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Growth and yield response of sweet potato (*Ipomoea batatas* var. batatas) under acid sandy soil, northeast of Thailand

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Abstract. Sweet potato is one of the major crops grown for food, animal feed and industrial products. The yield obtained in the Northeast of Thailand is far below its genetic potential due to soil degradation, erosion, acidification, loss of organic matter, waterlogging and salinization causing nutrient deficiency. The objectives of this research are to investigate yield components, accumulation of nutrients and food nutrition of different sweet potato species under acidic sandy soil. The experiment with four replications was laid out in a farmer's field at Phu Wiang and Nong Ruea District, Khon Kaen Province, where young smart farmers are interested to grow sweet potato. Trials were planted for 2 years using four species of sweet potato: (A) Honey Sweet, (B) Okinawan Orange, (C) Okinawan Purple and (D) Purple Sweet Lord. All plots were treated with a basal application of 1.56 t ha^{-1} of cow and poultry manure with 0.03 t ha^{-1} of chemical fertilizer formula (N12-P4-K4). An addition of 0.15 t ha^{-1} of chemical fertilizer formula (N12-P4-K20) was made at 15 and 30 days after growing. The results show that Okinawan Orange and Purple Sweet Lord were higher growth in Phu Wiang district than Nong Ruea district. If the cost and unit price are the same, Okinawan Orange will give farmers a higher return than Purple Sweet Lord. Regarding the leaf residues of Okinawan Orange and Purple Sweet Lord are suitable to be used for fish farming, because they contain the highest protein and carbohydrates.

Key words: acid soil, decision, growth, sweet potato, yield components.

INTRODUCTION

Since there is a trend towards healthy food, sweet potato is grown throughout all regions of Thailand with different colors. Thailand consumers mostly prefer dessert types and salad. Dessert types of sweet potato generally have orange flesh and are served with coconut milk, with 70% consists of starch from dry matter (Karan & Şanli, 2021). Sweet potato is a good source of phytochemicals, which have beneficial health effects, while roots and leaves contain β-carotene (provitamin A), ascorbicacid (vitamin C), vitamin B complex and phenolic compounds such as anthocyanins (Teow et al., 2007; Ji et al., 2015). Teow et al. (2007) reported that β-carotene content significantly to the sweet potato genotypes, orange potato roots are rich sources of β-carotene while yellow potato roots provide moderate amounts of β-carotene. Nowadays, the consumption demand for sweet potatoes in various countries has also increased. Thailand has higher potential production and export compared to Japan, republic of China (Taiwan) and the republic of Korea. These producers have limited agricultural areas and high labor costs for production compared to Thailand. Therefore, when starting to produce sweet potatoes suitable for available planting areas, it is necessary to help farmers select sweet potato varieties that meet the highest growth potential and market demand. Sweet potatoes for fresh consumption come in a variety of flesh colors, including white, yellow, orange and purple, depending on the species. For the processing industry, white-fleshed sweet potato varieties are needed with a high starch percentage. While eating for health by steaming or grilling, it is popular to consume sweet potatoes with yellow, orange and purple flesh.

Sweet potato has a wide tolerance to soil conditions, allowing extended cultivation in previously marginal areas. It produces yield earlier (average 140 days) and the high edible proportion of the harvested product contributes to a very high edible energy yield compared to potato, banana, maize, cassava, wheat, rice and sorghum. In Ethiopia, average sweet potato yield is 33.74 t ha^{-1} (CSA, 2014) which is very low as compared to the crop potential which rises to 50 t ha^{-1} (Gurmu & Mekonen, 2017). Amede et al. (2006) submitted that most soils in southern Nigeria are acidic due to the nature of parent materials, leaching and intense weathering. In addition, high acidity induces nutrient deficiency. The yield obtained in Nigeria is far below its genetic potential due to soil degradation, erosion, acidification, and loss of organic matter, waterlogging and salinization (FAO, 2008). Popradit (2021) reported that the yield of sweet potato (Okinawan) was significantly lower than that of sweet potato (Native sweet potato). The maximum yield weight of native sweet potato in plot 3 (0.96 kg $tree^{-1}$, using 150 kg of compost fertilizer and the yield weight of Okinawan show the lowest yield in the plot 4 (0.27 kg $tree^{-1}$, which was the control plot with natural conditions. The chemical fertilizer formula (N13-P13-K21) used in the sweet potato cultivation by Hmong hill tribe farmers had lower quantities of K and P, while the amount of N in such a formula was suitable to the growing needs. However, the studies have also shown that sweet potato is unsuitable for upstream cultivation due to its high uptake of soil nutrients, which could cause soil deterioration. Many of these factors play a role in many countries which have adopted sweet potato as a subsistence crop.

Moreover, sweet potato crops take up large amounts of nutrients from the soil (Troncoso & Pedreschi, 2009). Considering that the uptake and removal of nutrients by the sweet potato are relatively high (Fernandes et al., 2020), nutrient supplementation in an appropriate and balanced way becomes necessary to attain the full production potential of sweet potato (Dawit & Habte 2023). For maximum benefit to producers, planting sweet potato for suitable cultivars under acid sandy soil in Northeast Thailand need to be explored. As a result of the above problems, various cultivars of sweet potato efficacy were tested, in order to obtain suitable quantity and quality of sweet potato yield, macronutrients content and this study's results could guide decision making on sweet potato production by new farmers in the future.

MATERIALS AND METHODS

Experimental site

The study was conducted at the beginning of the rainy season in 2021–2022, on farmer fields in Phu Wiang and Nong Ruea District, Khon Kaen Province, Northeast Thailand. The site is located within Latitudes 16° 22.65′ N and 16° 57.6′ N and Longitudes

102° 43.42′ E and 102° 48.5′ E in a dry area at an elevation of 210 and 192 m respectively. The rainy season is characterized from May to October following the winter and the dry season. Total rainfall of 864 and 850 mm occurred during the crop growth period of 6 months in Phu Wiang and Nong Ruea District, respectively. The maximum and minimum temperatures were recorded as 31.67 and 25 °C in Phu Wiang District and 32 and 25 °C in Nong Ruea District. The dominant soil order in the studied area is acid sandy soil. Prior to field experimentation, a composite soil sample was obtained from the experimental site and was analyzed for its chemical properties. The results of the soil analysis are given in Table 1.

Experimental design and treatments

The trial was established as a randomized complete block design with four replications of across sites. The treatments involved four varieties (Okinawan Orange, Okinawan Purple, Purple Sweet Lord and Honey Sweet) of sweet potato. Each plot measured 1×50 m with a spacing of 1 m between plots and 2.00 m between blocks.

Cultural practices

Sweet potatoes were planted in farmers' fields at the end of March, 2021–2022. For both fields, cured poultry and cow manure was incorporated into the soil at a rate of 6.25 t ha^{-1} two weeks prior to planting. At planting, vines of 25–30 cm length with 5–7 nodes were collected from the apical meristem and planted at a spacing of 1 m between ridges and 0.50 m within rows, during the early hours of the day. The vines were planted at an angle of 45° and a planting depth of 5 cm with 3–4 nodes in the soil. The plots were irrigated by drip irrigation system immediately after planting. Weeding was done manually using hoes two weeks after planting and subsequently as was necessary. Harvesting was done at 12–14 weeks after planting when fresh tubers were fully grown, depending on varieties, and when the leaves and vines had turned brown and dried up. Harvesting was done by removing the dried vines using a machete and uprooting the tubers using spades and hoes.

Data collection

During the growing phase, data were taken for survival percentage, vine length, nodes length, SPAD, leaf area, leaf and stem fresh weight, leaf and stem dry weight, N, P and K content in leaf and stem at 1 and 2 months after planting. Sweet potato leaf area (LA) was estimated using a leaf area meter LI-Cor 3100, LI-COR Inc., Lincoln, NE, USA. At harvest, data were collected on the number of tubers per plant, tuber length, tuber diameter, tuber weight, tuber yield, leaf and stem fresh weight, leaf and stem dry weight, nutrition in tuber, leaf and stem of sweet potato such as fresh moisture percentage, ash, protein, fat, fiber and carbohydrate. Tuber weight was determined by weighing all harvested tubers within each net plot of 1×10 m in kg and dividing by the number of plants within the net plot. Tuber yield was estimated thus:

Tuber yield = kg tuber weight within each net plot of (10 m^2×1,600 m^2)/10 m^2.

Data analysis

Collected data were subjected to analysis of variance using Statistix 10 software. Significantly different treatment means were separated and compared using Fisher's least significant different (LSD) at the 0.05 level of probability.

RESULTS

Chemical properties of soil prior to cropping

The results of the pre-cropping soil properties of the experimental site are presented in Table 1. The soil was sandy loam, with a strongly acidic condition in the Nong Ruea district field. Organic matter, total nitrogen, available phosphorus, exchangeable potassium, calcium, magnesium, iron, manganese, copper and zinc, total chromium and lead were significantly different between the fields. The Nong Ruea district field tended to have soil chemical properties such as organic matter, total nitrogen, exchangeable calcium, magnesium, iron, manganese, copper and zinc, total chromium and also heavy metal like lead more than the Phu Wiang district field. However available phosphorus and exchangeable potassium were higher in the soil at the Phu Wiang district field. Simson et al. (2016) point out of the effect of tuber variety, location and specific interactions among ions must be considered. Nitrogen element may mainly results in delayed maturity, K deficiency reduces partitioning of dry matter and P aids to alleviate adverse NK interaction in terms of dry matter content.

Table 1. Soil chemical properties before growing sweet potato (*Ipomoea batatas* L.)

Soil chemical properties	Phu Wiang district	Nong Ruea district
pH^{**} (1:1 H_2O)	5.75^a	4.71^b
OM^{**} (%)	0.38^b	0.62^a
EC (mS cm^{-1})	0.02	0.02
Total N^{**} (%)	0.02b	0.06^a
Available P^{**} (mg kg^{-1})	406.25^a	204.17^b
Exchangeable K^{**} (mg kg^{-1})	53.77^a	49.14^b
Exchangeable Ca^{**} (mg kg^{-1})	109.83^b	222.44^a
Exchangeable Mg^{**} (mg kg^{-1})	17.24^b	60.58^a
Exchangeable Fe^{**} (mg kg^{-1})	54.99^b	263.41^a
Exchangeable Mn^{**} (mg kg^{-1})	4.58^b	26.22^a
Exchangeable Cu^{**} (mg kg^{-1})	0.12^b	0.46^a
Exchangeable Zn^{**} (mg kg^{-1})	0.38^b	0.51^a
Total Cr^{**} (mg kg^{-1})	8.39^b	12.45^a
Total As (mg kg^{-1})	1.76	1.80
Total Cd (mg kg^{-1})	0.55	0.53
Total Pb^{**} (mg kg^{-1})	1.38^b	4.27^a

a Treatments at $p \leq 0.05$, derived from *LSD*. **: Represent significance at $p \leq 0.01$.

Growth of sweet potato

When sweet potatoes were planted for 1 month, it was found that Honey Sweet and Okinawan Orange varieties had the highest survival percentage in both fields (Table 2). Okinawan Purple and Purple Sweet Lord with such a low survival rate in both fields, according to the use of lack integrity and strength of the vines. Vegetative growth of Okinawan Orange and Purple grown in Phu Wiang district were highest according to the longest node lengths of 2.44 and 2.81 cm respectively. In particular Okinawan Orange has the highest leaf area for photosynthesis, therefore giving more biomass than Okinawan Purple, Purple Sweet Lord and Honey Sweet. Moreover, the leaf SPAD observation obtained from chlorophyll meter (Minolta SPAD502, Japan) by measuring mature leaves, had no statistical difference. It is positively correlated with leaf chlorophyll and N contents (Kandel, 2020). The chlorophyll content will increase in proportion to the amount of nitrogen present in the leaf. For a particular plant species, a higher SPAD value indicates a healthier plant. Similar to the research work of Novikova et al. (2021) biomass is consumed for the leaf surface formation at the beginning of vegetative growth and then the biomass produced was spent on tuberization.

Table 2. Variables of sweet potatoes at 1 month of growing

Field experiment	Sweet potato	Survival (%)	Vine Length (cm)	Nodes Length (cm)	SPAD	Leaf Area/ Plant (cm^2)	Leaf Fresh Weight/ Plant (g)	Stem Fresh Weight/ Plant (g)	Leaf Dry Weight/ Plant (g)	Stem Dry Weight/ Plant (g)
Phu Wiang District	Honey Sweet	100.00^{a}	28.18^{b}	1.21^{b}	44.08	1,375.50^{b}	11.25^{b}	10.50^{b}	2.75^{b}	2.00^{b}
	Okinawan Orange	98.00^{a}	54.25^{a}	2.44^{a}	45.70	6,256.80^{a}	57.00^{a}	65.00^{a}	10.75^{a}	7.00^{a}
	Okinawan Purple	47.00^{c}	53.95^{a}	2.81^{a}	47.23	1,066.80^{b}	17.75^{b}	11.75^{b}	3.00^{b}	1.75^{b}
	Purple Sweet Lord	59.25^{b}	26.58^{b}	2.26^{a}	45.18	1,628.00^{b}	17.50^{b}	18.00^{b}	2.25^{b}	0.75^{c}
Nong Ruea District	Honey Sweet	94.44^{a}	19.83^{b}	2.63	41.33^{b}	479.30^{b}	5.25^{b}	5.25^{b}	1.63^{b}	0.88
	Okinawan Orange	89.00^{a}	22.75^{b}	1.96	46.93^{a}	1,063.80^{a}	12.50^{ab}	8.00^{ab}	2.50^{ab}	1.13
	Okinawan Purple	68.50^{b}	58.80^{a}	4.23	41.08^{b}	1,308.30^{a}	19.75^{a}	15.50^{a}	4.00^{a}	2.25
	Purple Sweet Lord	60.00^{c}	30.83^{b}	2.48	45.51^{a}	1,066.50^{a}	16.25^{a}	11.00^{ab}	3.50^{ab}	1.25

a Treatments at $p \leq 0.05$, derived from *LSD*.

High tuber yields, sufficient leaf area is necessary to provide by the onset of tuberization. This is the basic information to assess performance and adaptation particularly in areas with short growing seasons before leaf senescence. Also, the vegetative growth of Okinawan Purple grown in Nong Ruea district had the longest vine length of 58.80 cm with leaves area per plant for photosynthesis higher than Honey Sweet, thus giving the most biomass. Sweet potato, like any other root crop, is a heavy feeder exploiting a greater volume of soil for nutrients and water. It was found that the leaf part of Purple Sweet Lord and Okinawan Purple accumulated nitrogen, phosphorus and potassium more than Okinawan Orange and Honey Sweet, respectively (Table 3) in Phu Wiang district. Also, nitrogen and potassium accumulated more in the stem part, while Okinawan Purple and Orange accumulated more nitrogen, phosphorus and potassium in Nong Ruea district.

Table 3. Macronutrients content of sweet potatoes at 1 month of growing

Field experiment	Sweet potato	Leaf			Stem		
		N (%)	P (%)	K (%)	N (%)	P (%)	K (%)
Phu Wiang district	Honey Sweet	2.92^{c}	0.16^{c}	3.24^{c}	1.28^{c}	0.25^{a}	4.71^{d}
	Okinawan Orange	3.48^{b}	0.17^{b}	3.01^{d}	1.20^{d}	0.18^{b}	4.90^{c}
	Okinawan Purple	4.02^{a}	0.20^{a}	3.43^{b}	1.82^{b}	0.17^{c}	5.52^{b}
	Purple Sweet Lord	4.10^{a}	0.20^{a}	3.87^{a}	2.27^{a}	0.16^{d}	6.13^{a}
Nong Ruea district	Honey Sweet	3.18^{b}	0.17^{b}	1.18^{d}	2.10^{b}	0.14^{a}	2.07^{d}
	Okinawan Orange	2.45^{c}	0.19^{a}	1.83^{b}	2.28^{a}	0.14^{a}	2.84^{a}
	Okinawan Purple	3.57^{a}	0.16^{c}	2.89^{a}	1.89^{c}	0.11^{b}	2.20^{c}
	Purple Sweet Lord	3.35^{b}	0.15^{d}	1.40^{c}	1.49^{d}	0.09^{c}	2.37^{b}

a Treatments at $p \leq 0.05$, derived from *LSD*.

After 2 months of transplanting, the vine lengths of all sweet potatoes in Phu Wiang and Nong Ruea districts increased due to the length of the node (Table 4), especially Purple Sweet Lord, followed by Okinawan Purple and Okinawan Orange. As a result, the biomass of leaf and stem increased at 1 month from transplanting, despite the decrease in leaf area for photosynthesis per plant in Phu Wiang district. But in Nong Ruea district, the leaf area for photosynthesis per plant increased in all sweet potatoes compared to 1 month from transplanting. Okinawan Orange in both fields still had the highest accumulation of nitrogen in the leaf and stem part (Table 5). Potassium accumulation of all sweet potatoes in Nong Ruea district increased compared to 1 month from transplanting, especially Purple Sweet Lord which accumulated 5.09% of potassium. Alternately, the potassium accumulation of all sweet potatoes in Phu Wiang district tended to decrease. This may be linked to the tuber formation of sweet potatoes in Phu Wiang district beginning before sweet potatoes in Nong Ruea district. Early bulking maturity implies an ability to produce a high yield of tubers and allows avoiding biotic and abiotic stresses (Novikova et al., 2021).

Table 4. Growth of sweet potatoes at 2 months of growing

Field experiment	Sweet potato	Vine Length (cm)	Nodes Length (cm)	SPAD	Leaf Area/ Plant (cm^2)	Leaf Fresh Weight/ Plant (g)	Stem Fresh Weight/ Plant (g)	Leaf Dry Weight/ Plant (g)	Stem Dry Weight/ Plant (g)
Phu Wiang district	Honey Sweet	31.28^{b}	1.55^{c}	41.43^{b}	448.39^{b}	31.75^{c}	33.50^{b}	22.65^{b}	19.77^{b}
	Okinawan Orange	65.68^{a}	3.30^{b}	39.43^{b}	527.86^{ab}	39.50^{bc}	66.75^{a}	21.65^{b}	24.40^{a}
	Okinawan Purple	98.25^{a}	4.73^{a}	39.73^{b}	546.65^{a}	44.75^{ab}	57.75^{a}	23.50^{b}	23.35^{a}
	Purple Sweet Lord	96.95^{a}	3.53^{ab}	47.42^{a}	608.32^{a}	51.50^{a}	64.50^{a}	25.63^{a}	23.73^{a}
Nong Ruea district	Honey Sweet	28.93^{c}	1.16^{b}	48.12^{ab}	667.60^{c}	31.75^{b}	34.25^{b}	20.33^{b}	19.32^{b}
	Okinawan Orange	89.75^{ab}	5.19^{a}	50.90^{a}	1,268.50^{b}	37.50^{ab}	55.50^{ab}	21.13^{ab}	21.75^{ab}
	Okinawan Purple	81.58^{b}	3.94^{a}	45.63^{b}	1,566.10^{b}	50.25^{a}	55.00^{ab}	24.20^{a}	21.88^{ab}
	Purple Sweet Lord	116.12^{a}	5.45^{a}	51.40^{a}	2,141.90^{a}	51.75^{a}	63.00^{a}	24.55^{a}	23.18^{a}

a Treatments at $p \leq 0.05$, derived from *LSD*.

Table 5. Macronutrients content of sweet potatoes at 2 months of growing

Field experiment	Sweet potato	Leaf			Stem		
		N (%)	P (%)	K (%)	N (%)	P (%)	K (%)
Phu Wiang district	Honey Sweet	2.57[c]	0.26[a]	2.87[a]	0.89[c]	0.40	3.51[d]
	Okinawan Orange	3.23[a]	0.18[b]	2.61[c]	0.85[c]	0.19	4.64[a]
	Okinawan Purple	2.56[c]	0.16[c]	2.18[d]	1.18[a]	0.16	3.64[c]
	Purple Sweet Lord	3.10[b]	0.18[b]	2.75[b]	0.99[b]	0.16	4.02[b]
Nong Ruea district	Honey Sweet	3.49[d]	0.14	2.31[d]	1.51[c]	0.10	4.90[b]
	Okinawan Orange	4.42[a]	0.18	2.86[a]	1.68[a]	0.07	3.34[d]
	Okinawan Purple	3.92[c]	0.17	2.43[c]	1.68[a]	0.08	4.17[c]
	Purple Sweet Lord	4.05[b]	0.17	2.63[b]	1.42[d]	0.07	5.09[a]

a Treatments at $p \leq 0.05$, derived from *LSD*.

To investigate planting of four sweet potato types in Phu Wiang and Nong Ruea district, Okinawan Orange gave the highest tuber yields at 15,515 and 8,080 kg ha^{-1} (Table 6), respectively, with the average number of tubers per plant being 3.75 and 4.50 tubers, respectively, and the average tuber length being between 12.90 and 17.52 cm. But Honey Sweet and Okinawan Purple grown in Nong Ruea district did not provide the tuber yield. Dimante & Gaile (2018) mention that under field conditions plant development was significantly affected by cultivar. The significantly different response of cultivars tested revealed the necessity for field performance after planting and more growing degree days required to emerge and tuberization, when compared to medium early and medium late cultivar. For the nutritional value after harvest, Okinawan Orange and Purple Sweet Lord in Phu Wiang district had the highest percentage of tuber moisture content at 74.98% and 74.64%, respectively, followed by Honey Sweet and Okinawan purple (Table 7). The highest percentage of tuber moisture content lowered the content of undissolved minerals (ash) than in sweet potatoes with a lower percentage of tuber moisture content. The Purple Sweet Lord has higher protein and carbohydrates followed by Okinawan Orange, Okinawan Purple and Honey Sweet. However, Okinawan Orange and Purple Sweet Lord had lower fiber in the tuber yield than Honey Sweet and Okinawan Purple; even Okinawan Orange is higher in fat than other varieties. In addition, the leaf biomass of Okinawan Orange and Purple Sweet Lord tend to produce more protein and carbohydrates (Table 8) while the stem biomass was higher in fiber than leaf biomass (Table 9).

Table 6. Yield components of sweet potatoes

Field experiment	Sweet potato	No. of Tubers/ Plant	Tuber Fresh Weight/ Hectare (kg)	Tuber Length (cm)	Tuber Diameter (cm)	Leaf Fresh Weight/ Hectare (kg)	Stem fresh weight/ Hectare (kg)	Leaf dry weight/ Hectare (kg)	Stem dry weight/ Hectare (kg)
Phu Wiang district	Honey Sweet	3.25	1,716.88[c]	16.63[a]	3.75	880.00[c]	2,240.00[c]	142.38[c]	376.56[b]
	Okinawan Orange	3.75	15,515.00[a]	17.52[a]	4.81	4,260.00[b]	6,986.88[bc]	468.81[bc]	697.44[b]
	Okinawan Purple	2.75	1,835.00[c]	17.57[a]	4.00	5,320.00[b]	10,213.13[ab]	829.38[b]	1,697.13[a]
	Purple Sweet Lord	4.25	10,260.00[b]	11.19[b]	4.48	8,506.88[a]	14,946.88[a]	1,363.25[a]	1,932.25[a]
Nong Ruea district	Honey Sweet	-	-	-	-	633.31[b]	680.00[b]	412.69	377.31
	Okinawan Orange	4.50[a]	8,080.00[a]	12.90	4.10	5,420.00[a]	9,466.88[a]	649.19	972.31
	Okinawan Purple	-	-	-	-	853.31[b]	873.13[b]	458.00	403.31
	Purple Sweet Lord	2.75[b]	3,535.00[b]	12.90	4.28	4,653.31[a]	5,460.00[ab]	690.13	630.94

a Treatments at $p \leq 0.05$, derived from *LSD*.

Table 7. Nutritional content of tuber sweet potatoes

Field experiment	Sweet potato	Fresh Moisture (%)	Ash (%)	Protein (%)	Fat (%)	Fiber (%)	Carbohydrate (%)
Phu Wiang district	Honey Sweet	72.91[b]	4.07[a]	2.35[d]	0.39[c]	7.77[a]	82.03[c]
	Okinawan Orange	74.98[a]	3.59[b]	3.50[c]	1.69[a]	3.62[b]	86.43[a]
	Okinawan Purple	70.47[c]	4.01[a]	3.87[b]	0.69[c]	8.11[a]	80.47[c]
	Purple Sweet Lord	74.64[a]	3.15[c]	5.33[a]	1.28[b]	3.15[b]	84.46[b]
Nong Ruea district	Honey Sweet	-	-	-	-	-	-
	Okinawan Orange	71.80	3.64[a]	4.87[b]	1.80[a]	2.39[b]	84.67[b]
	Okinawan Purple	-	-	-	-	-	-
	Purple Sweet Lord	72.20	3.03[b]	5.13[a]	1.11[b]	2.52[a]	85.84[a]

a Treatments at $p \leq 0.05$, derived from *LSD*.

Table 8. Nutritional content of leaf sweet potatoes

Field experiment	Sweet potato	Ash (%)	Protein (%)	Fat (%)	Fiber (%)	Carbohydrate (%)
Phu Wiang district	Honey Sweet	12.61^{c}	2.26^{c}	37.99^{a}	33.28^{d}	9.47^{b}
	Okinawan Orange	19.92^{a}	3.84^{a}	11.12^{c}	52.78^{b}	12.09^{a}
	Okinawan Purple	12.15^{d}	2.33^{c}	36.81^{b}	36.13^{c}	8.68^{c}
	Purple Sweet Lord	14.99^{b}	2.61^{b}	8.54^{d}	65.62^{a}	7.08^{d}
Nong Ruea district	Honey Sweet	-	-	-	-	-
	Okinawan Orange	24.76^{a}	3.52^{a}	10.17^{a}	49.41^{b}	11.45^{a}
	Okinawan Purple	-	-	-	-	-
	Purple Sweet Lord	23.36^{b}	3.16^{b}	8.77^{b}	56.55^{a}	7.48^{b}

a Treatments at $p \leq 0.05$, derived from *LSD*.

Table 9. Nutritional content of stem sweet potatoes

Field experiment	Sweet potato	Ash (%)	Protein (%)	Fat (%)	Fiber (%)	Carbohydrate (%)
Phu Wiang district	Honey Sweet	3.94^{b}	1.96^{c}	36.72^{a}	47.29^{d}	7.59^{b}
	Okinawan Orange	3.20^{d}	3.61^{a}	24.80^{d}	56.05^{b}	9.61^{a}
	Okinawan Purple	4.27^{a}	2.50^{b}	34.80^{b}	49.20^{c}	6.83^{c}
	Purple Sweet Lord	3.76^{c}	2.55^{b}	26.39^{c}	59.29^{a}	6.75^{c}
Nong Ruea district	Honey Sweet	-	-	-	-	-
	Okinawan Orange	7.48	2.29^{b}	21.15^{b}	55.48^{b}	10.71^{a}
	Okinawan Purple	-	-	-	-	-
	Purple Sweet Lord	7.41	3.27^{a}	22.42^{a}	57.43^{a}	8.02^{b}

a Treatments at $p \leq 0.05$, derived from *LSD*.

DISCUSSION

Present consumer preference for more nutritious foods, sweet potato has gradually improved as one of the most nutritious vegetables (Truong et al., 2018) with exciting colors and flavor profiles, for instance purple, cream and orange colors. The crop is now extended to northeast of Thailand with acid sandy soil and drought. However, sweet potato is recognized as adapted to cope to numerous types of soils and climates, especially warm-season with daily maximum air-temperatures between 29.7 °C and 35.3 °C for storage root production. Suitable soils texture for sweet potato production ranges from sand to loamy sand and low in salts. Recent studies have shown sweet potato can grow in heavy soils, but yield and quality can decrease (Duque et al., 2022). From the experiment, Okinawan Orange, Okinawan Purple and Purple Sweet Lord showed the longest vine length respectively. These differences in vine length might be attributed to variation in the genotypes' genetic make-up and their interaction with the environment. Their performance varies from place to place due to genotype by environment interaction and this calls for specific area recommendation. Shamil (2021) discovered vine lengths ranging of sweet potato varieties could be from 135.2 cm to 175.1 cm. Similar to the study result of Nazrul (2018) also reported significant variation in sweet potato vine length which ranged from 119 cm to 192.3 cm among sweet potato varieties, this variability might be attributed to their growth traits. This indicates that it's could be used as a good vine source for vines sweet potato producing. While Honey Sweet had the lowest vine length in both fields. Moreover, the young vines and leaves of the crop can be eaten as vegetables for human consumption or given to animal due to proteins and minerals richness (Kebede et al., 2008).

Sweet potato canopy is the main source of photosynthetic material that will be distributed to tubers production (Rahmawati et al., 2020). In this study, variety with medium vine length (Okinawan Orange) produced maximum storage root yield. This might be due to the growth in vine length up to optimum stage may improve storage root yield up to some point through increased leaf number that photosynthesize and accumulate more dry matter. However, excess vine length growth may result in reduced storage root yield which could be attributed to most of the assimilates produced used in leaf and vine growth instead of tuber growth as a consequence of higher competition for assimilates. At the beginning of growth stage, Okinawan Orange produced the largest leaf area, followed by Purple Sweet Lord, its were also moderate vine length in the trials during establishment in the field for sunlight and carbohydrate synthesis than those with a small leaf area (Van den Berge et al., 2004; Ahmed et al., 2012; Kareem, 2013). This is an opportunity of the tubers crop for the highest yield and quality from weeds (Laurie & Niederwieser, 2004; Moyo et al., 2004; Ministry of Agriculture & Food Security, 2007; Workayehu et al., 2011). Usually, storage root formation started between the 30^{th} and 60^{th} DAP. Then vegetative growth and rapid storage root during 60^{th} and 90^{th} DAP refer to the different genetic potential to form tubers. The environment and technical culture also influenced on number of sweet potato tubers. Generally, Okinawan Purple and Purple Sweet Lord are well varieties on root growth, if farmers can't remove the vines in time, this sweet potato will provide a lot of roots with incomplete tubers. Moreover, fibrous roots formation was re-direct photosynthates towards than storage roots with temperatures greater than 28 °C (Eguchi et al., 2003). During the experimental run, the maximum and minimum temperatures were 31.67 and 25 °C in Phu Wiang District and 32 and 25 °C in Nong Ruea District. High temperatures increase of gibberellic acid (GA) and trigger Indoleacetic Acid (IAA) oxidase activity, these causes to promote vine growth and storage root formation decrease (Kelm et al., 2000).

Along with the growing period from April to June with high temperature and rainy before harvesting in both fields, provided some stress environment for storage root growth and productivity. The sweet potato cultivars were grown in Nong Ruea district tended to slowly for root yield formation and roots yield rarely reached full size even genetic constituents. While Honey Sweet was consistently the lowest tuber yielding variety according to its shortest vine length. Storage roots yield significantly different due to genotypes also reported in other sweet potato trials (Rahmawati et al., 2020; Dawit & Habte 2023). High acidity induces nutrient deficiency which causes yield potential of different genotypes by tuber yield reduction. Phu Wiang district showed the highest tuber yield across genotypes under suitable soil pH for nutrients absorption and the suitable available P and exchangeable K, while the yield at Nong Ruea district was the lowest. Tuber yield was related to tuber size and tubers number which are affected by soil fertility conditions (Dawit & Habte 2023). Our results showed that Okinawan Orange produced significantly different average tuber fresh weights, starch content, fat content and tuber moisture content. The growing sites influences the yield and quality of tubers which causes a very significant decrease in the parameters of tuber weight, tuber length, protein content, starch content and tuber water content. Stated that the high production of Okinawan Orange is able to adapt to the environment. The genetic potential is very supportive in the success of farming, means Okinawan Orange converted more its photosynthetic products to roots carbohydrates stored. Tuber moisture content is a parameter influenced by the availability of water that can be absorbed by the roots to meet plant needs. Additionally, genotype and location had a substantial influence on sweet potatoes productivity in Khon Kaen province, northeast of Thailand. Our study clearly revealed that the farmer should select suitable sweet potato cultivars for the field, since all introduced cultivars were popular in market demand. Among the introduced genotypes, Okinawan Orange look interesting for farmer fields to increase an income as its higher total tuber root yield under the same investment. Despite its importance and suitability to the agro-ecology of the region including the presence of suitable soil type, temperature and rainfall for sweet potato production. However, further adaptation studies should be investigated in new areas for more acceptable, stability of yield production, β-carotene content, sweetness and flavor as potentially useful.

CONCLUSIONS

Yields of four sweet potato types under acid sandy soil in Phu Wiang and Nong Ruea district, Khon Kaen province, Northeast of Thailand were significantly lower than approximately 80–100 t ha^{-1}. Okinawan Orange provided the maximum yield weight of 15,515 kg ha^{-1} in Phu Wiang district and 8,080 kg ha^{-1} in Nong Ruea district. Okinawan Orange provided the highest tuber root yield and showed stability in the trial. For tuber production, Okinawan Orange seem to be beneficial to grow in the northeast Thailand. Some promising lines with the large leaf area and longer vines such as Okinawan Purple and Purple Sweet Lord, were benefit for vine production. However, studies have also shown that sweet potato have high uptake of soil nutrients, which could possibly cause soil deterioration. Then the farmer should manage fertilizer properly for sweet potato production.

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REFERENCES

Ahmed, M., Nigussie-Dechassa, R. & Abebie, B. 2012. Effects of planting methods and vine harvesting on shoot and tuberous root yields of sweet potato (*Ipomoea batatas* (L.) Lam.) in the afar region of Ethiopia. *Afric. J. Agric. Res* **7**(7), 1129–1141.

Amede, T., German, L., Rao, C., Opondo, C. & Stroud, A. 2006. Integrated natural resource management in practice: enabling communities to improve mountain livelihoods and landscapes. In: Proceedings of the African Highland Initiative Conference, October, 2004, pp. 1215.

CSA (Central Statistical Agency). 2014. Crop production forecast sample survey, 2013/14. In: *Report on Area and Production for Major Crops* (for Private Peasant Holdings 'Meher' Season). Addis Ababa, Ethiopia.

Dawit, M. & Habte, A. 2023. Yield and profitability of sweet potato (*Ipomoea batatas* (L.) Lam) as a function of increasing levels of phosphorus and varieties in southern Ethiopia. *Applied and Environmental Soil Science*. https://doi.org/10.1155/2023/2716227

Dimante, I. & Gaile, Z. 2018. Assessment of potato plant development from Minitubers. *Agron. Res* **16**(4), 1630–1641.

Duque, L.O., Sánchez, E., Pecota, K. & Yencho, C. 2022. A win–win situation: performance and adaptability of petite sweetpotato production in a temperate region. *Horticulturae* **8**, 172. https://doi.org/10.3390/horticulturae8020172

Eguchi, T., Kitano, M., Yoshida, S. & Chikushi, J. 2003. Root temperature effects on tuberous root growth of sweet potato (*Ipomoea batatas* (L)). *Env. Cont. Biol.* **41**, 43–49.

FAO. 2008. Corporate Document Repository. The impact of HIV/AIDS on the agricultural sector. Retrieved 2015 February 28 from http://www.fao.org/docrep/005/Y4636E/y4636e05.htm

Fernandes, A.M., Natália, S.A., Nathalia, P.R., Bruno, G. & Rudieli Machado, S. 2020. Nutrient uptake and removal by sweet potato fertilized with green manure and nitrogen on sandy soil. *Rev. Bras. Cienc. Solo* **44**.

Gurmu, F. & Mekonen, S. 2017. Registration of a newly released sweet potato variety 'Hawassa-09' for production in Ethiopia. *Agrotechnology* **6**(2), 1–3.

Ji, H., Zhang, H., Li, H. & Li, Y. 2015. Analysis on the nutrition composition and antioxidant activity of different types of sweet potato cultivars. *Food Nutr Sci*. **6**, 161.

Kandel, B.P. 2020. Spad value varies with age and leaf of maize plant and its relationship with grain yield. *Kandel BMC Res Notes* **13**, 475. https://doi.org/10.1186/s13104-020-05324-7

Karan, Y.B. & Şanli, O.G. 2021. The assessment of yield and quality traits of sweet potato (*Ipomoea batatas* L.) genotypes in middle Black Sea region, Turkey. *PLoS ONE* **16**(9), e0257703. https://doi.org/10.1371/journal. pone.0257703

Kareem, I. 2013. Effects of phosphorus fertilizer treatments on vegetative growth, tuberous yield and phosphorus uptake of sweet potato (*Ipomoea batatas*). *Afri. J. Agric. Res* **8**(22), 2681–2684.

Kelm, M., Brück, H., Hermann, M. & Sattelmacher, B. 2000. Plant productivity and water use efficiency of sweet potato (*Ipomoea batatas* (L)) as affected by nitrogen supply. CIP program report, pp. 273.

Laurie, S.M. & Niederwieser, J.G. 2004. The sweet potato plant. In: Niederwieser JG (Ed). *Guide to sweet potato production in south africa*. ARC-Roodeplaat Vegetable and Ornamental Plant Institute, Pretoria, South Africa, pp. 7–14.

Ministry of Agriculture & Food Security (MoAFS). 2007. *Cassava and sweet potato production handbook*. Lilongwe, Malawi, pp. 23–39.

Moyo, C.C., Benesi, I.R.M., Chipungu, F.P., Mwale, C.H.L., Sandifolo, V.S. & Mahungu, N.M. 2004. Cassava and Sweet Potato Yield Assessment in Malawi. *Afric. Crop Sci. J.* **12**(3), 295–203.

Murdock, L, Jones, S, Bowely, C, Needham, P, James, J & Howe, P. 1997. *Using a chlorophyll meter to make nitrogen recommendations on wheat*. Cooperative Extension Service University of Kentucky-college of Agriculture. http://www2.ca.uky.edu/agcomm/pubs/agr/agr170/agr170.pdf

Nazrul, M.I. 2018. On-farm evaluation of orange fleshed sweet potato varieties under acidic soil of north-east region in Bangladesh. *Bangladesh Agron J.* **21**(2), 59–65.

Novikova, L. Yu., Chalaya, N.A., Sitnikov, M.N., Gorlova, L.M., Kiru, S.D. & Rogozina, E.V. 2021. Dynamics of tuber weight in early potato varieties in the contrasting weather conditions of the Northwestern Russia. *Agron. Res.* **19**(1), 185–198.

Popradit, A. 2021. Yield response and soil nutrient change of sweet potato varieties to different fertilization treatments. *Thai Environ. Eng. J.* **35**(2), 29–37.

Rahmawati, N., Lahay, R.R., Irmansyah, T. & Mawarni, L. 2020. Yield and tuber quality of orange-fleshed sweet potato cultivars under drought stress in greenhouse. *International Conference on Agriculture, Environment and Food Security* (AEFS) 2019. IOP Conf. Series: Earth and Environmental Science **454**. doi:10.1088/1755-1315/454/1/012159

Shamil, A.S. 2021. Evaluation of sweet potato (*Ipomoea batatas* (L) Lam) varieties at tepi, southwestern Ethiopia. *World J. Agric. Soil Sci.* **6**(4), 1–4.

Simson, R., Tartlan, L., Nugis, E. & Eremeev, V. 2016. The effect of fertilizer and growing season on tuber dry matter and nitrate content in potato. *Agron. Res.* **14**(4), 1486–1493.

Teow, C.C., Truong, V.D., McFeeters, R.F., Thompson, R.L., Pecota, K.V. & Yencho, G.C. 2007. Antioxidant Activities, Phenolic and Β-carotene Contents of Sweet Potato Genotypes with varying Flesh Colours. *Food Chem* **103**, 829–838.

Troncoso, E. & Pedreschi, F. 2009. Modeling water Loss and oil uptake during vacuum frying of pre-treated potato slices. *LWT - Food Sci. Technol. J.* **42**(6), 1164–1173.

Truong, V.D., Avula, R.Y., Pecota, K.V. & Yencho, G.C. 2018. Sweetpotato production, processing, and nutritional Quality. In Handbook of Vegetables and Vegetable Processing; John Wiley and sons Ltd.: New York, NY, USA, pp. 811–838.

Van den Berge, A.A. & Laurie, S.M. 2004. Cultivation. In: niederwieser JG (Ed). Guide to sweet potato production in south africa, ARC-Roodeplaat vegetable and ornamental plant institute, Pretoria, South Africa, pp. 15–27.

Workayehu, T., Mangezia, W. & Hidoto, L. 2011. Growth habit, plant density and weed control on weed and root yield of sweet potato (*Ipomoea batatas* L.), Areka, Southern Ethiopia. *J. Hort. and For* **3**(8), 251–258.