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Research Article

Influence of Harvest Stage on Yield and Yield Components of Orange Fleshed Sweet Potato [*Ipomoea batatas* (L) Lam] at Adami Tullu, Central Rift Valley of Ethiopia

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A field experiment was conducted at Adami Tullu Agricultural Research Center in 2018 under rainfed condition with supplementary irrigation to determine the influence of harvest stage on vine yield and tuberous root yield of orange fleshed sweet potato varieties. The experiment consisted of four harvest stages (105, 120, 135 and 150 days after planting) and Kulfo, Tulla and Guntute varieties. A 4 X 3 factorial experiment arranged in randomized complete block design with three replications was used. Interaction of harvest stage and variety significantly influenced above ground fresh biomass, vine length, marketable tuberous root weight per hectare, commercial harvest index and harvest index. The highest mean values of above ground fresh biomass (66.12 t/ha) and marketable tuberous root weight (56.39 t/ha) were produced by Guntute variety harvested at 135 days after planting. Based on the results, it can be recommended that, farmers of the study area can grow Guntute variety by harvesting at 135 days after planting to obtain optimum vine and tuberous root yields.

Keywords: *harvest stage, leaf number, tuberous root, varieties, vine yield*

INTRODUCTION

Sweet potato [*Ipomoea batatas* (L) Lam] is an important tuberous root crop belonging to the family Convolvulaceae. Globally it is the seventh most important food security tuberous root crop after wheat, rice, maize, potato, barley, and cassava (Van Jaarsveld *et al.*, 2005; Lebot, 2009; Ahn *et al.*, 2010; Wang *et al.*, 2011; Daniel and Gobaze, 2016). Wider adaptability and beta carotene content of orange fleshed varieties are special attributes of sweet potato unlike staple food crops (Trancoso-Reyes *et al.*, 2016). Production of 112.8 million tons (in 115 countries) reported in 2017 and China is the leading producer, followed by Sub-saharan African countries (FAOSTAT, 2019). Asia (75.1 %), Africa (20.8 %), America (3.3 %), Oceania (0.08 %) and Europe (0.1 %) are regions shared production of sweet potato from 2007 to 2017 (FAOSTAT, 2019).

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In Ethiopia during 2017/18 cropping season about 53,449 hectares of land was cultivated and it takes the second position, next to potato among tuberous root crops with 34.6 t/ha tuberous root yield (CSA, 2018). Orange fleshed sweet potato varieties have been popularized in Ethiopia to eliminate micronutrient deficiencies, vitamin A deficiency (VAD), and malnutrition problems(Tofu *et al.*, 2007; Kidane *et al.*, 2013; Fekadu *et al.*, 2015). These varieties have not been tested at different harvest stages in Ethiopia.

Sweet potato is widely grown in Ethiopia with an average national tuberous root yield of 8 t/ha, which is low compared to the world's average production 14.8 t/ha (Tofu *et al.*, 2007). It has a potential of giving 50 to 60 t/ha but the yield obtained from farmer's field was lower than 6 to 8 t/ha (Daniel and Gobeze, 2016). This indicates that national as well as regional yield is lower than attainable yield at research station. Total tuberous root yield of 0.88 t/ha was obtained from Tulla variety at Jimma University College of Agriculture and Veterinary Medicine(Bezawit*et al.*, 2015). According to Regassa *et al.* (2015) marketable tuberous root yield of 4.6 t/ha recorded by Kulfo at Borena Zone. This yield gap could be attributed to inappropriate land preparation, sub-optimal plant population, lack of improved varieties, poor crop management practices, improper harvest stage and post-harvest problems (Fekadu *et al.*, 2015). Sweet potatoes have a different varieties and the productivity of these varieties were different even in the same environmental conditions.

Optimum harvest stage is important for vine yield and tuberous root yield. It varies among varieties, environmental conditions and market demand. Sweet potato is commonly harvested 150 days after planting (DAP), but there is variability in maturity stages among varieties (Alvaro *et al.*, 2017). Harvesting vines at 105 DAP gave optimum production of above ground fresh biomass without reducing yield of tuberous roots(Ahmed *et al.*, 2012). Tuberous roots were smaller when harvested at 90 DAP than 120, 150 and 180 DAP (Alvaro *et al.*, 2017). Tuberous root yield of 12.77 t/ha was found when tuberous roots were harvested at 150 DAP while 9.0 t/ha at 120 DAP (Islam and Shimu, 2018).

In Ethiopia preliminary and national variety trials on sweet potato were done at Hawassa Agricultural Research Center (HARC) and various institutions. As a result promising varieties have been identified. Moreover, a research on some identified varieties with different plant spacing and fertilizers trials were done at Adami Tullu Agricultural Research Center. However, basic information on how above ground fresh biomass yield and tuberous root yield of this crop is affected by harvest stage, variety and their interaction are still limited. This calls for further studies to be conducted in Central Rift Valley of Ethiopia. Therefore, the study was conducted to assess the influence of harvest stage on yield and yield components of orange fleshed sweet potato at Adami Tullu condition.

MATERIALS AND METHODS

Description of the Study Area

The experiment was conducted at Adami Tullu Agricultural Research Center (Horticulture research site) located in Central Rift Valley of Ethiopia, Oromia national regional state, East Shoa zone, under Central Rift Valley of Ethiopia in main season from June to October 2018 under supplementary irrigation. The geographical location of the site is at 7º 9' N latitude and 38º 7' E longitudes and at an altitude of 1650 meter above sea level (m.a.s.l) and about 168 km south from Addis Ababa, capital city of Ethiopia. The area has minimum and maximum average annual temperatures of 12.6ºC and 27ºC, respectively. An area received bimodal and unevenly distributed average annual rainfall of 760 mm. Rainfall extends from February to September with a dry period from May to June, which separates the preceding short rains from the following long rains. The pH of the soil is 7.88. The soil texture is fine sandy loam with sand, clay and silt in proportions of 34, 48 and 18%, respectively (ATARC, 1998).

Experimental Materials

Three orange fleshed sweet potato [*Ipomoea batatas* (L.) Lam] varieties (Kulfo, Tulla and Guntute) were grown at Adami Tullu Agricultural Research Center (ATARC) from June to October in 2018 under rainfed condition and supplementary irrigation was used twice a week during rain fall is terminated.

Table 1: Description of the varieties used for the experiment

Varieties	Growth habit	Year of release	Altitude	Maturity days	Flesh colour	Yield (t/ha)	Center of release
Kulfo	SC	2005	1200-2200	150	orange	27	Hawassa
Tulla	SC	2005	1200-2200	150	orange	28.5	Hawassa
Guntute	SC	1997	1500-1800	120-150	orange	34.5	Hawassa

Source: Ministry of Agriculture Crop variety registration bulletin (1983-2017).
SC: Semi Compact

Treatments and Experimental Design

The experiment was laid out in randomized complete block design (RCBD) with three replications. Factorial combination of four harvest stages (105, 120, 135 and 150 DAP) and three orange fleshed sweet potato varieties (Kulfo, Tulla and Guntute) were used.

The gross size of experimental plot was 3m × 3m (9m^2) accommodating five rows of sweet potato planted at a spacing of 60cm between rows and 30cm between plants. The net sampling plot size was 2.4m × 2.7m (6.48m^2) in all the cases, in which the two outer most rows and one plant at both ends of the row considered as borders leaving three middle rows for sweet potato with the length of 2.7m for data collection and measurement.

Experimental Procedure and Field Management

Land preparation was done at the beginning of May with tractor, harrowed and leveled before planting. The three months old sweet potato cuttings were transplanted at row spacing of 60cm and plant spacing of 30cm recommended for sweet potato and done by hand in the rows as uniformly as possible and covered with soil manually. Transplanting was conducted on first date of June, 2018.

All other necessary agronomic management practices like watering, earthing-up, cultivation, weeding and crop protection measures were carried out uniformly as recommended for sweet potato. The experimental plot was supplemented by furrow irrigation during off rain.

Data Collection and Measurement

Vine Yield Indicators

The following parameters were collected from five randomly sampled plants of each plot at respective harvest stages (105, 120, 135 and 150 DAP) during morning.

Number of Vines per Plant (NVPP): Number of vines per plant was counted and expressed in number at respective harvest stage. It was taken from five randomly sampled plants and the sum total was divided by number of sampled plants to get average vine number per plant. The average value was used for data analysis.

Vine Length (VL) (cm): Vine length was measured from the base of the plant to the terminal leaf by meter tape and it was expressed in cm at respective harvest stage. It was taken from five randomly sampled plants and the sum total was divided by number of sampled plants to get average vine length. The average value was used for data analysis.

Vine Thickness (VT) (mm): Vine thickness was measured at 20cm above soil by digital Caliper and it was expressed in mm at respective harvesting stage. It was taken from five randomly sampled plants and the sum total was divided by number of sampled plants to get average vine thickness. The average value was used for data analysis.

Number of Leaves per Plant (NLPP): Number of leaves per plant was counted and expressed in number at respective harvest stage. It was taken from five randomly sampled plants and the sum total was divided by number of sampled plants to get average leaf number per plant. The average value was used for data analysis.

Leaf Area Per Plant (LAPP) (cm^2): At respective harvest stages leaf area per plant (cm^2) was taken by measuring the length of leaves from the entire attachment of petiole (lobe) to tips of the leaves, then, multiplied by the width, that was measured from large part of the leaves by rulers and finally multiplied by correction coefficient 0.8 for larger width part of the leaves as stated by Sutoro (1991**).**

$\boldsymbol{LA = 0.8 * L * W}$ … … … … ..Sutoro (1991) ---------------------- ***Equation (1)***

Where: **LA** = Leaf area, **L** = Leaf length and **W**= Leaf width. Hence, three leaves taken from top, middle and bottom of five randomly sampled plants from the middle three rows and length (from the tip of the leaf to petiole attachment and width (from the widest part) were measured and expressed in centimeter. Therefore, the average leaf area of each plant from the plot was multiplied by the average leaf number of each plant and average value was calculated.

Leaf Area Index (LAI): Leaf area index was measured from average of 15 leaves per plant; of these, 5 from lower, 5 from middle and 5 from top portion of the plants; totally from average five plants per plot. It was calculated by dividing average leave area (ALA) to the ground area (GA).To this experiment, it was 30cm*60cm (0.3m*0.6m), which had an area of 0.18m^2 per plant.

$\mathbf{LAI} = \frac{\mathbf{LA}}{\mathbf{GA}}$ … … … … … … … … … … … . .Cristofori *et al.* (2007)**-------------------Equation (2)**

Where, **LAI** = Leaf area index, **LA**= Leaf area and GA= Ground area, which is an area that shaded by the leaf canopy.

Tuberous Root Yield and Yield Components

The following yield and yield component parameters were collected from all plants in the net plot of each plot at the respective harvest stage (105, 120, 135 and 150 DAP).

Tuberous Root Length (TL) (cm): The average tuberous root length was measured by a hand ruler (50cm) in cm and average of three tuberous roots (large, medium and small) from net plot were used at respective harvest stages.

Tuberous Root Diameter (TD) (cm): Tuberous root diameter was measured by Vernier caliper (0-150mm) in mm from tuberous roots sampled from net plot and three tuberous roots (large, medium and small) from net plot were used at respective harvest stages and average was considered for analysis.

Above Ground Fresh Biomass (AGFB): Above ground fresh biomass weighed from all plants in the central three rows of each plot was harvested and weighed using hanging digital balance (50 kg) expressed in kg per plot at respective harvest stages. Obtained value was converted to t/ha.

Tuberous Root Grade: Tuberous roots were graded into marketable (small sized 100-200g, medium sized 200-350g and larger sized 350-500g) whereas unmarketable ones (very small size less than 100g and oversized more than 500 g, tuberous roots with injury, rotting and greening symptoms(Terefe, 2003).

Marketable Tuberous Root Number per Plant (MTNPP): Marketable tuberous root number per plant was counted from tuberous root of marketable category and expressed in number per plant at respective harvest stage. It was taken from all plants in the net plot and the sum total was divided by number of plants in the net plot to get average. The average value was used for data analysis.

Unmarketable Tuberous Root Number per Plant (UNMTNPP): Unmarketable tuberous root number per plant was counted from tuberous roots of unmarketable category and expressed in number per plant at respective harvest stages. It was taken from all plants in the net plot and the sum total was divided by number of plants in the net plot to get average. The average value was used for data analysis.

Total Tuberous Root Number per Plant (TTNPP): Total tuberous root number per plant was obtained by adding number of marketable and unmarketable tuberous roots category and expressed in number per plant. The average value was used for data analysis.

Marketable Tuberous Root Weight per Plant (MTWPP) (kg): Marketable categories of tuberous roots per plant were weighed by hanging digital balance and expressed in kg at respective harvest stage. The sample was taken from all plants in the net plot and the sum total was divided by number of plants to get average. The average value was used for data analysis.

Unmarketable Tuberous Root Weight per Plant (UMTWPP) (kg): Unmarketable categories of tuberous roots per plant were weighed by hanging digital balance and expressed in kg at respective harvest stages. It was taken from all plants in the net plot and the sum total was divided by number of plants to get average. The average value was used for data analysis.

Total Tuberous Root Weight per Plant (TTWPP) (kg): Marketable and unmarketable categories of tuberous roots weight per plant were added and expressed in kg at respective harvest stages. The average value was used for data analysis.

Marketable Tuberous Root Weight per Hectare (MTW t/ha): To get marketable tuberous root weight per hectare first tuberous roots of marketable category was weighed and expressed in kg per plot basis by using hanging digital balance at respective harvest stage. The yield obtained in plot basis then converted to t/ha. The obtained value was used for data analysis.

Unmarketable Tuberous Root Weight per Hectare (UNMTW t/ha): To get unmarketable tuberous root weight per hectare first tuberous roots of unmarketable category was weighed and expressed in kg per plot basis by using hanging digital balance at respective harvest stage. The yield obtained in plot basis was converted to t/ha. The obtained value was used for data analysis.

Total Tuberous Root Yield per Hectare (TTY t/ha): Total tuberous root weight per hectare was obtained by adding the marketable and unmarketable tuberous root weight per hectare of the above mentioned categories. Then obtained value was used for data analysis.

Harvest Index (HI) (%): Harvest index was calculated as the ratio of the total tuberous root yield to total biomass at harvest (i.e. sum of the tuberous root yield and above ground biomass)(Yeng *et al.*, 2012).

$$\mathbf{HI} = \frac{\textit{Total tuberous root yield}}{\textit{Total tuberous root yield+ above ground fresh biomass}} * \mathbf{100} \ldots\ldots\ldots\ldots\ldots\ldots \textbf{\textit{Equation (3)}}$$

Commercial Harvest Index (CHI) (%): Commercial harvest index was calculated as the ratio of the weight of the marketable tuberous roots to the total tuberous root yield(Yeng *et al.*, 2012).

$$\mathbf{CHI} = \frac{\textit{Marketable tuberous root yield}}{\textit{Total tuberous root yield}} * \mathbf{100} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{\textit{Equation (4)}}$$

2.6. Data Analysis

Data collected were subjected to analysis of variance (ANOVA) using the Genstat 15 edition, (Genstat, 2012) and interpretations were made following the procedure described by Gomez and Gomez (1984). Whenever the effects of the treatments were found significant, the means were compared using least significance difference (LSD) test at 5% level of significance.

RESULTS AND DISCUSSION

Vine Yield Indicators

Influence of harvest stage on vine number per plant, vine thickness, petiole length, leaf area and leaf area index of orange fleshed sweet potato (OFSP) variety

Analysis of variance showed that vine number per plant, vine thickness, petiole length, leaf area and leaf area index were not significantly influenced by interaction of harvest stage and variety. Similarly, vine numbers per plant and vine thickness were not significantly influenced by the main effect of harvest stage and variety. However, the main effect of harvest stage and variety significantly ($P<0.01$) affect petiole length. Leaf area and leaf area index were significantly influenced by main effect of variety. However, the main effect of harvest stage did not significantly influence leaf area and leaf area index. The highest petiole length (17.98cm) was produced at 135 DAP, which was statistically at par with the petiole length produced at 120 DAP (16.82cm). The lowest petiole length (13.99cm) was recorded at 150 DAP (Table 2). Petiole length was increased significantly when harvest stage delayed from 105 to 135 DAP. This increase in petiole length might be due to favorable growth climate condition and extended duration of harvest stage. Guntute variety recorded the highest petiole length (19.03cm), whereas the lowest petiole length was registered with Kulfo variety (14.04 cm) which was statistically at par with Tulla (14.24 cm) (Table 2). The difference in petiole length might be due to the presence of genetic variation among the tested varieties.

Leaf area was significantly ($P<0.01$) influenced by variety main effect. The highest leaf area (91.56 cm^2) was produced by Guntute variety whereas the lowest leaf area was produced by Kulfo variety (38.88 cm^2) which was statistically at par with Tulla variety (39.29 cm^2) (Table 2). The present study in line with the work of Kathabwalika *et al.* (2013) who reported significant variation among different varieties of sweet potato with regard to leaf area and other morphological characteristics. Isa *et al.* (2015) stated that if the vegetative growth was very high, sweet potato would be difficult to form tuberous roots. The widest leaf area combined with longer vine length give an advantage during establishment in the field (Kathabwalika *et al.*, 2013). A varieties with wider leaf area can easily trap sunlight and carry out better photosynthesis required for carbohydrates synthesis in the plant than those with small leaf area (Ahmed *et al.*, 2012; Kareem, 2013).

Leaf area index was also significantly affected by the variety. The highest leaf area index (18.18) produced by Guntute variety whereas the lowest was produced by Kulfo variety (7.52). Leaf area index is influenced by varieties that have different morphological characters, especially the shape and size of the leaves (Tsialtas *et al.*, 2008).

Table 2: Main effects of harvest stage on vine number, vine thickness, petiole length, leaf area and leaf area index of OFSP variety at ATARC in 2018

Treatment Harvest stages	Vine number	Vine thickness (mm)	Petiole length (cm)	Leaf area (cm^2)	Leaf area index
Stage 1 (105 DAP)	3.53	5.40	14.28b	54.63	10.49
Stage 2 (120 DAP)	3.42	5.12	16.82ab	57.59	12.13
Stage 3 (135 DAP)	3.22	5.35	17.98a	59.02	11.91
Stage 4 (150 DAP)	3.48	5.50	13.99b	55.06	10.04
LSD	NS	NS	2.93	NS	NS
Varieties					
Kulfo	3.58	5.19	14.04b	38.88b	7.52b
Tulla	3.45	5.33	14.24b	39.29b	7.73b
Guntute	3.21	5.50	19.03a	91.56a	18.18a
LSD (0.05)	NS	NS	2.54	8.50	2.005
CV	11.66	6.94	19.04	17.76	21.3

Means followed by the same letters within same column are not significantly different from each other at 5% level of probability. CV = Coefficient of variations and LSD = Least significant difference.

Influence of harvest stage on above ground fresh biomass, vine length and leaf number of OFSP variety

Interaction effect of harvest stage and variety significantly influenced vine length ($P<0.05$), above ground fresh biomass (AGFB) ($P<0.01$) and leaf number (LN) ($p<0.01$). The highest above ground fresh biomass (AGFBM) (66.12 t/ha) was produced by Guntute variety harvested at 135 DAP followed by 150 DAP (49.34 t/ha) (Table 3). The lowest AGFB (27.41 t/ha) was produced by Tulla variety harvested at 105 DAP. As harvest stage increases from 105 DAP to 150 DAP, AGFB yield was increased up to 135 DAP and decreased then after. This might be due to better growth of plants in terms of plant height and number of vines per plant, which might have resulted due to longer growth period. The present study is in line with the work of Çalişkan *et al.* (2007) who reported that as harvest stage delayed from 90 to 120 DAP,AGFB increased and decreased after 120 DAP in most varieties. Similarly, Etela and Kalio (2011) also reported that AGFB decreased with increasing harvest date 90, 120 to 150 DAP. Vine growth was slow at 30 DAP, fastest at 60 DAP and slowed down at 90 and 120 DAP forming a sigmoid growth curve in most of the varieties(Kathabwalika *et al.*, 2013).Decrease in AGFB as harvest stages delayed is linked to senescence and leaf abscission, death of the whole plants.

The highest vine length (126.1 cm) was recorded by Guntute variety harvested at 135 DAP, followed by those harvested at 120 DAP(125.0cm) and 105 DAP(122.1cm) (Table 3).The shortest vine length (100.9 cm) was recorded by Tulla variety harvested at 150 DAP. As harvest stage delayed vine length decreased at 150 DAP. This result is similar with findings of Ahmed *et al.* (2012) who reported that reduced growth of sweet potato was realized towards 120 and 150 DAP. This might be due to reduced nutrient uptake and ageing of the vines beyond 150 DAP which resulted in reduction of nutrient and dry matter accumulation (Etela and Kalio, 2011). Variety like Guntute, apart from tuber yield benefits obtained from this variety, it can also be used as a good vine source especially where production is aimed at producing vines for animals feed and planting material business especially at off season for its longest vine length.

The highest leaf number per plant (405) was produced by Guntute variety harvested at 120 DAP, followed by Tulla variety (387) harvested at 135 DAP and Kulfo variety (377) harvested at 135 DAP. The lowest leaf number per plant was produced by Tulla variety (322.6) harvested at 150 DAP. Sweet potato continues to branching as long as environmental conditions are favorable which increases leaf number per plant. But the leaves formed earlier in the growing season start to fall and the total number of leaves and leaf area decrease toward end of the growing season (Somda and Kays, 1990). This agrees with our findings which stated that leaf number was reduced at 135 and 150 DAP harvest stages.

Table 3: Interaction effects of harvest stage and variety on average vine length, leaf number and above ground fresh biomass of OFSP at ATARC in 2018

Varieties	Harvest stages	Vine length (cm)	Leaf number	Above ground fresh biomass(t/ha)
Kulfo	Stage 1 (105 DAP)	104.3c	334.9d	33.10de
	Stage 2 (120 DAP)	103.7c	326.1d	39.77cd
	Stage 3 (135 DAP)	105.1c	377.2abc	43.96bc
	Stage 4 (150 DAP)	105.1c	340.3cd	30.34e
Tulla	Stage 1 (105 DAP)	110.0b	346.1bcd	27.41e
	Stage 2 (120 DAP)	112.3b	344.1cd	30.88e
	Stage 3 (135 DAP)	111.0 b	386.5ab	31.23e
	Stage 4 (150 DAP)	100.9c	322.6d	28.48e
Guntute	Stage 1 (105 DAP)	122.1a	346.6bcd	38.80cd
	Stage 2 (120 DAP)	125.0a	405.1a	48.39b
	Stage 3 (135 DAP)	126.1a	345.1cd	66.12a
	Stage 4 (150 DAP)	113.7b	325.1d	49.34b
LSD (0.05)		4.82	40.74	7.34
CV (%)		2.5	6.9	11.1

Means followed by the same letters within same column are not significantly different from each other at 5% level of probability. CV = Coefficient of variations and LSD = Least significant difference

Yield and Yield Components of Sweet potato

Influence of harvest stage on marketable and unmarketable tuberous root number per plant of OFSP variety

The analysis of variance showed that interaction effect of harvest stage and variety highly significantly ($p<0.01$) influenced marketable and unmarketable tuberous root number per plant. Guntute variety harvested at 135 DAP produced the highest marketable tuberous root number per plant (4.57), which was statistically at par with 150 DAP (4.51). The least marketable tuberous root number per plant was recorded by Tulla variety harvested at 105 DAP (1.93) (Table 4). This result is in line with the report of Nath *et al.* (2007) who reported that there was significant increase in marketable tuberous root number per plant till 120 DAP and declined then after up to 180 DAP. Shigwedha (2012) also reported that percentage of large tuberous root number per plant was lower when the sweet potato harvested at 90 DAP, whereas percentage of large tuberous roots number obtained when the crop was harvested at 150 DAP which was much higher than when harvested at 90 and 120 DAP. Chowdhury (2014) pointed out that the number of marketable tuberous root number per plant increased as more time was allowed for tuberous root development before harvest; meaning that at 105 DAP tuberous roots categorized as unmarketable due under sized turned to marketable category as time of harvest delayed, due to tuberous bulking. The differences in marketable tuberous root number per plant could also be attributed to varietal and harvest stage differences. The reduction in the marketable tuberous root number at early harvest stage may be due to the impact of source sink activity of the plant early harvested tuberous roots were immature. The early harvest may leads to minimal partitioning of photo assimilates to the tuberous roots thereby reducing their marketable tuberous root number per plant and increased unmarketable tuberous root numbers which were immature.

Guntute variety harvested at 105 DAP produced the highest unmarketable tuberous root number per plant (1.64). The least unmarketable tuberous root number per plant was recorded by Tulla variety harvested at 105 DAP (0.25), which was statistically at par with Kulfo variety harvested at 105 DAP (0.50), 120 DAP (0.26) and 150 DAP (0.43). More unmarketable tuberous root number per plant was recorded at early harvest stage due to more number of immature tuberous roots, whereas at later harvest stage due to cracking and oversized tuberous roots.

Table 4: Interaction effects of harvest stage and variety on marketable and unmarketable tuberous root number per plant of OFSP at ATARC in 2018

Varieties	Harvest stages	Marketable tuberous root number per plant	Unmarketable tuberous root number per plant
Kulfo	Stage 1 (105 DAP)	2.12e	0.50de
	Stage 2 (120 DAP)	2.57d	0.26ef
	Stage 3 (135 DAP)	3.45b	0.05f
	Stage 4 (150 DAP)	3.37b	0.43de
Tulla	Stage 1 (105 DAP)	1.93e	0.25ef
	Stage 2 (120 DAP)	2.50d	0.26ef
	Stage 3 (135 DAP)	2.77d	0.13f
	Stage 4 (150 DAP)	2.80cd	0.30ef
Guntute	Stage 1 (105 DAP)	2.77d	1.64a
	Stage 2 (120 DAP)	3.17bc	1.03b
	Stage 3 (135 DAP)	4.57a	0.68cd
	Stage 4 (150 DAP)	4.51a	0.94bc
LSD (0.05)		0.38	0.27
CV (%)		7.3	30.0

Means followed by the same letters within same column are not significantly different from each other at 5% level of probability. CV = Coefficient of variations and LSD = Least significant difference.

Influence of harvest stage on total tuberous root number per plant, tuberous root length and tuberous root diameter of OFSP variety

The main effects of harvest stage and variety highly significantly (P<0.01) influenced total tuberous root number per plant, whereas, the interaction effect did not affect total tuberous root number per plant. The highest total tuberous root number per plant was recorded at 150 DAP (4.12), followed by 135 DAP (3.88). The least total tuberous root number per plant was recorded at 105 DAP (3.07) (Table 5). This result is in line with the report of Nath *et al.* (2007) who reported significant increase in total tuberous root number per plant till 120 DAP and thereafter declined up to 180 DAP. Total tuberous root number per plant was also influenced by variety. The highest total tuberous root number per plant was recorded with Guntute variety (4.82) whereas the least was recorded with Tulla variety (2.73) which might be attributed to varietal differences.

The interaction of harvest stage and variety did not significantly influence tuberous root length and diameter. However, these parameters were significantly influenced by the main effects of harvest stage and variety (p<0.01). The highest tuberous root length was recorded at 150 DAP (19.53cm), followed by 135 DAP (18.67cm). The least tuberous root length was recorded at 105 DAP (15.33cm) (Table 5). A significant increase in tuberous root length was observed from 105 DAP to 150 DAP. This shows that tuberous roots gained enough photo assimilates as time of harvest increases .De Albuquerque *et al.* (2016) Reported similar results, stating that the highest tuberous root length (19.70cm) was obtained at 120 DAP. The variety main effect also influenced the tuberous root length. The highest tuberous root length was recorded by Guntute variety (24.58cm) whereas the least was recorded by Kulfo variety (13.75cm) which was statistically at par with Tulla variety (14.43cm). This result is in line with the report of Nath *et al.* (2007) who reported that, tuberous root length was found to be maximum by WBSP-4 variety (15.21 cm) followed by Kamala Sundari

(14.55 cm) and Tripti (14.50cm) varieties. These differences were observed due to varietal differences.

Tuberous root diameter was also influenced by the harvest stage and variety main effects. The highest tuberous root diameter was recorded at 150 DAP (9.35cm) which was statistically at par with 135 DAP(8.77cm) whereas the least tuberous root diameter was recorded at 105 DAP(6.49cm) which was statistically at par with 120 DAP(6.90cm). Nath *et al.* (2007) reported similar trend to this study, that the tuberous diameter showed linear increase up to 150 DAP and then decreased at 150 DAP.

Tuberous root diameter also influenced by variety main effect. The highest tuberous root diameter was recorded by Guntute variety (9.33cm), whereas the least tuberous root diameter was recorded by Kulfo variety (7.43cm) which was statistically at par with Tulla variety (6.88cm).The results of this study were higher than those reported by Queiroga *et al.* (2007), in which three sweet potato varieties (ESAM 1, ESAM 2 and ESAM 3) where tuberous root diameter varied from 4.59 to 5.29cm were observed. According to Nath *et al.* (2007) the varietal differences were reported in tuberous root diameter. The differences observed in tuberous length and diameter among the OFSP varieties could be attributed to varietal differences (Rahman *et al.,* 2013).

Total tuberous root weight per plant was not significantly influenced by the interaction of variety and harvest stage. However, it was influenced by the harvest stage and variety main effects (P<0.01). The highest total tuberous root weight per plant (4.11 kg) was produced at 150 DAP, which was statistically at par with at 135 DAP (3.87kg) (Table 5). This result agrees with what has been reported by Jahan *et al.* (2009) that harvest time had a significant effect on the weight of tuberous roots, with the maximum weight obtained at 150 DAP. Total tuberous root weight per plant was significantly influenced by the varieties main effect. The highest total tuberous weight per plant (4.82 kg) was produced by Guntute variety; whereas the least (2.73 kg) was produced by Tulla variety. There is varietal difference in total tuberous root weight per plant. The maximum weight per plant were obtained at ten months, 1.57kg for 'NP001' variety and 1.98 kg for 'Solomon' variety (Richardson, 2011). Late harvested plants have more time to deposit photo assimilates from vegetative parts to tuberous roots, which resulted in increased root size and weight.

Table 5: Main effects of harvest stage on total tuberous root number per plant, total tuberous root weight per plant, tuberous root length and tuberous root diameter of OFSP variety at ATARC in 2018

Treatment Harvest stages	Total tuberous root number per plant	Total tuberous root weight per plant (kg)	Tuberous root length (cm)	Tuberous root diameter (cm)
Stage 1 (105 DAP)	3.07b	3.06b	15.33c	6.49b
Stage 2 (120 DAP)	3.26b	3.26b	16.83bc	6.90b
Stage 3 (135 DAP)	3.88a	3.87a	18.67ab	8.77a
Stage 4 (150 DAP)	4.12a	4.11a	19.53a	9.35a
LSD	**0.24**	**0.24**	**2.05**	**0.94**
Varieties				
Kulfo	3.19b	3.18b	13.75b	7.43b
Tulla	2.73c	2.73c	14.43b	6.88b
Guntute	4.82a	4.82a	24.58a	9.33a
LSD (0.05)	0.21	0.21	1.77	0.82
CV	6.93	8.19	11.92	12.33

Means followed by the same letters within same column are not significantly different from each other at 5% level of probability. CV = Coefficient of variations and LSD = Least significant difference.

Effects of harvest stage on marketable and unmarketable tuberous root weight per plant of OFSP variety

The result of this experiment revealed that, interaction of variety and harvest stage significantly (p<0.05) influenced marketable and unmarketable tuberous root weight per plant (p<0.01). The highest marketable tuberous root weight per plant (1.85 kg) was produced by Guntute variety harvested at 135 DAP, followed by the same variety harvested at 150 DAP (1.75 kg). The least marketable tuberous root weight per plant (0.82 kg) was recorded by Kulfo variety harvested at 105 DAP, however, it was not significantly different from that harvested at 120 DAP (0.98 kg) (Table 6). Similar with this finding, varieties produced the highest tuberous root weight per plant, from root formation until final harvest, although some reductions were recorded after 120 DAP (Çalişkan *et al.*, 2007). There was a significant increase in marketable tuberous root weight per plant from 90 DAP to 150 DAP (Nath *et al.*, 2007). Marketable tuberous root weight per plant was increased with delays in harvest stage. This might be because plants have enough time to accumulate photo assimilates to roots from above ground parts as the time of harvesting was delayed.

Unmarketable tuberous root weight per plant was significantly influenced by the interaction of variety and harvest stage. The highest unmarketable tuberous root weight per plant (0.90kg) was produced by Guntute variety harvested at 105 DAP. The least unmarketable tuber weight (0.00kg) was recorded by Tulla variety harvested at 150 DAP. In our case the increase of unmarketable tuberous root weight per plant at first harvesting was due to more number of unmarketable tuber numbers as a result of immature tubers.

Table 6: Interaction effects of harvest stage and variety on average marketable and unmarketable tuberous root weight per plant of OFSP at ATARC in 2018

Varieties	Harvest stages	Marketable tuberous root weight per plant (Kg)	Unmarketable tuberous root weight per plant (Kg)
Kulfo	Stage 1 (105 DAP)	0.82ef	0.01e
	Stage 2 (120 DAP)	0.98de	0.01e
	Stage 3 (135 DAP)	1.22bc	0.00e
	Stage 4 (150 DAP)	1.07cd	0.00e
Tulla	Stage 1 (105 DAP)	0.57h	0.01e
	Stage 2 (120 DAP)	0.65gh	0.01e
	Stage 3 (135 DAP)	0.94de	0.00e
	Stage 4 (150 DAP)	0.75fg	0.00e
Guntute	Stage 1 (105 DAP)	1.11cd	0.90a
	Stage 2 (120 DAP)	1.37b	0.81b
	Stage 3 (135 DAP)	1.85a	0.51c
	Stage 4 (150 DAP)	1.75a	0.22d
LSD (0.05)		0.18	0.07
CV (%)		9.5	20.3

Means followed by the same letters within same column are not significantly different from each other at 5% level of probability. CV = Coefficient of variations and LSD = Least significant difference.

Influence of harvest stage on marketable, unmarketable and total tuberous root weight per hectare of OFSP variety

Marketable (P<0.01), unmarketable (P<0.05) and total tuberous root weight per hectare (P<0.01) were significantly influenced by the interaction of variety and harvest stage. The highest marketable tuberous root weight per hectare was produced by Guntute variety harvested at 135 DAP (56.39 t/ha). The least marketable tuberous root weight per hectare was produced by Tulla variety harvested at 105 DAP (15.20 t/ha) (Table 7).This result agrees with the findings of Alcoyº *et al.* (1993) who reported that the highest yield was attained from plants harvested at 120 DAP with a mean yield of 35.49 t/ha, followed by those harvested at 105 DAP (25.30 t/ha) and 90 DAP (17.5 t/ha) in decreasing order. De Albuquerque *et al.* (2016) also found highest marketable tuberous root yield per hectare (17.67t/ha) at 150 DAP. Similarly, early maturity studies showed that the yield of three varieties at 75, 90 and 105 DAP were 13, 23 and 33 t/ha, respectively in increasing order (Vimala and Hariprakash, 2011).Tuberous root yield (12.77 t/ha) was found when the tuberous roots were harvested at 150 DAP while it was 9.0 t/ha at 120 DAP (Islam and Shimu, 2018). Shigwedha (2012) reported that the percentage of large tuberous roots was significantly lower when the crop was harvested at 90 DAP and while the percentage of large tuberous roots obtained when the crop was harvested 150 DAP. Jahan *et al.* (2009) reported the maximum weight obtained at 150 DAP. In line with this tuberous roots were significantly smaller at 90 DAP than 120, 150 and 180DAP (Alvaro *et al.*, 2017).The highest marketable yield were reported at later harvesting (Andrade Júnior *et al.*, 2014).Tuberous root yields were higher at 150 DAP and lower at 90 DAP (Larbi *et al.*, 2007). Alcoy *et al.* (1993) made similar observations from their study that mean tuberous root yield increased as the time of harvest increased from 90, 105 and 120 DAP. The tuberous root bulking continued under favorable conditions, to accumulate photo assimilates in the roots. The marked reduction in marketable tuberous root weights of plants harvested during growth attributed to the suboptimal synthesis and partitioning of photo assimilates to the tuberous roots. At this stage the leaves were not mature enough to prepare photo assimilates to feed tuberous roots (strong sink at later growth stages).

Mean of unmarketable tuberous root weight per hectare were significantly influenced by the interaction of harvest stage and variety. The highest unmarketable tuberous root weight per hectare was produced by Guntute variety harvested at 105 DAP (1.17t/ha) whereas the lowest was produced by Tulla variety harvested at 150 DAP (0.12t/ha). This shows that as harvest date delayed the unmarketable root yield was reduced. The result was did not agree with the previous works reported by Alvaro *et al.* (2017) who reported that unmarketable root yield was increased as harvesting dates delayed from 90 DAP to 180 DAP, this is due to sweet potato weevil damage to tuberous roots at prolonged harvest stage.

The highest total tuberous root weight per hectare was produced by Guntute variety harvested at 135 DAP (56.71 t/ha), followed by at 150 DAP (56.29 t/ha). The least total tuberous root weight per hectare was recorded by Tulla variety harvested at 105 DAP (15.84 t/ha). In line with this results total tuberous root yield increased as the harvest stages were delayed from 90 to 150 DAP (Alvaro *et al*., 2017). The highest total tuberous root yield were reported at later harvest stage (Andrade Júnior *et al.*, 2014).As harvest stage delayed means of total tuber weight per hectare was increased due to the optimal synthesis and partitioning of carbohydrates to the tuberous roots from vegetative parts at later harvest stages.

Table 7; Interaction effects of harvest stage and variety on average marketable, unmarketable and total tuberous root weigh per hectare of OFSP at ATARC in 2018

Varieties	Harvest stages	Marketable tuberous root weight(t/ha)	Unmarketable tuberous root weight (t/ha)	Total tuberous root weight(t/ha)
Kulfo	Stage 1 (105 DAP)	22.65gh	0.63b	23.28fg
	Stage 2 (120 DAP)	25.13fgh	0.43cd	25.56fg
	Stage 3 (135 DAP)	36.33c	0.21ef	36.55c
	Stage 4 (150 DAP)	26.27efg	0.15ef	26.42ef
Tulla	Stage 1 (105 DAP)	15.20i	0.64b	15.84h
	Stage 2 (120 DAP)	20.93h	0.45bcd	21.38g
	Stage 3 (135 DAP)	30.85de	0.29def	31.14de
	Stage 4 (150 DAP)	28.11ef	0.12f	28.23ef
Guntute	Stage 1 (105 DAP)	34.83cd	1.17a	36.00cd
	Stage 2 (120 DAP)	43.04b	0.56bc	43.61b
	Stage 3 (135 DAP)	56.39a	0.32de	56.71a
	Stage 4 (150 DAP)	55.96a	0.33de	56.29a
LSD (0.05)		5.01	0.19	5.031
CV (%)		9.0	25.8	8.9

Means followed by the same letters within same column are not significantly different from each other at 5% level of probability. CV = Coefficient of variations and LSD = Least significant difference.

Effects of harvest stage on commercial harvest index and harvest index of OFSP variety

The interaction of harvest stage and variety significantly influenced commercial harvest index (CHI) and harvest index (HI) (P<0.05). The highest commercial harvest index of 99.6% was significantly produced by Tulla variety harvested at 150 DAP, followed by Kulfo and Guntute varieties harvested at 135 and 150 DAP. The least commercial harvest index was recorded by Tulla variety harvested at 105 DAP (96.0%)(Table 8).
Significantly the highest harvest index (54%) was produced by Guntute variety harvested at 150 DAP, followed by Tulla variety harvested at 135 DAP (50%) and 150 DAP (50%). The least harvest index was recorded by Tulla variety (37%) harvested at 105 DAP (Table 8). Harvest index increased as time of harvest stage delayed. This finding did agree with the finding of Bhagsari and Ashley (1990) who stated that harvest index ranged from 43 to 77% at final harvest 135 DAP and at 105 DAP, the harvest index ranged from 22 to 62%. The harvest index for sweet potato ranged from 1.2% to 56% (Bhagsari and Harmon, 1982). Harvest index (HI) is a measure of partitioning photo assimilates from above ground parts to tuberous roots. The harvest index was proportional to marketable and total fresh tuberous root yield and inversely proportional to total biomass. The highest harvest index of Guntute variety means is high yielder variety compared to other varieties. As harvest stages delayed the increase of harvest index were obtained due to more accumulate of photo assimilates to tuberous roots.

Table 8: Interaction effects of harvest stage and variety on commercial harvest index and harvest index of OFSP at ATARC in 2018

Varieties	Harvest stages	Commercial harvest index (%)	Harvest index (%)
Kulfo	Stage 1 (105 DAP)	97.3ef	41cd
	Stage 2 (120 DAP)	98.3cd	39d
	Stage 3 (135 DAP)	99.4a	45bc
	Stage 4 (150 DAP)	99.4a	47b
Tulla	Stage 1 (105 DAP)	96.0g	37d
	Stage 2 (120 DAP)	97.9de	41cd
	Stage 3 (135 DAP)	99.1ab	50ab
	Stage 4 (150 DAP)	99.6a	50ab
Guntute	Stage 1 (105 DAP)	96.8f	48b
	Stage 2 (120 DAP)	98.7bc	47b
	Stage 3 (135 DAP)	99.4a	46b
	Stage 4 (150 DAP)	99.4a	54a
LSD (0.05)		0.01	0.05
CV (%)		0.4	6.2

Means followed by the same letters within same column are not significantly different from each other at 5% level of probability. CV = Coefficient of variations and LSD = Least significant difference.

CONCLUSION

Sweet potato [*Ipomoea batatas* (L) Lam] is an important food security crop and is widely grown throughout the world including Ethiopia for its multipurpose uses. The vine yield and tuberous root yield of sweet potato are known to be affected by various factors, such as inappropriate agronomic practices, unfavorable climate conditions, sub optimal harvest stage, use of unimproved variety and postharvest handling problems. The field experiment was conducted at Adami Tullu Agricultural Research Center to determine the effect of harvest stage on vine yield and tuberous root yield of orange fleshed sweet potato among factors mentioned above.

Vine yield indicators such as vine number, vine thickness, petiole length, leaf area and leaf area index were not significantly influenced by the interaction of harvest stage and variety. However, vine length, leaf number and above ground fresh biomass were significantly affected by the interaction of harvest stage and variety main effects. Yield and yield components such as total tuberous root number per plant, total tuberous root weight per plant, tuberous root length and tuberous root diameter were not significantly affected by interaction of the harvest stage and variety. However, marketable tuberous root number per plant, unmarketable tuberous root number per plant, unmarketable tuberous root weight per plant, marketable tuberous root weight ton per hectare and total tuberous root weight ton per hectare were significantly influenced by the interaction of harvest stage and variety. Interaction of harvest stage and variety significantly influenced average commercial harvest index and harvest index.

The highest vine length (126.1cm) and above ground fresh biomass (66.12t/ha) were recorded by Guntute variety harvested at 135 DAP, whereas the highest leaf number (405) at 120 DAP by the same variety. Similarly this variety at 135 DAP scored significantly the highest marketable tuberous root number per plant (4.57), whereas the highest unmarketable tuberous root number per plant (1.64) and unmarketable tuber weight per plant (0.90kg) were scored at 105 DAP. The highest average of marketable tuber weight per hectare (56.39 t/ha) and total tuber weight per hectare (56.71t/ha) were recorded with Guntute variety harvested at 135 DAP.

The highest commercial harvest index of 99.6 % was recorded by Tulla variety harvested at 150 DAP, followed by Kulfo and Guntute varieties harvested at 135 and 150 DAP (99.4 %). The highest harvestable index (HI) (54%) was recorded by Guntute variety harvested at 150 DAP.
It can be concluded that most vine yield and tuberous root yield parameters studied were significantly influenced by the interaction effects of harvest stage and variety main effects. This study has revealed that harvesting sweet potato at 105 DAP reduced above ground fresh biomass, tuberous root yield and number of tuberous roots. However, harvesting at 135 DAP gave the highest above ground fresh biomass and tuberous root yield production. In Ethiopia above ground parts of sweet potato used for animal feed and those of tuberous roots are used for human consumption. Considering vine yield and tuberous root yield parameters observed from this study, growers at Adami Tullu area can obtain maximum vine yield and tuberous root yield by growing Guntute variety and harvesting at 135 DAP. Since, present experiment conducted under rainfed condition

with supplementary irrigation, over location, under full irrigation condition was suggested.

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