INFLUENCE OF HARVEST STAGE ON VINE YIELD, TUBEROUS ROOT YIELD ANDQUALITY OF ORANGE FLESHED SWEET POTATO (*Ipomoea batatas* (L) Lam) AT ADAMI TULLU, CENTRAL RIFT VALLEY OF ETHIOPIA

MScTHESIS

BY

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MSc Thesis

Submitted to the School of Graduate Studies, Jimma University College ofAgriculture and Veterinary Medicine, in Partial Fulfillment of the Requirements for the Degree of Master ofScience in Horticulture

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November, 2019

Jimma, Ethiopia

STATEMENT OF AUTHOR

I, Kedir Jaleto, hereby declare that this thesis is a result of my own work and I have duly acknowledged all sources of materials that I used for writing it. This thesis has been submitted in partial fulfillment of the requirements for the MSc degree at Jimma University College of Agriculture and Veterinary Medicine (JUCAVM). The thesis is deposited at the University's library to be made available to borrowers for reference under the rules and regulations of the library. I solemnly declare that; this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate.

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BIOGRAPHICAL SKETCH

The author, Kedir Jaleto, was born from his mother Kabele Birki and his father Jaleto Bento on 23 July 1991 in Ilka chelamo Kebele, Adami Tullu Jiddo Kombolcha Woreda, East Shoa Zone, Oromia National Regional State. He attended Elementary School Education at Abine Gowota Primary School from1997-2004and Secondary School Education at Batu High School andPreparatory from 2005-2008. Thenhe joined Ambo University in 2010 and graduated with Bachelor of Science degree in Horticulture on 20 June, 2012. The authorgot employed as Junior Horticulturistby Ethiopian Horticulture Development Agency (EHDA). After serving for about a year, feeling the need for career change, he resigned his job from the organization and joined Ethiopian Institute of Agricultural Research (EIAR); Mehoni Agricultural Research Center (MeARC) in 2014 as Junior Researcher in Horticulture Case Team, under Crop Core Processes. After serving for two years in the same institution, he joined Jimma University College of Agriculture and Veterinary Medicine (JUCAVM)in 2016 to pursuehis MSc study leading to Master of Science degree inHorticulture.

TABLE OF CONTENTS

Contents Page

TABLE OF CONTENT *(Continued)*

LIST OF TABLES

Tables Pages

LIST OF TABLES IN APPENDIX

Tables **Page**

LIST OF FIGURES IN APPENDIX

Figures Page

ACRONYMS

ATARC	Adami Tullu Agricultural Research Center
DAP	Days after planting
EIAR	Ethiopian Institute of Agricultural Research
HARC	Hawassa Agricultural Research Center
JARC	Jimma Agricultural Research Centre
JUCAVM	Jimma University College of Agriculture and Veterinary Medicine
MARC	Mehoni Agricultural Research Center
MoARD	Ministry of Agriculture and Rural Development
OFSP	Orange Fleshed Sweet Potato
RDA	Recommended Daily Allowance
DMC	Dry Matter Content
SSA	Sub-Saharan Africa
VAD	Vitamin A Deficiency
VITAA	Vitamin A for Africa

ABSTRACT

Sweetpotato (Ipomoea batatas (L) Lam) is food security tuberous rootcrop in Ethiopia and orange fleshed is the cheapestsource of beta-carotene. However, its vine yield, tuberous root yield and quality are low due to various constraints.Inappropriate harvest stageand lack of improved varietyhavebeen identified to be constraints in Central Rift Valley of Ethiopia. Thus, field experiment was conducted atAdami Tullu Agricultural Research Centerin 2018 under rainfed condition with supplementary irrigation to determine the effect of harvest stage on vine yield, tuberous root yield and quality of orange fleshed sweet potato varieties. The experiment consisted of fourharvest stages (105, 120, 135 and 150 days after planting) and three varieties (Kulfo, Tulla and Guntute). A 4 X 3 factorial experiment arranged in randomized complete block designwith three replications was used. Data on vine yield, tuberous root yield and tuberous root quality werecollected and subjected to analysis of variance using SAS version 9.3. The analysis of variance revealed that the interactionof harvest stage and varietysignificantly influenced (P<0.01) leaf number (LN), above ground fresh biomass (AGFB), marketable tuberousroot number per plant (MTNPP), marketable tuberousroot weight (MTWPP),tuberousroot dry matter content (TDMC) and vine length (VL), marketable tuberousroot weight per plant (MTWPP), unmarketable tuberousroot weight (UMTW), Commercial harvest index (CHI), harvest index (HI) and ash content(P<0.05). Leaf area (LA), leaf area index (LAI), tuberousroot length (TL), tuberousroot diameter (TD), vine dry matter content (VDMC) and leaf dry matter content (LDMC) were significantly affectedby the main effects of harvest stageand variety(P<0.01). The highest mean values of UMTWPP (0.90 kg), UMTW(1.17t/ha) & ash (5.72 %)werescored byGuntute variety harvested at 105 DAP andAGFB (66.12 t/ha), MTW (56.39 t/ha) and TTW (56.71 t/ha)were produced by the same variety harvested at 135 DAP.The highest mean value of tuber dry weight (29.70%) and crude fiber (8.16 %) were produced byKulfo varietyharvested at 150 DAP.Farmers of the study area and areas having similar agro-ecologies can grow Guntute variety harvested at 135 DAP can be recommended to obtain best vine and tuberous yields. Since the present study was conducted under rainfed with supplementary irrigation, over locationunder irrigated condition wassuggested.

Key Words: tuberous root, flour, beta carotene, photo assimilates, shoot

1. INTRODUCTION

Sweetpotato (*Ipomoea batatas* (L) Lam) belongs to the family Convolvulaceae. It is originated in central America or tropical south America and globally the seventh most important food security tuberous root crop after wheat, rice, maize, potato, barley, and cassava(Lebot, 2009; Ahn *et al*., 2010; Wang *et al*., 2011; Daniel and Gobaze, 2016). It is food security crop for humans in many developing countries (Van Jaarsveld *et al*., 2005). Adaptability in wider agro-ecologies, ability to grow in drought prone areas 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).

In Ethiopia over 95% of the crop is produced in Eastern, Southern and Southwestern parts of the country for human consumption and animal feed(Terefe, 2003). In Ethiopia about53,449hectares of land was cultivated and it takes the second position, next to potatoamong root crops with 34.6 t/ha tuberous root yield (CSA, 2018). In Oromia region, it was cultivated at about 16,796 hectares and takes secondnext to potato among rootcrops grown in the region (CSA, 2018). About 1035529.5 ton yields were produced per year,making it first among tuber and root crops with 62 t/ha, which also makes it first ranking among all cropsyield in the region(CSA, 2018). Orange fleshed varietieshave been popularized in Ethiopiato eliminate micronutrient deficiencies, VAD (vitamin A deficiency) and malnutritionproblems(Tofu *et al*., 2007; Kidane *et al*., 2013; Fekadu*et al*., 2015). These varietieshave not been tested with different harvest stage in Ethiopia.

Sweetpotato is widely grown in Ethiopia with an average national tuberous root yield 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 is lower than 6 to 8 t/ha (Daniel and Gobeze, 2016). Teshome and Amenti (2010) reported that average yield of 37.1 t/ha obtained for the Belela variety at Adami Tullu area without application of fertilizer. This indicates that national as well as regional yield is lower than attainable yieldat research station. The result obtained from Melkassa Agricultural Research Center showed that Kudadie variety produced the highest total tuberous root yield (138.7 t/ha)(Terefe, 2003). Total storage 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 Desalegn*et al*. (2015)mean marketable yield varied from 4.6 t/ha for Kulfo variety to 111.06 t/ha for local varietyat 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). Sweetpotatoes 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, tuberous root yield and quality of tuberous root. It varies among varieties, environmental conditions and market demand. Sweet potatois commonly harvested 150 DAP, but there is variability in maturity stages among varieties (Alvaro *et al*., 2017).Harvesting vines at 105 DAPgave optimum production of above ground fresh biomass without reducing yield of tuberous roots(Ahmed *et al*., 2012). Alvaro *et al*. (2017) concluded that the dry matter increases with increasing stage of maturity at harvest. 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 doneat Adami Tullu Agricultural Research Center. However, basic information on how vine yield tuberous root yield and quality 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, this study was conducted with the followingobjectives:

General objective

- To assess the influence of harvest stageon vine yield, tuberous root yield and quality of orange fleshed sweet potato at Adami Tullu condition

Specific objectives

- To determine the proper harvest stagefor optimum vine yield, tuberous root yield and qualityof selected orange fleshed sweet potato varieties
- To determine interaction effect of harvest stage and varietyon vine yield, tuberous root and quality of selected orange fleshed sweet potato varieties

2. LITERATURE REVIEW

2.1. Origin, Taxonomy and Distribution of SweetPotato

Sweetpotato(*Ipomoea batatas*(L)Lam) is herbaceous dicotyledonous plant with creeping vines and adventitious roots whichbelongs to the family*Convolvulaceae*(Purseglove, 1972). It is originated from central America specifically in Mexico which is a centre of origin and diversity of *Ipomoea batatas*(Martin and Jones, 1972; Nishiyama *et al*., 1975). It is widely distributed throughout the tropics and warm temperate regions of the world between latitudes 40^{o}N and 40^{o}S of the equator and between sea level from to 2300 m altitude(Jana, 1982).

It has chromosome number of 2n = 90 and since the basic chromosome number for the genus *Ipomoea* is 15, it is hexaploid and highly heterozygous cross pollinated crop. Most varieties are self-incompatible and they cannot produce viable seed.Itis also a branching,creeping vine with spirally arranged lobed, heart shaped leaves and white or lavender flowers depending on varieties.Enlarged roots called tuberous roots which stored energy for the plant and an economic part of the plant. Vines can reach 4 m to 6m in length depending on varieties, environmental conditions and agronomic practices. The skin and flesh colour may vary from variety to variety and the colourswhite, cream,yellow, orange, pink, or deep purple. White/cream and yellow/orange flesh colours aremostcommon. Tuberous root can be shaped like a potato, being short and blocky withrounded ends, while other times it can be longer with tapered ends depending on varieties and sandy soil on which grown. Intensity of the tuberous root flesh color like yellow or orange flesh is directly correlated with its beta-carotene content (Dincer, 2011).

2.2. Production Status of SweetPotato in the World

Globally sweet potato is the seventh most important food security crop (Lebot, 2009; Ahn *et al*., 2010; FAO, 214; Markos and Loha, 2016). It was food security crop for humans in many developing countries (Van Jaarsveld *et al*., 2005). Wider adaptability to various agro ecologies, ability to grow in drought prone area, higher productivity in short durations and beta carotene content of orange fleshed sweet potato varieties are special attributes of sweet potato in contrast to the other staple food crops (Trancoso-Reyes *et al*., 2016). Sweet potato production was reported to be 112.8 million tons (in 115 countries) in 2017, and China is the leading producer, followed by Sub-Saharan countries (FAOSTAT, 2019).

Asia (75.1%), Africa (20.8%), America (3.3%), Oceania (0.08%) and Europe (0.1%) are the regions shared production of sweet potato from 2007 to 2017 (FAOSTAT, 2019). The world average productivity of tuberous root yield has been estimated to be 14.8 t/ha (FAO, 2014).

In Africa it is secondimportant tuberousroot crop after cassava which is concentrated inNigeria, Uganda, Tanzania and Ethiopiafor its high yield potential and adaptability to a wide range of environmental conditions(Wang *et al.*, 2011). Africanfarmers produce about 9.1 million tons annually and most of the crop iscultivated for human consumption (Belehu, 2003). In Africa the crop is grown on small scale, primarily to ensure food security of therural households (Ewell and Mutuura, 1991; Sanginga and Mbabu, 2015).

In Ethiopia it is economically important food crop after Ensete (Tsegaye *et al*., 2006; Tofu *et al.*, 2007). About 53,449hectares of land were cultivated in Ethiopia and sweet potato ranked the second next topotato among root crops grown (CSA, 2018).

2.3. Importance of Orange Fleshed SweetPotato

According to Food and Agricultural Organization (FAO, 2014) there were 805million chronically undernourished people.Globally, 163 million children under 5 years of age suffer from vitamin A deficiency and among themhighest prevalence rates found in Sub-saharan Africa and south Asia (Sanginga and Mbabu, 2015). Most varieties in Sub-saharan Africa are white fleshed, low yielding and low or zero beta carotene. Vitamin A was foundto be important for pregnant women, lactating women and children and orange fleshed varieties are source of vitamin A,lacking in diets of African peoples(Van Jaarsveld *et al*., 2006).. Use of OFSPintroduced along with nutrition and education at the community level is cost effective strategy for providing vitamin A tovulnerable populations such as young children, pregnant and lactating women(Van Jaarsveld *et al*., 2006).

Vitamin A deficiencyis a serious public health problem in Ethiopian children and pregnant & lactating mothers (Kassaye *et al*., 2001; Tofu *et al*., 2007;Demissie *et al.*, 2010). Food based intervention has been proposed in Ethiopia to control VADas the long term option and to shift from a subsidized periodiccapsule distributionto OFSP (Kidane *et al.*, 2013).OFSP is naturally biofortified crop and used in food based intervention programs to address VAD. Animal and other horticultural cropslike vitamin A richfoods are unpalatable to young children and often expensive. Therefore, OFSP is a promising solution to combat VAD, substantially better absorbed than others leaves and vegetables for its easy digestion, easy to grow and affordable to resource poor communities(Jalal *et al.*, 1998). Result indicated that, bread enriched with 30% OFSP flour cancontribute 83.3% and 74.2% of VA to 1 to 3 and 4 to 6 years old children's daily requirement,respectively,(Kidane *et al.*, 2013).

In Ethiopia farmers in southern area are familiar with OFSP. Survey resultindicated that, in Sidama 78.3%, Wolayta 83.1% and Gamo Gofa 67.7% of the respondentswere familiar with OFSP (Fekadu*et al.*, 2015). OFSP varieties have low dry mattercompared to white fleshed varieties and preferable for its vitamin A content to improve humanregular growth, development, improved eyesight, metabolic functions and aneffective immune system (Burri, 2011).

In Ethiopia sweetpotato is traditionally processed into bread, enjera, flourand cookies, wot (stew), local beer, starch, sugars and juice. These would reduce the postharvest losses of the crop related to its short shelf life and quality of the storage roots. It serves as a main source of carbohydrate,protein, vitamin A, B_1, B_2, C, minerals such as K, Na, P and Ca (Magagula *et al*., 2010). Young leaves are rich in protein, most vitamins and minerals that is why it is used as vegetable in some localities, whereas the stem and leaves used for animal feed and tuberous roots for human food. Theyare well known as a source of carbohydrate 25% - 30 %, protein 1.6% - 2.0 %, fat 0.7 % and1.0 % ash.Fresh tuberous roots contain 60-70 % water, 15-25 % starch, 1-2% proteins and 1-2 % sugar (CIP, 2007).

2.4. SweetPotato Production and Use in Ethiopia

Sweet potato is cultivated in Ethiopia mostly for human consumption and animal feed. It ranks secondin area coverage after potato (*Solanum tuberosum*L.) among the important root crops produced in the country. It is manly grown by small scale,resource poor farmers. Even though, there are favorable agro ecological conditions, like good climaticsweet potatoyields in Ethiopia arelow.

Ethiopia has three climatic zones according to elevation. Tropicalzone is hot and humid, below 1830 m.a.s.l and has an average annual temperature of 27 ^{o}C with annual rainfall of about 510 mm. Subtropical zone is warm, and includesthe highland areas of 1830 to 2440 m.a.s.l and has an average annual temperature of about 16 ^{o}Cand annual rainfall between 1270 and 1280 mm. The third iswhose altitude is 2440-3200 m.a.s.l and average temperature of 0-16 ^{o}C(Terefe, 2003). In Ethiopia the dry season prevails from October to May whereas the rainy season is bimodal, the short and the long rain seasons. The short rain season is from February to April, whilethe long rainy season extends from June to September (Terefe, 2003).Sweetpotato is adapted to tropical zone and subtropical zone area ofEastern, Southern, and South-western parts of the country.

In Ethiopia tuberous roots are boiled unpeeled or roasted unpeeled in the ash of a fire before being eaten.The above ground parts such as leaves,stalks and stems have a high nutritive value that is why widely used as animal feed. Growing of sweet potato in Ethiopia is faced with a number of problems. Among them drought, high temperature at low altitude and lack of adaptedcultivars, lack of sufficient quantity of good quality planting materials especially during dry season, sub-optimal plantpopulation, careless harvesting, poor post-harvesthandling, and lack of crop rotation are some of the factors that contribute to poor cropestablishment and low yield (Terefe, 2003).

2.5. Growing Condition and Cultural Requirement of SweetPotato

Sweetpotato is widely grown between latitude 40^{o}N and 40^{o}S, and altitude 2500m.a.s.l. at the equator(Hahn and Hozyo, 1984). In the tropics, yields decline with increasingaltitudedue to temperature difference (Ngeve *et al.*, 1992). It grows best where average temperature is 24^{o}C(Root, 2010) and at a temperature below 10^{o}C, growth is severely retarded and inhibit tuberization. The cultivation in the temperature region is restricted to area with a minimumfrost-free period of 4 to 6 months because of frost damage.Due to sun loving nature, sweet potato adapts best where the light intensity is relatively high. Daylength affects both flowering and tuberous root formation process. In Ethiopia, sweet potato is largely produced in mid and lower altitudes where the altitude is less than 2000 m.a.s.l and optimum range of 1500-1800 m.a.s.l (Terefe, 2003).

It grows best on sandy loam soils and does poorly on clay soils, since the crop cannot withstand water logging that restricts tuberous root bulking. To solve this problem in localities where the water table is high, thecrop is planted on ridges for better water drainage. Soil with poor aeration tends to retard tuberous root formation and result in reduced yield(Mukherjee *et al.*, 2006) and wet soil condition at harvest alsoadversely affected yield storage life, nutrition and baking quality (Nedunchezhiyan and Ray, 2010). Sweet potato grown well on soils with pH of 5.6 to 6.6. It is sensitive toalkaline or saline conditions.It isadaptive to poor soils and well suited to sandy soils that are often infertile.

Storageroot yields are sometimes depressed under in heavily fertilized soils since vegetative growth is enhanced in heavy fertilized condition.

Sweetpotato has a high requirement for potassium relative tonitrogen and phosphorusfor tuberous root development. Various research results indicated that application of N increasing The tuberous root yield(George and Mitra, 2001), however, high amount of Napplication encourages vine growth which decreases tuberization at later crop stages. A moderate dose of50 to 75 kg N/hais optimum for root production(Nair *et al.*, 1996).Sweet potato response to phosphorus is very low and a dose of 25-50kg P_2O_5/ha is optimum(Akinrinde, 2006) and potassium is also a major key element essential for sweetpotatoproduction (Byju and Nedunchezhiyan, 2004). A moderate dose of 75-100kg K_2O wasrecommended (Mukhopadhyay *et al.*, 1990). In Ethiopia response of sweet potato varieties to different fertilizers has not beenclearly established and the crop is often not paying to cover the costs of fertilizers(Terefe, 2003).

In sweet potato farms weeds are a problem only during the first two months of growth and then after vigorousgrowth of the vines cause rapid and effective coverage of the ground. During the above ground covers the surface it smoothenthe weeds and prevent the light no to reach weeds in order to prepare photo assimilates. Therefore, farmers donot worry to weed damage and saves cost of production. Nedunchezhiyan and Satapathy (2002)reportedthat weed competition set at early for water and nutrient due toinitial slow growth of the crop. In Ethiopian condition weeds are not a serious problemand controlled easily by hand weeding specially during first growing weeks. The crop has few pests and diseases, why pesticides are rarely used. Sweetpotatomosaic is a serious virus disease of Sweetpotato in the USA and becoming increasinglyserious in Africa.Sweet potato weevil and sweet potato butterfly were major insect pests of sweet potato in Ethiopia.

Yellowing of the leaves, cracking of the soil and calendar count indicate readiness of the crop for harvesting. In other instancesthere is no extremely visible sign of readiness for harvesting and if harvesting is done too early,yields are low due to the tubers are not fully developed, but if the crop is left in the ground too long, the storage roots becomes fibrous,unpalatable and are prone to attack by sweet potato weevil and various rots(Kakaty *et al.*, 1992).All the tuberous roots on a given plant do not reach maturity at the same time,so that harvesting is done at a time when a reasonable number of tuberous roots are mature.This could be determined by harvesting a few representative plants and judging whether ornot the entire field is ready for harvesting or not(Indira and Lakshmi, 1984).

2.6. SweetPotato Production Constraints

Production of sweetpotato is constrained by biotic and abiotic factors. Thebiotic factors include diseases, insect pests and weeds; whereas abiotic factors are drought,heat and low soil fertility (Ndunguru *et al.*, 2009).Constraints related to socio-economic and quality attributes are: lack ofimproved varieties, lack of planting materials, low storage root yield, low or zero beta carotene contentin white fleshed sweet potato and low storage root dry matter content of OFSP which are available currently. Inadequate supplyof improved varieties among the farmers, less adoption rate of improved agronomic practicesand insect pest damage causes low productivity in sweet potatoes production (Daniel and Gobeze, 2016). The major postharvest constraints among farmers were: poor prices, low yields, low dry matter content of tuberous roots, lack of knowledge about tuberous roots processing and preservation (Fekadu*et al*.,2015). Daniel and Gobeze (2016) reported that, sweet potato crop has apotential giving about 50 to 60 t/ha root yield in Ethiopia.

2.7. Influence of Variety on Yield and Quality of Sweet Potato

Orange fleshed sweet potato varieties havehigh nutrient value mainly beta carotene a precursor of vitamin A. InNorth Ethiopia OFSP were used in food based intervention andresult indicated that, bread enriched with 30% OFSP flour can contribute 83.3% and74.2% of vitamin A to 1-3 and 4-6 years old children's daily requirement respectively(Kidane *etal*., 2013). General trend showed that moisture, ash, fiber, beta carotene increased as proportion of OFSP flour increased; while protein, fat, carbohydrate and energy contentdecreased. Orange fleshed sweet potato flour enriched breads have nutritional advantages (Kidane *et al*., 2013). Tumwegamire *et al.* (2011) reported that, selected East African white and OFSP varieties were evaluated for tuberous root dry matter,nutrient content and farmer varieties had higherdry matter, higher starch and lower sucrose contents than the control clone introducedResisto variety. For the OFSP control (Resisto): beta carotene content of 27.1 mg/100gdry weight basis was reported.In Bangladesh, different OFSP varieties indicated that highest tuber rootyields (31.59 t/ha) were found in CIP 194513.15 variety and the lowest yield (13.34 t/ha) were reported in BARI SP 3 variety. The maximum drymatter (29.83%) was recorded in H6/07 while the minimum dry matter (17.61%) wasobtained in CIP 441132 variety. Among the tested varieties the highest Vitamin A (919.2 µg/100 gRAE) fresh weight basis were recorded in CIP 440267.2 varieties and recommended in Bangladesh on thebasis of yield and quality mainly of carotene contents (Rahman *et al*., 2013).

Wide variability in tuberous root yield among varieties and among individualplants of the same varieties has been influenced by varieties, environment and soil factors. Genetic, climatic and edaphic factors influences leafproduction &abscission, leaf area, leaf photosynthetic rate, tuberous root formation & development and total dry matter production & dry matter partitioning determine sweet potatoyield(Lowe and Wilson, 1975). Vitamins A and B are present in significant amounts and the tuberous are richin Vitamin C(Rose and Vasanthakaalam, 2011). Sweetpotatoes skin may be white, yellow, orange, red or purple. The tuberous roots may have red color due to anthocyanin pigmentcontent (Salunkhe and Kadam, 1998). Variety selection, mineralnutrients, plant population, moisture stress, soil moisture and rainfall, pest management, harvestingtime, harvesting method, spacing and storing are major factors that affect sweet potato quality(Amajor *et al*., 2011).

Dry matter content related to thestate of juvenility age of the mother plants(Williams *et al.*, 1995). Matureplants have higher dry matter than young plants. Nitrogen and potassium applicationcould have induced delayed senescence of mother plants, leading to a decline in dry matter ofleaves and stems(Burns, 1992). This may also be associated with the influence of thesenutrients on cytokinin and other phytohormonal activities which have direct influence onplant growth and dry matter accumulation.

2.8. Effect of Variety on Yield and Yield Contributing Parameters

2.8.1. Effects of orange fleshed varieties on tuberous root number per plant

Study conducted at JUCAVM on five OFSP varieties: namely Beletech, Birtukanie, Kulfo, Tulla and a local variety, at field condition showed that number of tuberous roots per plant wasnone significant difference among the five varieties tested. The highest mean number of tuberous roots per plant (6.27) was recorded byTullavariety similar to the other yield and yield contributing parameters significantly differing among the varieties. On the other hand the lowest mean number of tuberous roots per plant (4.88) and (4.80) were obtained in Local variety and Kulfo variety respectively compared to the other orange fleshed varieties evaluated (Bezawit*et al*., 2015). The highest mean number of tuberous roots per plant was about 5.13 in variety CIP 440267.2 in one study and in another similar study the number of storage roots per plant varied from 1.73-6.03 among the varieties studied (Rahman *et al*., 2013).. The accession F2M5/3 produced the highest number of tuberous roots per plant (6.7) while the accession ELINDA produced the lowest number of 1.7 tubers per plant(Namo *et al*., 2017). The differences in number of tuberous roots per plant could be attributed to genotypic differences.

2.8.2. Effects of orange fleshed varieties on tuberous root diameter

Rahman *et al*. (2013) reported that the highest tuberous root diameter was observed in the varietyH19/06 (6.92 cm). Bezawit*et al*. (2015)pointedout that tuberous root diameter was highly significantly (P<0.01) affected by variety and showed significant differences among the five varieties evaluated. The highest mean value in tuberous root diameter (4.90 cm) was recorded in Tulla variety while the lowest mean value (3.39 cm) was recorded in the Local variety compared to the remaining OFSP varieties. Rahman *et al*.(2013), concluded that variety, H19/06 gave significantly the highest tuberous root diameter (6.92 cm) compared to the other varieties included in their study.

2.8.3.Effects of orange fleshed varieties on marketable yield

According to Rahman *et al*. (2013) the maximum marketable yield (27.85 t/ha) was recorded by variety CIP 194513.15.Bezawit*et al*. (2015)concluded that significant (P<0.05) differences occurred in marketable storage root yield. The highest mean value of marketable storage root yield (0.78 t/ha) was recorded from Tulla variety. The lowest mean value of marketable tuberous root yield (0.35 t/ha) was recorded from Local variety compared to the remaining two OFSP varieties Beletech and Kulfo. Omiat*et al*.(2005) obtained the highest marketable tuberous root yield from variety Ejumula but the lowest marketable tuberous root yield from variety Arivumaku. Varietal effect had a significant influence on the marketable weight, Ejumula had the highest weight of marketable tuberous roots(Omiat *et al*., 2005). According to Desalegn*et al*. (2015) report, mean marketable yield varied from 4.6 t/ha for kulfo variety to 111.06 t/ha for local cultivar.

2.8.4. Effects of orange fleshed varieties on unmarketable yield

According to (Rahman *et al*.,2013) the unmarketable yield (3.74 t/ha) was recorded by variety CIP 194513.15. Unmarketable tuberousroot yield was none significantly different among the OFSP varieties, the highest unmarketable tuberous root yield (0.11 t/ha) was recorded in Tulla variety. On the other hand, the lowest unmarketable storage root yield (0.06 t/ha) was recorded in Kulfo variety which is also not significantly different from Local Variety already grown by the local farmers in the study area(Bezawit*et al*., 2015).

2.8.5. Effects of orange fleshedvarieties on total yield

According to *Rahman et al.* (2013) the maximum total yield (31.59 t/ha) was recorded by variety CIP 194513.15.The highest total storage root yield (0.88 t/ha)was recorded in Tulla variety followed by Birtukanie and Beletechvarietieswhich were none significantly different from each other. However, the lowest total tuberous rootyield (0.61 t/ha) was recorded in Kulfo variety which is also not significantly different fromtotal tuberous root yield (0.47 t/ha) obtained from Local variety already grown by the localfarmers, implying that Kulfo variety was probably the poorest in total tuberous root yieldamong the newly introduced four OFSP varieties. Ejumula had the highest total yield(8.75 t/ha), followed by Kakamega and Kala with 8.61 t/ha and 8.21 t/ha respectively. The lowest total yields were from Arivumaku, followed by 4-4, implying that Arivumaku was probably the poorest yielding of the varieties tested in this agro ecological zone(Omiat *et al*., 2005).

2.9. Influenceof harvest stage on vine yield productionof orange fleshed Sweetpotato varieties

2.9.1. Influence of harvest stage on petiole length per plant of orange fleshed Sweetpotato varieties

Variety MD harvested at 80 DAP, produced leaves with the longest petiole length per plant (7.2cm) and at 120 DAP, the longest petiole length per plant (7.8cm) was produced by the same variety (Namo*et al*., 2017). Different varieties produced different petiole length per plant due to their varietal differences (Tewe*et al*., 2003). Varieties with erect leaves and long petiole per plant are better placed to capture photosynthetically active radiation than those with short petiole length per plant. During the early stages of development, petiole length per plant was at its minimum. Toward the middle and the latter part of the growing season, petiole length per plant on primary branches increased substantially at all plant densities, but increased minimally or not at all on secondary branches. On an individual branch basis, petioles found at the apex were still elongating, while those at the middle portion were at maximal length. Occasionally, a short petiole was found within a series of long petiole per plant (Somada and Kays 1990).

2.9.2. Influence of harvest stageon vine length per plantof orange fleshed Sweetpotato varieties

Variety F1M4/11 harvested at 80 DAP, produced the longest vine length per plant (119.4cm) and at 120 DAP, the longest vine length per plant was also produced by the same variety (185.2cm). Shortest vine per plant was produced by variety TIS.87/0087/08 (44.2 cm) (Namo *et al*., 2017).Ahmed *et al*. (2012) reported thatreduced growth of sweetpotatoes is realized towards 120 and 150 DAP, 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). Vine length increased rapidly until 85 DAP after that increased slowly till at 125 DAP and vine length differ from 220.17-264.43cm due to their varietal differences(Rahman *et al*., 2015).Varieties having longest vine length per plant, used as forage for animal feed.

2.9.3. Influence of harvest stage on leaf area per plant of orange fleshed Sweetpotato varieties

Leaf area decreased between 90 and 154 DAP (Ferreira *et al*., 2019).Leaf area on the age of 45 DAP ranged from 408.75cm^2 to 1118.81cm^2 and at 90 DAP it ranged from 5948.83cm^2 to 12419.25cm^2 (Akbar*et al*., 2017). Conceição*et al*. (2005) state the emergence of tuberous roots, great potential to mobilize assimilates accelerates leaf senescence and reduces leaf area. Leaf area becomes a parameter that is directly related to the plant growth parameters. LA had increasing values after 154 DAP, due to the resume in plant growth and the restructuring of its photosynthetic organ, the leaves(Ferreira *et al*.,2019).Leaf area increased steadily 56 DAP and the total leaf area per plant increased progressively until the 120 DAP, the rate of which depended on plant density. The major increase and differences in total leaf area per plant occurred from 30 to 120 DAP (Somada and Kays 1990). The largest proportion of increase in the leaf area per plant, regardless of plant densities, resulted from leaves formed on primary and secondary branches. The average total leaf area on primary branches per plant increased with time until 90 DAP and subsequent changes until final harvest(Somada and Kays 1990).Leaf area determines the amount of light the plant intercepts, in carbon fixation, in water loss and even in ecosystem productivity.

2.9.4. Influence of harvest stage on leaf area index per plant of orange fleshed Sweetpotato varieties

Leaf area index at 45 DAP ranged between 1.2 and 3.62, at 90 DAP between 4.40 and 7.23 and at 120 DAP between 3.15 and 4.67 per plant(Akbar*et al*., 2017). Leaf area index was increased with time up to 90 DAP and thereafter decreased in all varieties (Namo *et al*., 2017). The highest leaf area index (1.28) was produced by variety SOLO – 1/144 harvested at 45 DAP. At 90 DAP the highest leaf area index (2.23) was produced by the same variety. At 120 DAP, the highest leaf area index (1.05) was produced by variety KWARA/00 (Namo *et al*., 2017). Differences in leaf area index attributed to the high number of leaves in plants and leaf area. Varieties with a large leaf area index can trap more light (Kareem, 2013). This could also help the crop to smother weeds which may affect crop growth and yield. Leaf area index is influenced by varieties of different morphological characters, especially the shape and size of the leaves (Tsialtas*et al*., 2008). Produced leaf area indexat 60 DAP, ranging between 1.64 and 3.49 , during the 90 DAP from 4.40-7.23and at 120 DAP, between 3.15 and 4.67(Widaryanto, 2017)..

2.9.5. Influence of harvest stage on leaf number per plant of orange fleshed Sweetpotato varieties

Leaf number per plant depends primarily on the number branches, rate of growth, and leaf losses (Somda and Kays, 1990). Leaf loss appeared to maintain a more or less stable leaf density from mid-season until harvest (126 days) and sweet potato continues to branching, 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 number per plant decrease as harvest of stage delayed(Somda and Kays, 1990).According to Otoo*et al*. (2001) leaf number per plant was reduced due to sequential senescence, which occurred as they reached a certain sage and this stage varied from 60 to 90 DAP (Ray and Tomlins, 2010).

2.9.6. Influence of harvest stage on above ground fresh biomass yieldof orange fleshed Sweetpotato varieties

Favorable environmental conditions favor branchingin sweet potato(Somda and Kays, 1990). Leaves formed at earlier in the growing season start to fall and the total number of leaves and leaf area decrease toward to the end of the growing season due to aging and senescence, this condition leads to reduction of above ground fresh biomass as crop delayed beyond maturity stage. Etela and Kailo (2011) reported that above ground fresh biomass yields decreased with increasing harvestingdate from 90, 120 to 150 DAP.Çalişkan *et al*. (2007)recorded rapid above ground fresh biomass growth until the 90 or 120 DAP and decreased after 120 DAP, whereas above ground fresh biomass growth increased until final harvest for some varieties in some location depending on varieties used.Etela and Kalio (2011)reported that above ground fresh biomass yields decreased with increasing harvestingdate 90, 120to 150 DAP due to reverse allocation of photo assimilate from tuberous roots to shoots.Above ground fresh biomass yield ranged between 23.8 t/ha and 56.7 t/ha at 90 DAP, while it ranged between 52.4 t/ha and 143.7 t/ha at 110 DAP (Ali *et al*, 2016).The above ground fresh biomass obtained from plants whose vines were harvested 105 DAP was greater than those obtained from plants in the other three treatments by 36, 15 and 12%, respectively(Ahmed *et al*., 2012).Thus, when vine harvesting was done at 105 DAP, the accumulated photo assimilates may have been partitioned to the shoots for enhanced regeneration of new leaves, thereby resulting in a superior above ground fresh biomass at 105 DAP(Ahmed *et al*., 2012). Lebot (2009) recommended that vines should be harvested late (90 to 120 DAP) after the tuberous cells in the tuberous roots have developed and accumulated sufficient photo assimilates in order to avoid suppression in growth and development of tuberous roots.

2.10. Influenceof harvest stages on tuberous root yield, yield components and qualityof orange fleshed sweetpotato varieties

2.10.1. Influence of harvest stage on tuberous root length and diameter

De Albuquerque *et al*. (2016)reportedthe highest tuberous length (19.70 cm) at 120 DAP. At second growing season he also reported that an increasing linear correlation with respect to harvesting stage for tuberous length, reaching 15.27 cm at 150 DAP. He also found the highest tuber diameter at the 150 DAP, reaching 6.38 cm.Queiroga *et al*. (2007) reported that in which three sweetpotato varieties (ESAM 1, ESAM 2 and ESAM 3) where tuberous root diameter varying from 4.59 to 5.29 cm. Higher tuberous root length and diameter at later harvesting stages due to accumulation of photo assimilate to tuberous roots from shoots. Varieties, SOLO – 1/144 (22.4cm), TIS. 87/0087/08 (19.1cm), F1M1/4 (17.8cm), A121B (17.3cm),F2M5/3 (17.3cm), SOLO-1/100 (17.1cm), F1M4/11 (16.6cm), Ng-Jay (16.2cm) and SOUL (16.1cm) produced tuberous rootswhich were statistically at par in tuberous root length, whereas variety, ELINDA, produced the lowest tuberousroot length of 11.9 cm(Namo *et al*., 2017). The highest tuberous root diameter of 17.9 cm was observed in the variety, Ng – Jay and the lowest tuberous root diameter of 10.4 cm was observed in the variety F1M4/11 (10.7cm) (Namo *et al*., 2017).

2.10.2. Influence of harvest stages on tuberous root yields

There are no visible signs of readiness for harvesting unless yellowing of the leaves and cracking of the soil may indicate the sweet potato readiness for harvesting in addition to calendar count. If harvesting is done too early, yields are low due to short time for tuberization, but if the crop is left in the ground too long, the tuberous roots become fibrous, unpalatable, and are prone to attack by the sweetpotato weevil and cracking of the tuberous roots that reduces market value of the tuberous roots (Woolfe, 1992). Harvesting is done at a time when a reasonable tuberous root number are mature. All tuberous roots on a given plant do not mature due to earthing-up of vines and tuberous roots formed on the vines at their nodes; hence, disparity in maturity between the tuberous roots is greater. Alcoyº *et al.* (1993)reported the highest yield (35.49 t/ha) was recorded at 120 DAP 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)recorded the greater marketable tuberous root yields 17.67 t/ha at 150 DAP. He also observed that all varieties showed an increasing linear response with respect to harvesting stage for all yield and yield components. At 75 DAP, the yield of three varieties ranged from 12-14 t/ha, at 90 DAP, 20–26 t/ha and at 105 DAP, 33t/ha was recorded(Vimala and Hariprakash, 2011).Tuberous roots 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 thepercentage of large tuberous roots obtained when the crop washarvested at150 DAP was highest than at 90 and 120 DAP. Jahan *et al*. (2009)reported the maximum tuberous roots weight at150 DAP. Late harvested crops have more timeto deposit photo assimilates from leaves to roots than earlier harvesting, which resulted inincreased tuberous root size and weight.Tuberous roots were significantly smaller at 90 DAP than 120, 150 and 180DAP(Alvaro *et al*., 2017). Alcoy *et al*. (1993) reported that tuberous roots yield increased as the time of harvest increased from 90, 105 to120 DAP with the 105 DAP recording the optimum.

2.10.3. Influence of harvest stages on tuberous root dry matter content

Dry matter refers to what is left after a plant part or whole plant is driedin an oven to remove the moisture and it indicates thenutrient content of the tuberousroots. A higher dry matter percentagewas obtained at 150 DAP (41.6 % and 23.4 %)respectively and this was higher than the dry matter recordedat 90 DAP(Shigwedha, 2012).Woolfe (1992) had described OFSP of Latin American origin as soft with dry matter content ranging between 45% and 55%.Dry matter content increased with interval from planting to harvest up to 150 DAP but not to 180DAP due to reallocation of photo assimilates to shoots at later harvesting stages (Alvaro *et al*., 2017).The dry matter content increased with age of the crop, varying over the harvesting stages between a range of 18.1-26.3% (Chattopadhyay *et al*., 2005).

2.10.4. Influence of harvest stages on nutritional quality of sweetpotato

Farmers pay particular attention to taste and quality traits before adopting a variety for starch were 53.2 % (120DAP), 59.0 (150DAP) and 56.9 % (180DAP).Alvaro *et al.* (2017)reportedthat iron content was stable from 90 to 180 DAP.Zinc content stabilized from 120 to 180 DAP. Beta-carotene was stable from 90 DAP up to 150 DAP andincreased up to 180 DAP. The starch content increased from 90 DAP to 150 DAP and then dropped slightly at 180 DAP.

Study conducted at the research farm of Bidhan Chandra, West Bengal, India from 2002-2003 to determine the optimum harvesting stage revealed that sweet potato varieties harvested at 90, 105 and 120 DAP revealed that the dry matter content of varieties over the harvesting stages ranged from 18.11 to 26.33 % and starch 5.55 to 18.00%. Linear increases in dry matter and starch content were found between 90 and 120 DAP(Chattopadhyay *et al*., 2005).

3. MATERIALS AND METHODS

3.1. Description of the study site

The study was carried out at the experimental field of Adami Tullu Agricultural Research Center (ATARC), East Shoa Zone, Oromia Regional State, from June to October 2018 under rainfed condition with supplementaryirrigation. ATARCis located in the Central Rift Valley (CRV) of Ethiopia at a distance of about 167 km South of Addis Ababa on the way to Hawassa city. It is situated at latitude of 7° 9’ Nand a longitude of 38° 7’ E. It is located at an altitude of 1650 m.a.s.l with a 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 long-term mean minimum and maximum temperature are 12.6^{o}C and 27^{o}C, respectively.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).

3.2. Experimental materials

Three orange fleshed sweetpotato (*Ipomoea batatas* (L.) Lam) varieties (Kulfo, Tullaand Guntute)weregrown at ATARC from June to Octoberin 2018 under rainfed condition with supplementaryirrigation.

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

3.3. Experimental design and treatments

The experimental plots were laid out in a 4 x 3 factorial combination arranged in randomized complete block design (RCBD) with three replications. There are 12 treatment combinations in each replication. The treatments consisted of four levels of harvest stages (*viz*105 DAP (H1), 120 DAP (H2), 135 DAP (H3)and 150 DAP (Days after planting)(H4)) and three orange fleshed varieties (Kulfo (V1), Tulla (V2)and Guntute(V3). The land was divided into three equal blocks, each having 12 equal plots and received 12 treatment combinations assignedrandomly.The space between rows and plants were 60cm x30cm having a gross plot size of 3.0m x 3.0m ($9m^2$) and 50 plants per plot were considered. The space between replications and plots were 1.5m and 1m respectively. Plants in the three middle rows, out of five rows per plot, constituted the net plot size of $6.48m^2$and were used as sampling units, whereas the rest two rows and border plants of three middle rows were left for border effect. Plants from net plot were taken for yield parametersand tuberous roots were randomly sampled for flour moisture, ash and crude fiber content determination.

3.4. Experimental procedures

3.4.1 Cultural practices and datacollection procedures

The land was preparedfirst by removing crop residues, weeds and other unwanted materials. Experimental area was plowed deeply with oxen driven implements three times, 15 days, before planting. Ridges were preparedmanually with traditional hoes. Planting time was accomplished in June, 2018. Planting materialswereselected from a clean, healthy and vigorous vine of three months old. Young apical portion of 30cm long vine cuttings were kept under shade for two days before planting. During transplanting vine cuttings were planted with two-third (about 20cm) of its length was covered with soil. A vine cutting wasplanted per hole and replanting was done 7 DAP to replace the dead vines.All appropriate agronomic practices such as supplementary irrigation, hoeing, weeding, earthing up were done uniformly throughout the experimental plots.

3.5. Data collected

3.5.1 VineYield 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 measuredfrom the base of the plant to the terminal leafby 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 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 ofpetiole (lobe) to tips of the leaves, then, multiplied by the width, that was measured fromlarge part of the leaves by rulers and finally multiplied by correction coefficient 0.8 for largerwidth 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 from the tip of the leaf to petiole attachment and **W**= Leaf width from the widest lamina or middle part of the leaf.

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 fromlower, 5 from middle and 5 from top portion of the plants; totally from average five plants perplot. 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 $0.18m^2$ perplant.

$\mathbf{LAI} = \frac{\mathbf{LA}}{\mathbf{GA}}$ … … … … … … … … … … … … . .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.

3.5.2. 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 (50 cm) in cmand 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 of ten plants was measured by Verniercaliper (0-150mm) in mm from tuberous roots sampled from net plot and three tuberous roots (large, medium and small) fromnet plot were used at respective harvest stages and average was considered for analysis.For measurements of tuberous root length and diameter the same tuberous roots were used.

Above Ground Fresh Biomass (AGBFW): Above ground fresh biomass weighed from all plants in the central three rows of each plot was harvested and weighed using hanging digitalbalance (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, mediumsized 200-350g and larger sized 350-500g) whereas unmarketable ones (very small size less than 100g & oversized more than 500 g,tuberous roots with injury,rottingand greening symptoms(Terefe, 2003). It can also categorized by measuring tuberous root diameter from the middle portion of the tuberous rootusing Vernier caliper. Tuberous roots with a diameter of less than 3 cmwereconsidered unmarketable whereas the reverse is categorized as marketable(Yeng *et al*., 2012).

Marketable Tuberous Root Number per Plant (MTNPP): Marketable tuberous root number per plantwas 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 plantwas 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 plantwas obtained by adding 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 digitalbalance 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 digitalbalance 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 getmarketable tuberousroot weight per hectarefirst tuberous roots of marketable category was weighed and expressed in kg per plot basis by using hanging digitalbalance at respective harveststage. 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 getunmarketable tuberous root weight per hectarefirst tubers of unmarketable tuberous root category was weighed and expressed in kg per plot basis by using hanging digitalbalance 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 RootYield per Hectare (TTYt/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. Thenobtained value was used for data analysis.

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

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

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

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

3.5.3. Quality Parameters

The following quality parameters were analyzed from randomly sampled samples from plants of net plots at respective harvesting stage (105, 120, 135 and 150 DAP).

Leaf Dry MatterContent (LDMC)(%): Leaf dry matter per plant was estimated by taking 100g of fresh leaf weight of the plants from each sampleat respective harvest stages.The sample was dried in an oven dry forced air circulation at 70 ^{0}C for 72 hours. Then dried sample was weighed by sensitive balance (Model No yt-1002 and reading scale 0.01). Finally, the dry leaf weight was divided forfresh leaf weight and multiplied by 100 to get leaf dry matter in percentage.

Vine Dry MatterContent (VDMC)(%): Vine dry matter per plant was obtained by taking 100g of fresh vine weight of the plants from each sampled at respective harvest stages and were dried in an oven dry forced air circulation at 70 ^{0}C for 72 hours. Then dried sample was weighed by sensitive balance (Model No yt-1002 and reading scale 0.01). Finally, the dry vine weight was divided for fresh vine weight and multiplied by 100 to get vine dry matter in percentage.

Tuberous Root Dry Matter Content (TDMC)(%): To calculatetuberous dry matter first 100g of fresh tuberous roots were prepared from marketable categories of tuberous rootsrandomly taken from each harvested plot at respective harvest stages and tuberous roots sliced, chopped, composited and dried in an oven dry forced air circulation at 70 ^{0}C for 72 hours.Then dried sample was weighed by sensitive balance (Model No yt-1002 and reading scale 0.01). Finally, the dry tuberous root weight was divided for fresh tuberous root weight and multiplied by 100 to get root dry matter in percentage.

$$\textbf{Dry matter percentage } (\textbf{DM } \%) = \frac{\boldsymbol{Dryweightofsample}}{\boldsymbol{Freshweightofsample}} * \mathbf{100} \ldots \ldots \ldots \textit{Equation (5)}$$

Ash content (%): The ash content was determined by heating a flour sample in a muffle furnace(AOAC, 2005) at Jimma University College of Agriculture and Veterinary Medicine (JUCAVM) (Postharvest Laboratory). Five grams of flour sample was weighed and transferred to a furnace at 550°C for eight hours. After heating the ash was weighed and expressed as percentage of the original sample weight on dryweight basis:

$$\textbf{Ash } (\%) = \frac{\boldsymbol{M3 - M1}}{\boldsymbol{M2 - M1}} * \mathbf{100} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \textit{Equation (6)}$$

Where $\mathbf{M_1}$=Weight of the crucibles; $\mathbf{M_2}$=Weight of fresh flour sample and crucibles; $\mathbf{M_3}$=Weight of ash andcrucibles.

Flour Moisture Content (FMC %): The flour moisture contents of the experimental samples weredetermined according to AOAC (2005) method 925.09 at JCVAM (Postharvest Laboratory). The empty dish with its lidwas dried in the oven (Leicester, LE67 5FT, England) for 15 min and then transferred intodesiccators for cooling before it was weighed to the nearest milligram. About 5g of thesample was transferred to the dish and then the dish was placed inside the oven (Leicester;LE675FT; England) at 103℃ in order to dry the samples to a constant weight, cooled indesiccators and re-weighed. Then, the moisture content was estimated by the followingformula:

$$\textbf{FMC}\ (\%) = \frac{M2-M1}{M2} * \mathbf{100} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textit{Equation (7)}$$

Where **M1** = Mass of sample after drying and **M2** = mass of sample before drying

Crude fiber (CF %): Crude fiber was determined atJUCAVM (Animal Nutrition Laboratory) using dilute acid and alkali hydrolysis using Fibertec (2010) by Weende method.Exactly 1.5 g of the sample was accurately taken into glass crucible, about 200 ml of boiled1.25% $H_2SO_4$was poured into the flask and the mixture boiled for 30 minutes under refluxcondenser. The insoluble matter was washed with boiling 4 times until the residue was freefrom acid. About 200 ml of boiling 1.25% KOH solution was added into the residue and thenheated for 30 minute under reflux condenser. The residue was filtered, washed with boilingwater and then the crucible was transferred to the cold extraction unit and washed with acetone. After digestion, the residue was dried at 105°C in an air conventional oven, cooledin desiccators until constant weight was obtained. The residue was incinerated in an electric furnace at 525°C until all the carbonaceous matters were burnt. The crucible was left to cooldown to below 250°C, then removed from the furnace and transferred to the desiccators,cooled to room temperature and weighed. The crude fiber was calculated and expressed aspercentage (AOAC, 2005).

$$\textbf{Crude fiber}\ (\%) = \frac{M1-M2}{W} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \textit{Equation (8)}$$

Where **M1**= Mass of the crucible (the sand and wet residue); **M2**=Mass of the crucible (thesand and ash); **W** = Sample weight dry matter basis.

3.6. Data analysis

Data collectedfor growth, yield and quality parameters were subjected to analysis of variance (ANOVA) mean separation procedure was also undertaken. The ANOVA model used for the analysis was:

$$\mathbf{Y_{ikj} = \mu + V_i + H_j + GH_{ij} + R_k + \acute{\varepsilon}_{ijk}}$$

Where, $\mathbf{Y_{ikj}}$ = mean value of the response variable of the $\mathbf{i}^{th}$ varieties at the $\mathbf{j}^{th}$ harvesting stages in $\mathbf{k}^{th}$ block, $\boldsymbol{\mu}$ = over all mean, $\mathbf{V_i}$ = Effects of varieties, $\mathbf{H_j}$ = Effects of harvest stages, $\mathbf{GH_{ij}}$= Interaction effects of varieties and harvesting stages, $\mathbf{R_k}$ = Effects of blocks and $\acute{\boldsymbol{\varepsilon}}_{\mathbf{ijk}}$ = Random error term due to those uncontrolled factors. After fitting analysis of variance (ANOVA) model for those significant interactions or main effects a mean separation procedure using LSD (Least Significant Difference) mean methods were done at required levels of probability at 1% and 5%. All the statistical analysis was carried out using Statistical Analysis System (SAS) version 9.3 (SAS, 2012). When there was a statistically significant interaction between the factors, the interaction was considered, rather than the main effects, otherwise, only the main effects of treatments was presented.

4. RESULTS AND DISCUSSION

4.1. Vine YieldIndicators

4.1.1. 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

Vine number per plant, vine thickness, petiole length, leafarea and leaf area index were not significantly influenced by interaction of harvest stages and varieties. Similarly, vine number per plant and vine thickness were notsignificantly 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 (Appendix Table 1).Leaf area and leaf area index were significantly influenced by main effect variety. However, the main effect of harvest stage did not significantly influence leaf area and leaf area index. The 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 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 varietyrecorded the highest petiole length(19.03cm), whereas the lowest petiole length is registered with Kulfo variety (14.04 cm) which was statistically at parwith 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 (Appendix Table 1). 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 *etal.* (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 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 wasalso 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

4.1.2. Influence of harveststage onabove ground fresh biomass, vine length and leaf number of OFSP variety

Interaction effect of harvest stage and varietysignificantly influenced vine length ($P<0.05$), above ground fresh biomass (AGFB) ($P<0.01$)and leaf number(LN) ($p<0.01$) (Appendix Table 2). The highest above ground fresh biomass (AGFBM) (66.12 t/ha) was produced byGuntute varietyharvested at 135 DAP followed by 150 DAP(49.34 t/ha) which werestatistically at par(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 delayedfrom 90 to 120 DAP AGFB increased, at all locations and decreased after 120 DAP in most varieties.Similarly, Etela and Kalio (2011) also reported that AGFB decreased with increasing harvestdate 90, 120 to 150 DAP. Vine growth was slow at 30 DAP, fastest at 60 DAP andslowed 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 and reverse allocation of photo assimilates from tuberous roots to shoots at later harvest stage than earlier.

Vine length (126.1 cm) was recorded by Guntute varietyharvested at 135 DAP, followed by thoseharvested 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 stages delayed vine length decreased at 150 DAP. This result is similar with findings of Ahmed *et al*. (2012) who reported thatreduced growth of sweetpotatoes is 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 byTullavariety (387) harvested at 135 DAP and Kulfo variety (377) harvested at 135 DAPTheLowest leaf numberper plant was produced byTulla variety (322.6) harvested at 150 DAP. Sweetpotato 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)
	Stage 1 (105 DAP)	104.3c	334.9d	33.10de
Kulfo	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
	Stage 1 (105 DAP)	110.0b	346.1bcd	27.41e
Tulla	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
	Stage 1 (105 DAP)	122.1a	346.6bcd	38.80cd
Guntute	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

4.2. Yield and Yield Components of Sweet potato

4.2.1. Influence of harvest stageon marketable and unmarketabletuberous root number per plant of OFSP variety

The result of this study showed thatinteraction effect of harvest stage and varietyhighly significantly ($p<0.01$)(Appendix Table 3) influenced marketable andunmarketable tuber number per plant. Guntute variety harvested at 135 DAP producedthe highestmarketable tuberous root number (4.57), which was statistically at par with 150 DAP (4.51). The least marketable tuberous rootnumber per plant was recorded in Tulla varietyharvested 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 inmarketable tuberous root numberper plant till 120 DAP and declinedthen after up to 180 DAP.Shigwedha (2012)reported that percentage of large tuberous root number per plant was lower when the crop harvested at 90 DAP, whereas percentage of large tuberous roots number obtained when the crop was harvested at 150 DAPwhich was much higher than when harvested at 90 and 120 DAP. Chowdhury (2014) pointedoutthat thenumber of marketable tuberous roots per plant increased as more time was allowed for tuber 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 stages 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 and increases unmarketable tuberous root numbers which were immature.

Guntute varietyharvested at 105 DAP producedthe highest unmarketable tuberous root number (1.64). The least unmarketable tuberous rootnumber was recorded by Tulla varietyharvested at 105 DAP (0.25), which was statistically at par with Kulfo varietyharvested at 105 DAP (0.50), 120 DAP (0.26) and 150 DAP(0.43). More unmarketable tuberousroot number per plant was recorded at early harvest stages due to more number of immature tuberous roots, whereas at later harvest stages 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

4.2.2. Influence of harvest stageon 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 ($P<0.01$)(Appendix Table 3) 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 rootnumber 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 intotal 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 Tullavariety (2.73) which might beattributed to varietal differences.

The interaction of harvest stage and varietydid not significantly influence tuberous root length and diameter. However, these parameters were significantly influenced by the main effects of harvest stageand variety($p<0.01$)(Appendix Table 3). 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 wasobserved 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, statingthat the highest tuberous 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 Tullavariety (14.43cm). This result is in line with the report of Nath *et al*. (2007) who reported that, tuberousroot length was found to be maximum in"WBSP-4" variety (15.21cm) followed by "Kamala Sundari"(14.55 cm) and "Tripti" (14.50cm) varieties. These differences were observed due to varietal differences.

Tuberous root diameter was alsoinfluenced by the harvest stage and variety. 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)reportedsimilar trend to this study, that the tuberous diameter showed linear increase up to 150 DAPand then decreased at 150 DAP.

Tuberous root diameter also influenced by variety main effect. The highest tuberous root diameter was recorded by Guntutevariety (9.33cm), whereas the least tuberous rootdiameter was recorded by Kulfovariety (7.43cm)which wasstatistically at parwith Tullavariety (6.88cm).The results of this study were higher than those reported byDe 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 varietymain effects (P<0.01)(Appendix Table 3). 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 results agrees with what has been reported by Jahan *et al*. (2009) that harvest time had a significant effecton the weight of tuberous roots, with the maximum weight obtained at150 DAP.Total tuberous root weight per plant was significantly influenced by the varieties main effects. 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 1.98kg for ‘Solomon’ variety (Richardson, 2011).Late harvested plants have more timeto deposit photo assimilatesfrom vegetative parts to tuberous roots, which resulted inincreased 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

4.2.3. Effects of harvest stageon marketable and unmarketable tuberous root weight per plant of OFSP variety

The result of this experiment revealed that, interaction of variety and harvest stagesignificantly($p<0.05$) influenced marketableand unmarketable tuberous root weight per plant ($p<0.01$)(Appendix Table 4). The highest marketable tuberous root weight per plant (1.85kg) was producedby Guntute variety harvestedat 135 DAP, followed by the same variety harvested at 150 DAP(1.75kg). The least marketable tuberous weight(0.82kg) was recorded by Kulfo variety harvested at 105 DAP, however, it wasnot significantly different from that harvestedat 120 DAP (0.98kg) (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 marketabletuberous root weight from 90 DAP to 150 DAP and thendecreased among varieties(Nath *et al*., 2007). Marketable tuberousroot 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 is 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 DAPIn our case the increase of unmarketable tuberous root weight at first harvesting was due to more number of unmarketable tuber numberas 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

4.2.4. Influence of harvest stageon marketable, unmarketable and total tuberous root weight per hectare of OFSP variety

Marketable (P<0.01)&unmarketable (P<0.05)(Appendix Table 4) and total tuberous root weight per hectare (P<0.01)(Appendix Table 5) weresignificantly influenced by the interaction of variety and harvest stage. The highest marketable tuberous root weight per hectarewas produced byGuntute variety harvested at 135 DAP(56.39t/ha) and at 150 DAP(55.96t/ha). The least marketable tuberous root weight per hectare was produced byTulla varietyharvested at 105 DAP(15.20t/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 120DAP 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)foundhighestmarketable tuberous root yield (17.67t/ha)at 150 DAP. Similarly, early maturity studies showed that the yield of three clones at 75, 90 and 105 DAP were 13, 23 and 33 t/ha, respectively in increasing order(Vimala and Hariprakash, 2011).Tuberousroot 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 tuberousroots wassignificantly lower when the crop was harvestedat 90 DAP and while thepercentage of large tuberous roots obtained when the crop washarvested 150 DAP. Jahan *et al*. (2009)reportedthe maximum weight obtained at150 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 meanroot yield increased as the time of harvest increased from 90, 105 and 120 DAP with the 105 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 plantsharvested 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 hectarewere significantly influenced by the interaction of harvest stage and variety. The highest unmarketable tuberous root weight per hectare was produced by Guntute varietyharvested at 105 DAP(1.17t/ha) whereas the lowest was produced by Tulla varietyharvested 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 90DAP to 180DAP, this is due to sweet potato weevil damage to tuberous roots at prolonged harvest stages.

The highest total tuberous root weight per hectarewas produced by Guntute variety harvested at 135 DAP(56.71 t/ha), followed by at 150 DAP(56.29t/ha). The least tuberous root weight per hectare was recorded by Tulla variety harvested at 105 DAP(15.84t/ha).In line with this results total tuberous root yield increased as the harvest stages were delayed from 90 to 150 DAP(Alvaro *etal*., 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 partsat 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)
	Stage 1 (105 DAP)	22.65gh	0.63b	23.28fg
Kulfo	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
	Stage 1 (105 DAP)	15.20i	0.64b	15.84h
Tulla	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
	Stage 1 (105 DAP)	34.83cd	1.17a	36.00cd
Guntute	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

4.2.5. Effects of harvest stageon commercial harvest index, harvest index and tuber dry matter content of OFSP variety

The interaction of harvest stage and varietysignificantly influenced commercial harvest index (CHI)&harvest index(HI) ($P<0.05$) and tuber dry matter content (TDMC) ($P<0.01$)(Appendix Table 5). The highest commercial harvest index of 99.6% was significantly produced by Tulla variety harvested at 150 DAP, followed byKulfo 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%).

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 varietymeans 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.

Tuber dry matter content was significantly influenced by the interaction of variety and harvest stage. The highest tuberous root dry matter content (TDMC) (29.70%) was recorded by Kulfo varietyharvested at 105 DAP which was statistically at par with the Guntute variety harvested at 105 DAP(29.33%). The least tuber dry matter content was recorded by Guntute variety(19.73%) harvested at 120 DAP. Tuber drymatter accumulation increased with time(Monamodi *et al*., 2003).According to Vimala and Hariprakash (2011)data on the dry matter content of eight clones for three seasons showed that dry matter increased significantly from 75 to 90 DAP when the maximum dry matter occurs during this period and tends to deteriorate after that and at 105 days, the dry matter content inmajority of the clones decreased. Dry matter content of about 27% could be obtained when the crop harvested either at 105 or 120 DAP which was about 4% higher than when the crop was harvested at 90 DAP(Alcoy°*et al*., 1993).Dry matter content increased with interval from planting to harvest up to 150DAP but 180DAP(Alvaro *et al*., 2017). Similarly, decreasing tuberous root dry matter content towards harvest was reported by (Bhagsari and Ashley, 1990). A higher dry matter percentagewas obtained at 150 DAP (41.6 % and 23.4 %) and this was higher than the dry matter recordedat 90 DAP, but not at 120 DAP(Shigwedha, 2012).Jahan *et al*. (2009)also came to conclusion thatthere is a significant effect of harvest stage on the dry mattercontent of storage roots. This implies that when sweet potato is harvested at 150 DAP, it received maximum vegetative growth, aswell as development of tuberous roots which aided maximumphotosynthesis and hence the accumulation of dry matter inthe tuberous roots were higher.The average dry matter content in sweet potato is approximately 30%, butvary widely depending on cultivar, location, climate, daylength, soil type, incidence of pests, diseases andcultivation practices (Bradbury and Holloway, 1988).

Table 8. Interaction effects of harvest stage and variety on commercial harvest index, harvest index and tuber dry matter content of OFSP at ATARC in 2018

Varieties	Harvest stages	Commercial harvest index (%)	Harvest index (%)	Tuber dry matter content(%)
Kulfo	Stage 1 (105 DAP)	97.3ef	41cd	29.70a
	Stage 2 (120 DAP)	98.3cd	39d	20.47c
	Stage 3 (135 DAP)	99.4a	45bc	21.10c
	Stage 4 (150 DAP)	99.4a	47b	26.53b
Tulla	Stage 1 (105 DAP)	96.0g	37d	20.33c
	Stage 2 (120 DAP)	97.9de	41cd	20.50c
	Stage 3 (135 DAP)	99.1ab	50ab	20.33c
	Stage 4 (150 DAP)	99.6a	50ab	26.87b
Guntute	Stage 1 (105 DAP)	96.8f	48b	29.33a
	Stage 2 (120 DAP)	98.7bc	47b	19.73c
	Stage 3 (135 DAP)	99.4a	46b	20.83c
	Stage 4 (150 DAP)	99.4a	54a	26.03b
LSD (0.05)		0.01	0.05	2.22
CV (%)		0.4	6.2	5.6

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

4.2.6. Influence of harvest stage on vine and leaf dry matter content of OFSP variety

Vine and leaf dry matter content were not significantly influenced by the interaction of variety and harvest stage. However, they were influenced by the harvest stage and variety(P<0.01)(Appendix Table 5)main effects. Vine dry matter content (16.34%) was produced at 150 DAP,followed by harvest stages 135 DAP (15.03%) and 120 DAP(15.01%). The least vine dry matter content was produced at 105 DAP(12.74%) (Table9). Vine dry matter content played a great role forincrement of above ground fresh biomass weight which was proportional to vine length.Vine dry matter contentalso significantly influenced by variety main effect. Vine dry matter content significantly influenced by the varieties main effect. The highest vine dry matter content was recorded by Tulla variety(15.70%), followed by Kulfo variety (15.40 %). The least vine dry matter content was produced by Guntutevariety (13.24%). Tulla and Kulfo varieties could be recommended for animal feeds in study area and in areas with similar agro ecologies.Sanoussi *et al*. (2016)statedthat partition of sweetpotato dry matter content at vegetative growth would show the highest on the leaves and stems.

Leaf dry matter content was not significantly influenced by interaction of variety and harvest stage. It was significantly influenced by the variety and harvest stage main effects. The highest leaf dry matter content (20.46%) was recorded at 150 DAP, whereas the least leaf dry weight was recorded at 105 DAP(15.47%).Leaf dry weight was also significantly influenced by variety main effect. The highest leaf dry matter content(18.59%) was recorded by Guntutevariety,whereas the least leaf dry matter was recorded by Tulla variety(16.63%).

Table 9. Main effects of harvest stage on vine and leaf dry matter of OFSP variety at ATARC in 2018

Treatments	Vine dry matter content (%)	Leaf dry matter content (%)
Harvest stages		
Stage 1 (105 DAP)	12.74b	15.47c
Stage 2 (120 DAP)	15.01a	16.08c
Stage 3 (135 DAP)	15.03a	17.90b
Stage 4 (150 DAP)	16.34a	20.46a
LSD (0.05)	1.58	1.01
Varieties		
Kulfo	15.40a	17.22b
Tulla	15.70a	16.63b
Guntute	13.24b	18.59a
LSD (0.05)	1.37	0.87
CV (%)	10.95	5.92

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

4.3. Quality Parameters of Sweet potato

4.3.1. Influence of harvest stageson flour moisture, ash and crude fiber contents of OFSP variety

Flour moisture ($P<0.05$)&ash ($P<0.05$) and crude fiber contents ($P<0.01$)(Appendix Table 6)were significantly influenced by the interaction of harveststageand variety. The highest flour moisture content (7.88%) was recorded by Guntute variety harvested at 105 DAP. The least flour moisture content was recorded by Kulfovariety (4.65%) harvested at 105 DAP (Table 10).The flour moisture content at 120 DAP of harvest was lower than those harvested at 90 DAP(Kalu, 2018). The flour moisture content decreased at later harvest due to increase in fiber and carbohydrate contents.The varieties having low flour moisture content is very important to maintain long shelf life.

The highest ash content (5.72 %)was recorded by Guntute variety harvested at 105 DAP, followedKulfo variety harvested at 105, 120, 135 & 150 DAP, Tulla variety harvested at 135 & 150 DAP and Guntute variety harvested at 120, 135 & 150 DAP. The least ash content(4.05 %) was recorded by Tulla varietyharvested at 105 DAP statistically at parwith the same varietyharvested at 120 DAP(4.13 %) (Table 10).Kalu (2018)reportedincreased in ash content at 120 DAP of harvest for the two varieties at different spaces.The high ash content of variety indicates that the variety are rich in mineral and they could be recommended children and lactating mothers, since it shows micronutrient contents of the sweet potato.A significant increase in ash content of all the varieties, CEN variety increased from 0.27% - 0.53%, NRSP variety increased from 1.06% – 1.31% and 87 variety increased from 0.54% - 1.26% at 90 and 150 DAP, respectively (Onyemachi *et al*., 2018).

Crude fiber content wasinfluenced by the interaction of harvest stage and variety. The highest crude fiber content (8.16%) was recorded by Kulfo variety harvested at 150 DAP, followed byGuntutevariety harvested at 105 DAP and at 150 DAP. The least crude fiber content was recorded by Kulfovariety (1.62 %) harvested at 105 DAP. According to Kalu (2018)fiber content was higher at 120 DAP of harvest than at 90 DAP of harvest. This indicates that reduced moisture content and maturity favors increasedfiber at delayed harvest stage.The fiber content for all the varieties studied increased with increasing harvesting stages, NRSP variety increased from 1.20 % to 1.55%, CEN variety increased from 0.56 % to 0.67% and 87 variety increased from 0.63 to 0.77 at 90 and 150 DAP respectively (Onyemachi *et al*., 2018). Varieties having moderate crude fiber are ideal to be in adding foods for children.

Table 10. Interaction effects of harvest stage and variety on average flour moisture, ash and crude fiber contents of OFSP at ATARC in 2018

Varieties	Harvest stages	Flour moisture (%)	Ash (%)	Crude fiber (%)
Kulfo	Stage 1 (105 DAP)	5.60bcd	5.23ab	1.62f
	Stage 2 (120 DAP)	5.30cde	4.73ab	4.21de
	Stage 3 (135 DAP)	5.12de	4.39ab	4.95cd
	Stage 4 (150 DAP)	4.65e	4.45ab	8.16a
Tulla	Stage 1 (105 DAP)	6.30b	4.05b	2.17f
	Stage 2 (120 DAP)	6.03bc	4.13b	2.81ef
	Stage 3 (135 DAP)	5.67bcd	4.83ab	4.85cd
	Stage 4 (150 DAP)	4.95de	5.05ab	5.80cd
Guntute	Stage 1 (105 DAP)	7.88a	5.72a	6.41abc
	Stage 2 (120 DAP)	5.22de	5.00ab	6.23bc
	Stage 3 (135 DAP)	5.60bcd	5.06ab	5.80cd
	Stage 4 (150 DAP)	5.39cde	4.84ab	7.72ab
LSD (0.05)		0.80	0.82	0.97
CV (%)		8.3	10.1	11.4

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

5. SUMMARY AND CONCLUSIONS

Sweetpotato (*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, tuberous root yield and quality of sweet potato areknown to be affected by various factors, such as inappropriate agronomic practices, climate conditions, harvest stage, unimproved variety and postharvest handling problems. The field experiment was conducted at Adami Tullu Agricultural Research Centerto determine the effect of harvest stageon vine yield, tuberous root yield and quality of orange fleshed sweet potato among factors mentioned above.

Vine yield indicators such asvine 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. 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 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, harvest index, ash, flour moisture and crude fiber.

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 varietyharvested at 135 DAP. The highest tuber dry matter content(29.70%) recorded by Kulfo variety harvested at 105 DAP.

The highest commercial harvest index of 99.6 % was recorded byTulla variety harvested at 150 DAP, followed by Kulfo and Guntute varietiesharvested at 135 and 150 DAP (99.4 %). The highest harvestable index (HI) (54%) was recorded by Guntute variety harvested at 150 DAP. The highest mean of ash content (5.72%) was recorded by Guntute variety harvested at 105 DAP. The highest crude fiber content (8.16%) recorded by Kulfo variety harvested at 150 DAP.

It can be concluded that most vine yield, tuberous root yield and quality 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 better production above ground fresh biomass and tuberous root yield. 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, tuberousroot yield and tuberous root quality parameters observed from this study, growers at Adami Tullu areacan obtain maximum vine yield, tuberous root yield and quality flour by growing Guntute variety and harvest at 135 DAP. Since, present experiment conducted under rainfed condition with supplementary irrigation, over location, under irrigation condition was suggested.

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7. APPENDICES

Appendix1 Mean square of ANOVA for vine number, vine thickness, petiole length and leaf area

Source	DF	Vine number	Vine thickness	Petiole length	Leaf area
Variety	2	0.41333^{ns}	0.29890^{ns}	95.76440*	11013.2**
Harvest stages	3	0.17000^{ns}	0.22740^{ns}	34.18023**	39.17854^{ns}
Rep					
Var*HS	6	0.10222^{ns}	0.22800^{ns}	12.11300ns	34.98000^{ns}
Error					

** = significance at 0.01, * = significant at 0.05,Df = degree freedom.

Appendix 2Mean square of ANOVA for leaf area index, vine length, leaf number and above ground fresh biomass

Source	DF	Leaf area index	Vine length	Leaf number	AGFB
Variety	2	445.483**	968.111**	353.4^{ns}	1387.01**
Harvest stages	3	9.635^{ns}	107.244**	2816.6**	328.85**
Rep					
Var*HS	6	8.426^{ns}	34.418*	2200.5**	91.86**
Error					

** = significance at 0.01, * = significant at 0.05,Df = degree freedom and AGFB = above ground fresh biomass

Appendix 3 Mean Square of ANOVA for marketable tuber number per plant, unmarketable tuber number per plant, total tuber number per plant, tuber length and tuber diameter

Source	DF	MTNPP	UMTNPP	TTNPP	TL	TD
Variety	2	4.95878**	2.57767**	14.52973**	441.2994**	19.8100**
Harvest S	3	3.76040**	0.39712**	2.22193**	31.8413**	175755**
Rep						
Var*HS	6	0.25803**	0.12152**	0.15381^{ns}	3.29055^{ns}	0.3869^{ns}
Error						

** = Significance at 0.01, * = Significant at 0.05,Df = Degree freedom,HS = harvesting stages, MTNPP = marketable tuber number per plant, UMTNPP = unmarketable tuber number per plant, TTNPP = total tuber number per plant, TL = tuber length and T D = tuber diameter.

Appendix 4Mean square of ANOVA for marketable tuber weight per plant, unmarketable tuber weight per plant, total tuber weight per plant, marketable tuber weigh ton per hectare and unmarketable tuber weight per hectare

Source	DF	MTWPP	UMTWPP	TTWPP	MTW t/ha	UMTW t/ha
Variety	2	1.94174**	1.460472**	6.533734**	1957.262**	0.21108**
Harvest	3	0.43430**	0.097638**	0.21411**	507.707**	0.67721**
Rep						
Var*HS	6	0.03991*	0.093748**	0.01761**	41.167**	0.04554*
Error						

** = Significance at 0.01, * = Significant at 0.05,DF = Degree freedom, MTWPP = marketable tuber weight per plant, UMTWPP = unmarketable tuber weight per plant, TTWPP = total tuber weight perplant, MTW t/ha = marketable tuber weight ton per hectare and UMTW t/ha = unmarketable tuber weight ton per hectare.

Appendix5 Mean square of ANOVA for total tuber weight ton per hectare, commercial harvestable index, harvestable index, tuber dry weight, vine dry weight and leaf dry weight

Source	DF	TTW t/ha	CHI	HI	TDW %	VDW %	LDW %
Variety	2	1997.149**	0.00009025*	0.0104541**	20.160**	21.6458**	12.1058**
HS	3	474.281**	0.00149081**	0.0135072**	107.412**	20.1255**	45.1218**
Rep							
Var*HS	6	39.687**	0.00003587*	0.0033935*	21.940**	1.652500^{ns}	0.9165^{ns}
Error							

** = Significance at 0.01, * = Significant at 0.05, DF = Degree freedom, HS = harvesting stages,TTW t/ha = total tuber weight ton per hectare, CHI = commercial harvestable index, HI = harvestable index, TDW = tuber dry weight, VDW = vine dry weight and LDW = leaf dry weight.

Appendix6 Mean square of ANOVA for flour moisture content, ash content and crude fiber content

Source	DF	Flour moisture content	Ash content	Crude fiber content
Variety	2	2.2696**	1.3008*	21.7703**
Harvest stages	3	4.1077**	0.2248^{ns}	23.6380**
Rep				
Var*HS	6	1.0296**	0.7159*	4.4143**
Error				

** = Significance at 0.01, * = Significant at 0.05, DF = Degree freedom.

AppendixFigure 1.Vegetative growth stage

AppendixFigure 2. First harvesting stage (105 days after planting)

AppendixFigure 3Harvesting, data collection and processing activity for quality parametersassessment.

Appendix Figure 4.Sample preparation and measurement of qualities parameters.