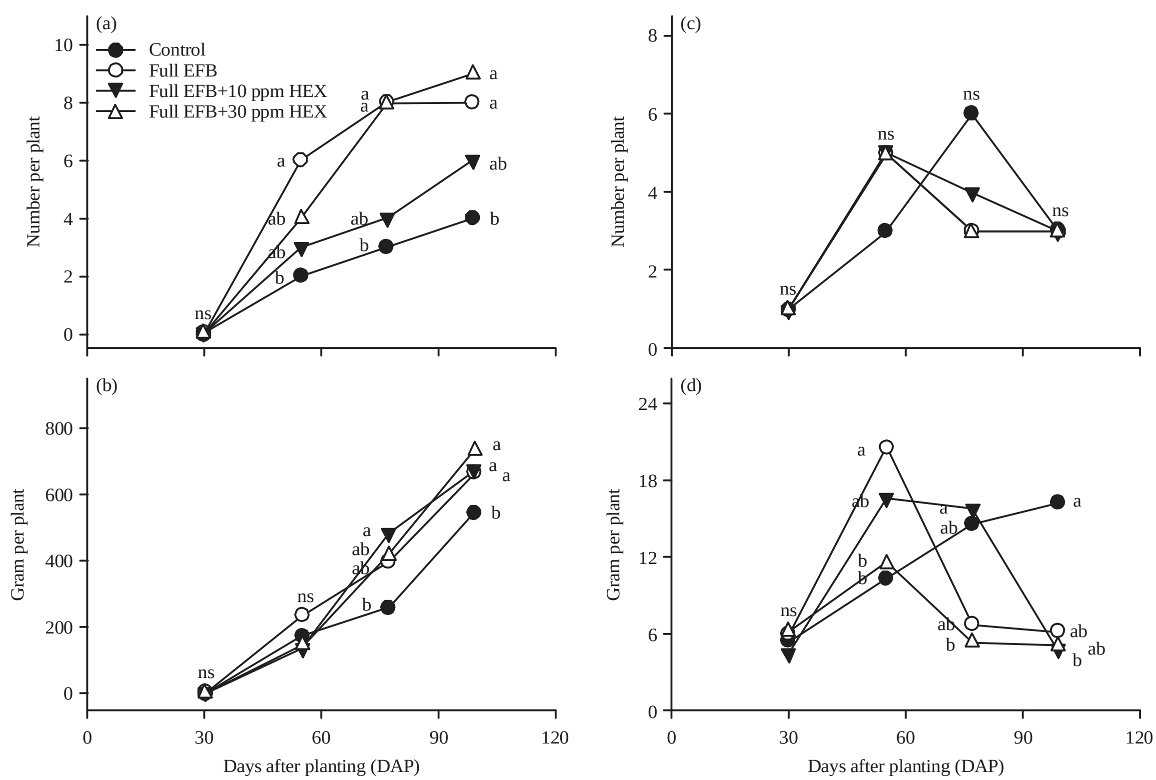

Fig. 2(a-d): Yield components, (a) Storage root number, (b) Storage root fresh weight, (c) Pencil size root number, (d) Pencil size root fresh weight as affected by various EFB compost and HEX combination treatments throughout the entire growing period, different letters follow different treatments at specific harvest time indicate a significant difference at $p \leq 0.05$ while ns indicate non-significant and the values are the means of four replicates

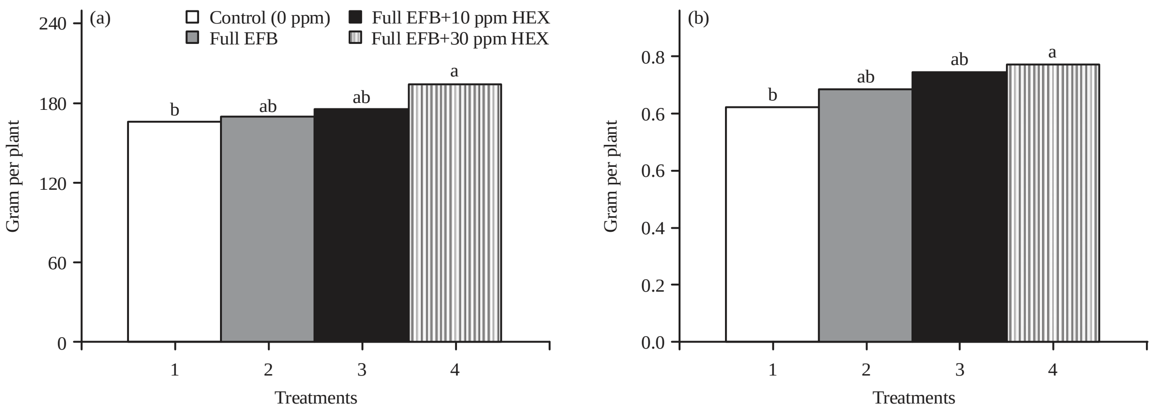

Fig. 3(a-b): Yield components (a) Storage root dry mass and (b) Harvest index as affected by various EFB compost and HEX combination treatments at the maturity stage, different letters follow different treatments at specific harvest time indicate a significant difference at $p \le 0.05$ while ns indicate non-significant and the values are the means of four replicates

Table 2: Correlation coefficients of various parameters related to yield components as affected by various EFB compost and HEX combination treatments during the entire growing period

Parameters	No. of storage root	Storage root fresh weight	No. of pencil size root	Pencil size root fresh weight	Storage root dry mass production
Storage root fresh weight	0.50***				
No. of pencil size root	-0.05^{ns}	-0.34*			
Pencil size root fresh weight	-0.14^{ns}	-0.24^{ns}	0.72***		
Storage root dry mass production	0.51***	0.97***	0.02^{ns}	0.001^{ns}	
Harvest index	0.51***	0.93***	-0.17^{ns}	-0.27^{ns}	0.90***

*, **, ***Significant at $p \le 0.05$, $p \le 0.01$ and $p \le 0.001$, respectively, ^{ns}No significant correlation and the values are the means of four replicates

Table 3: Nitrogen, phosphorus and potassium concentrations of storage root as affected by various EFB compost and HEX combination treatments at the maturity stage

	Nutrient concentration (%)			
Treatment	Control	F-EFB	F-EFB+10 ppm	F-EFB+30 ppm
Storage root				
Nitrogen	1.89^{a}	1.94^{a}	1.80^{a}	1.86^{a}
Phosphorus	0.18^{a}	0.16^{a}	0.13^{a}	0.18^{a}
Potassium	0.62^{c}	0.97^{ab}	0.77^{bc}	1.05^{a}

Different letters follow different treatments within row indicate a significant difference at $p \le 0.05$ and the values are the means of four replicates

Table 4: Nitrogen, phosphorus and potassium contents of storage root as affected by various EFB compost and HEX combination treatments at the maturity stage

	Nutrient content (g)			
Treatment	Control	F-EFB	F-EFB+10 ppm	F-EFB+30 ppm
Storage root				
Nitrogen	3.33^{a}	3.21^{a}	3.24^{a}	3.35^{a}
Phosphorus	0.32^{a}	0.21^{a}	0.22^{a}	0.30^{a}
Potassium	1.01^{b}	1.68^{ab}	1.29^{b}	2.09^{a}

Different letters follow different treatments within row indicate a significant difference at $p \le 0.05$ and the values are the means of four replicates

Correlation studies of the various parameters related to the yield components: Most yield component parameters shows significant positive correlation except with pencil size root number and fresh weight (Table 2). However, the pencil size root parameters were positively correlated to each others.

Nutrient concentrations and contents in the storage root: The F-EFB+30 ppm HEX had 69 and 36% significantly higher storage root K concentration than the control and F-EFB+10 ppm HEX treatments, respectively (Table 3). At the maturity stage, the K nutrient content of storage root was significantly higher in F-EFB+30 ppm treatment as compared to control and F-EFB+10 ppm HEX treatments. However, N and P contents were not significantly different in all treatments (Table 4).

Correlation studies of the various parameters related to storage root nutrient concentrations and contents with yield components at the maturity stage: The storage root K concentration was significantly correlated with storage root number (r = 0.83***) while K nutrient content of the storage root was significantly correlated with both storage root number and fresh weight (r = 0.82*** and 0.67**, respectively). However, both N and P concentrations and contents of storage root did not show any significant correlation with any of yield component parameters (Table 5).

Table 5: Correlation coefficient of various parameters related to yield components and storage root nutrient concentrations and contents as affected by various EFB compost and HEX combination treatments at the maturity stage

	Parameters					
Storage root	No. of storage root	Storage root fresh weight	No. of Pencil size root	Pencil size root fresh weight	Storage root dry mass	Harvest index
Nitrogen						
Concentration	0.10^{ns}	-0.23^{ns}	0.10^{ns}	-0.40^{ns}	-0.56^{ns}	0.04^{ns}
Content	-0.30^{ns}	-0.03^{ns}	0.46^{ns}	-0.50^{ns}	0.48^{ns}	0.04^{ns}
Phosphorus						
Concentration	0.55^{ns}	-0.18^{ns}	-0.15^{ns}	0.25^{ns}	0.00^{ns}	-0.25^{ns}
Content	0.48^{ns}	-0.20^{ns}	-0.15^{ns}	0.01^{ns}	0.34^{ns}	-0.22^{ns}
Potassium						
Concentration	0.83***	0.53^{ns}	-0.10^{ns}	-0.40^{ns}	0.24^{ns}	0.38^{ns}
Content	0.82***	0.67**	-0.08^{ns}	-0.50^{ns}	0.58*	0.45^{ns}

*, **, ***Significant at $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.001$, respectively, ^{ns}No significant correlation and the values are the means of four replicates

Yield components

Response of yield components to treatments application: In general, the storage root number, fresh weight, dry mass production and harvest index responded positively to the application of F-EFB and the combination treatments of EFB and HEX. Among these treatments, the F-EFB+30 ppm HEX was considered the best treatment since, it significantly increased all yield component parameters higher than the control. This study indicated that the application of EFB compost alone was able to increase yield components comparable to the application of recommended inorganic fertilization. The use of organic fertilizer as main sources of nutrients that lead to either better or comparable yield with inorganic fertilizer was reported in many sweet potato studies[6,7,23]. Similar applications on other crops were also reported such as corn applied with corn straw or farmyard manure[24] and cassava applied with cattle manure[25]. The hexaconazole application was also reported to increase storage root number, fresh weight and dry mass production of several crops such as carrot[11] and sweet potato[12,13]. Therefore, a combination of EFB compost with HEX was likely to further enhance the yield of VitAto as indicated by higher storage root number, fresh weight, dry mass production and harvest index.

Relationship among yield components: Storage root number is a yield component parameter that represents the sink size[26]. It acts as a storage organ that accumulates or stores assimilate or dry mass produced. The higher the storage root number the greater would be the sink capacity. Higher dry mass production and subsequent allocation are essential to ensure that all storage roots can be sufficiently filled. Storage root cells must be fully formed and expanded before they are able to store assimilates[27]. Treatments that can increase storage root numbers can also increase other yield components as shown particularly in the F-EFB+30 ppm HEX treatment. To maximize marketable yields, it is important to attain as high number of storage roots as possible[28]. As shown in the result, storage root number was significantly correlated with storage root dry mass production. This finding was in agreement with the results obtained by Bourke[29] and Bhagsari[30]. In this study, the storage root numbers also significantly correlated with storage root fresh weight similar to the finding of study by Bhagsari[30]. The higher storage root fresh weight contributed to higher storage root dry mass production as shown in correlation studies which was also observed by several researchers[30,31]. It showed that the higher dry mass partitioning to storage root led to the improvement of storage root size. The close relationship of the harvest index with the storage root yield found in this study was in agreement with other reported studies[30,31].

Storage root versus pencil size root: The number and fresh weight of smaller storage root or also known as pencil size root were higher for the control compared to other treatments. The maximum production of pencil size roots for F-EFB and other combination treatments were observed at 55 DAP while for the control it was at 77 DAP. The F-EFB and the combination treatments attained their maximum production of new and smaller storage roots much earlier than the control treatment which seemed to continuously increase even beyond the bulking stage. Similar pattern was also observed in the fresh weight of pencil size root in which F-EFB and the combination treatments attained their maximum values at 55 DAP and gradually decreased thereafter. However, the fresh weight continued to increase to the maturity stage for the control treatment. This study suggested that when the sweet potato plant had reached the bulking stage, the production of new and smaller storage roots were reduced and most of the dry mass produced would be used for the growth of existing storage root. Similar observations were also reported elsewhere[27,32].

Relationship between storage root nutrient concentrations and contents with yield components at the maturity stage: Storage root K concentration had significant correlation with storage root number while storage root K nutrient content showed significant correlation with storage root numbers, fresh weight and dry mass production. The K nutrient generally increased the yield through an increase in the storage root numbers[29]. The K nutrient facilitated greater amount of photosynthate translocation from the source leaves to the storage root through an increase in the photosynthetic efficiency which enhanced the storage root size[7,29,33]. The application of K fertilizer can increase the sink strength of storage root to attract greater photosynthate at all stages of growth, particularly during the maturity stage[34]. In contrast, K deficiency could have caused significant reduction in several physiological characteristics such as total biomass production and root yield[35]. The treatment that influences an increase in K concentration and content in plant are likely to increase the storage root yield at the harvestable stage as shown by F-EFB+30 ppm HEX treatment. Both EFB compost and HEX had something in common that capable of promoting the reproductive growth and at the same time reduced the growth of the vegetative parts. The EFB compost can effectively provide adequate K nutrients to the plant which in turn enhance assimilates translocation from leaves to the storage roots. The HEX is one of the triazole compounds that was reported to be capable altering nutrient uptake and plant nutrition apart from increasing the greater assimilate translocation from shoot to root as stated by Gomathinayagam *et al.*[17]. The HEX application[12] and K fertilization[33] were shown to increase root to shoot ratio of sweet potato.

The N and P concentrations and contents had non-significant correlation with any of the storage root yield components. Phosphorus nutrient was not considered important nutrient for sweet potato[7] and the reduction in P might not significantly affect the yield markedly[36]. This crop was reported to tolerate soil with low or deficient in P nutrient[37]. This study also indicated that N was not a critical nutrient at the maturity stage. However, N would be the most needed nutrient during the vegetative stage which can promote in the production of assimilates through enhancement in leaf photosynthetic rates. The higher total dry mass production is one of the factors that can influence the storage root yield[32]. The total dry mass must be high to ensure high storage root dry mass. This role probably efficiently carried out by N rather than P or K nutrients. Bourke[29] stated that N influenced the storage root yield as a consequent to the lengthening the leaf area duration which in turn increased the storage root weight. The second factor that can influence storage root yield is the efficiency of assimilates translocation to the storage root as described by Belehu[32]. This task is fulfilled by K nutrient as reported by previous studies[7,29,33,34]. Therefore, N is important nutrient during the vegetative stage while K is an important nutrient during the storage root bulking and maturity stage[36] where most of the assimilates was allocated to the storage root.

CONCLUSION

Insufficient of available K for plant growth during storage root development could be the key problem of smaller and lower grades of storage root under recommended fertilization practice using inorganic fertilizer. In contrast, the EFB compost that efficiently supply the K nutrient to the plant and HEX especially at 30 ppm concentration increased the sink strength of storage root to attract more assimilate from the source. Consequently, they increased the sink size with appropriate number of storage root. In conclusion, the better treatment that can increase storage root yield and quality of VitAto is the combination of EFB compost and 30 ppm HEX treatments. These combination treatments could be used as an alternative practice to the application of inorganic fertilizer in VitAto cultivation on sandy soil.

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