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Research article

Effect of harvesting time on root yield and nutritional composition of orange-fleshed sweet potato [*Ipomoea batatas* (L.) Lam] varieties in East Hararghe

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ABSTRACT

In eastern Ethiopia, sweet potato is a vital food and nutrition security crop; moreover, orange-fleshed sweet potato (OFSP) varieties are rich in beta-carotene content and have the potential to alleviate chronic Vitamin A malnutrition in the region. However, the unavailability of adaptable varieties and lack of information on production and post-harvest handling practices have limited its production and utilization in eastern Ethiopia. The research was conducted to identify the proper harvesting stage of OFSP varieties for optimum yield and nutritional compositions at Rare and Babile research stations of Haramaya University during the main rainy season of 2022. Three varieties (*Alamura, Kabode,* and *Bakule*) and four harvesting periods (120, 150, 180, and 210 days after planting (DAP) in factorial combinations were evaluated in randomized complete block design with three replications. Data were collected for growth, yield, and physicochemical composition-related parameters. Combined analysis of variance revealed the interaction effect of harvesting time and varieties had a significant ($p < 0.05$) effect on yield, yield-related parameters, and physicochemical components. *Alamura* variety produced comparable above-ground biomass (28.99 t ha^{-1}) and the highest marketable root yield of 36.40 t ha^{-1} at 150 DAP, with dry matter content of 33.01 and 30.58 % at 150 and 120 DAP, respectively. Harvesting *Alamura* at 150 DAP also had the highest β-carotene, zinc, and iron contents of 11809 μg/100 g, 3.79, and 14.47 mg/100 g, respectively. It was concluded that growing the *Alamura* variety and harvesting at 150 DAP was better for obtaining higher root yield with good nutritional compositions in the study area.

1. Introduction

Sweet potato [*Ipomoea batatas* (L.) Lam] is a perennial herbaceous plant in the Convolvulaceae family [1,2]. It is the source of a staple for human nutrition and welfare as it can assist the developing food security in vulnerable communities [3]. It is a significant

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economic crop in many countries and after potato and cassava, the world's third-largest root crop [4]. In Ethiopia, sweet potato plays a key role in maintaining food security and household income generation [5–7]. Under marginal conditions in Ethiopia, the crop requires few inputs, grows quickly, and produces a consistent yield [8]. The dominant white-fleshed sweet potato cultivars are commonly consumed; however, they do not provide the nutritional benefit that orange-fleshed variants do [9].

Orange-fleshed sweet potato (OFSP) varieties, in particular, produce the β-carotene source of storage roots and are important in fighting Vitamin A Deficiency (VAD) and developing more resilient farming systems in Sub-Sahara Africa (SSA) countries as a consequence of the high amount of naturally bio-available β-carotene [10,11]. It is regarded as the most successful biofortification of a staple crop to address VAD [12] and the different varieties of sweet potato contain significant quantities of essential micronutrients for women of childbearing age or who are pregnant and preschool children [3]. Orange-fleshed sweet potato cultivars are the cheapest and most readily available year-round source of dietary vitamin A for disadvantaged families in SSA [13].

Early-maturing sweet potato varieties can be harvested 3–4.5 months after planting, providing a vital source of food during the 'hunger season' in many Sub-Saharan African countries. However, sweet potato varieties have flexible harvesting and planting time with high-temperature tolerance character that adapts to different environments [14] Sweet potato is generally harvested at 150 DAP, however, maturation stages vary between varieties [15]. In Ethiopia, the sweet potato harvesting time often lasts 2–3 months after maturity [16], increasing the danger of sweet potato weevil attack, particularly during the dry period. This is due to farmers storing roots in the soil in the absence of storage facilities and technologies [17]. Weevil and other root damage are typically associated with drought and rose drastically as harvesting was delayed [15].

In Ethiopia, sweet potato was produced by 1,510,779 farmers on 39939.1 ha of land and the cultivated land (16.58 %) for sweet potato was the third largest among root and tuber crops only exceeded by potato and taro (godere). Oromia regional state had the largest share in terms of cultivated land (49.32 %), number of holders (53.72 %), and total production (55.22 %) of the country during the 2021/22 *Meher* season. East and West Hararghe administrative zones accounted for the largest share of cultivated land (36.55 %) and the number of holders (40.54 %) in the Oromia regional state of which East Hararghe sweet potato producers and cultivated land had 27.16 and 31.58 % share in Oromia regional state, respectively [18]. This indicated that sweet potato is a vital food and nutrition security crop in East and West Hararghe. In line with more than 90 % of eastern Hararghe households subsist primarily on a monotonous sorghum diet and consume almost no meat and limited vitamin-rich foods, such as fruit and vegetables [19]. In this regard, OFSP varieties rich in beta-carotene content have the potential to combat Vitamin A malnutrition in the region. However, the unavailability of OFSP varieties and lack of recommendations on production and post-harvest handling practices have limited its production and utilization in eastern Ethiopia. This is supported by the finding of [20] that the harvesting stage had a significant

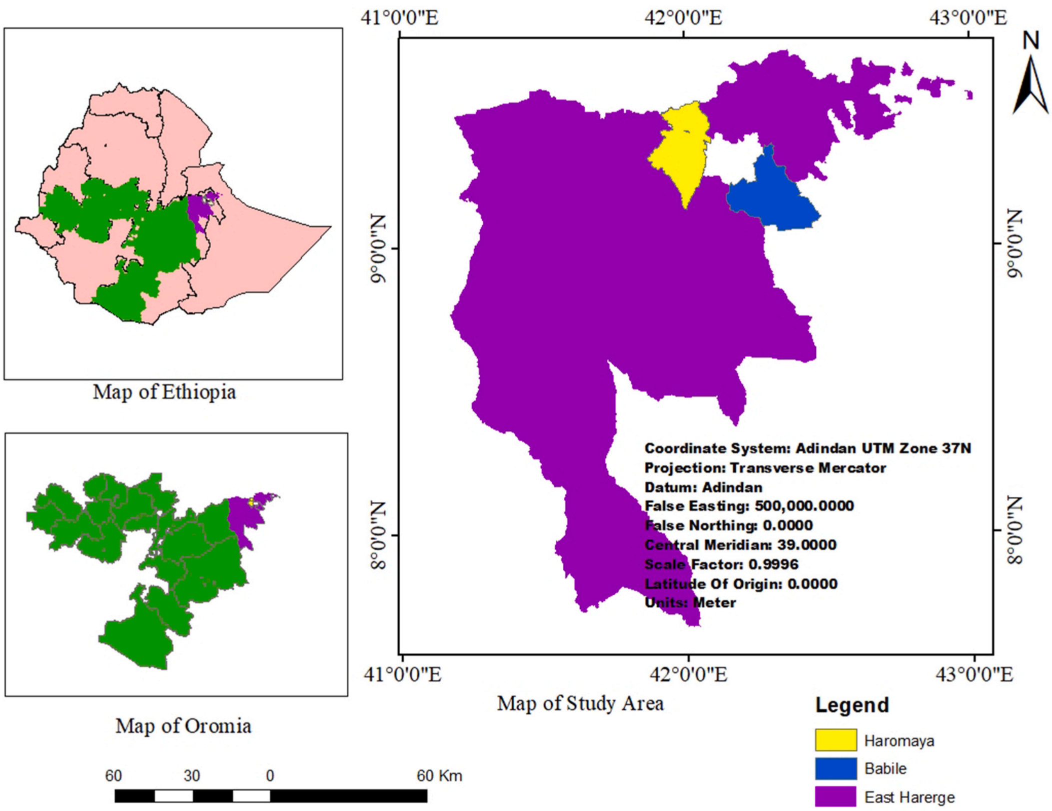

Fig. 1. Shows the sites of Haramaya (Rare) and Babile districts in Eastern Hararghe, Oromia, Ethiopia.

impact on the carotenoid and phytochemical concentrations of OFSP varieties. The limited information and understanding of parameters that determine the production and quality of OFSP roots in stallholder farmers' fields demands research on OFSP varieties in eastern Ethiopia. Therefore, this research was conducted to identify the proper harvesting stage of OFSP varieties for optimum yield and nutritional compositions in East Hararghe.

2. Materials and methods

2.1. Description of the experimental site

The research was conducted at the Rare and Babile experimental sites of Haramaya University (Fig. 1) starting from June 20, 2022, the main cropping season, and harvested based on the treatments designed (DAP). The site has a latitude and longitude of 9°24′N 42°01′E/9.400°N 42.017°E with an elevation of 2047 m above sea level (masl) and is located on the university's main campus. The area receives an average annual rainfall of 790 mm. The site experiences mean minimum and maximum temperatures of 8.3 and 25 °C, respectively, with an average annual temperature of 17 °C. The rainy season of the area is bimodal where the short rainy season stretches from March to May and the main rainy season from June to September. The soil is categorized as an alluvial deposit with a sandy loam texture [21]. The Babile research site is located at 09°13′ N 42°20′ E latitude and longitude respectively, with a height of 1648 masl in the eastern lowlands of Ethiopia. Two separate seasons exist for the distribution of rainfall: the first rainy season, which runs from March to May, and the second rainy season, which runs from June to September. The area's mean annual minimum and maximum temperatures ranged from 15.4 to 28.8 °C, with an average annual rainfall of 731 mm and an average annual humidity of 33–38 %, according to Ref. [22].

2.2. Description of sweet potato varieties

Two improved OFSP varieties, *Alamura* and *Kabode,* and a farmer's cultivar called *Bakule* were used as experimental materials (Table 1). The planting materials of OFSP varieties were collected from Awassa Agricultural Research Center, while *Bakule* cultivar cuttings were collected from a farmer's field in the Kersa district. The vines of the varieties were further multiplied at Haramaya University's research farm sites to obtain enough planting materials needed for establishing the trials.

2.3. Treatments and experimental design

Three sweet potato varieties (*Alamura, Kabode*, and *Bakule*) and four harvesting times (120, 150, 180, and 210 days after planting (DAP)) in a factorial combination and a total of 12 treatments were used in the experiment. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. Thirty-centimetre cuttings from healthy and middle vigorous growing vines of these varieties were prepared and used for planting. The 12 treatments are each assigned in one plot in each replication. Five ridges, each containing seven cuttings, were planted in each plot. Thirty-centimetre-long sweet potato cuttings were planted 40 cm apart from each other or spacing between plants and 80 cm between ridges.

2.4. Experimental procedure and field management

The experimental land was physically cleaned, then plowed, disked, and harrowed twice with tractor power, and then leveled by hand before planting. Three replication blocks and twelve plots were prepared. Five ridges and seven plants per ridge were arranged in a 4 × 2.8 m (11.2 m^2) area. Weeding, cultivation, and other management practices were carried out as per recommendations for sweet potato crops uniformly for all plots [24]. Harvesting was done carefully and manually without damaging the roots based on treatment arrangements.

Table 1
Description of sweet potato cultivars evaluated at two locations of East Hararghe in 2022 cropping season.

Variable	*Alamura* (Ukr/Eju-10)	*Kabode* (NASPOT 10 o)	*Bakule*
Year of release	2019	2019	nif
Adaptation area	Low to mid altitudes (700–2200 masl)	Low to mid altitudes (700–2000 masl)	nif
Maturity days	120 to 150	90 to 120	nif
Growth habit	Twining & spreading	Non-twining & semi-erect	nif
Predominant root skin color	Cream	Purple red	White
Predominant root flesh color	Deep orange	Intermediate orange	White
Root yield (t ha^{-1})	23 to 28	20 to 25	nif
Dry matter content (%)	31.5	30.3	nif
β-Carotene content of roots (mg/100g)	12.4	8.5	nif
Resistance to sweet potato virus diseases	Moderately resistant	Resistant	nif
Breeder center	AwARC/SARI	HawARC/SARI	nif

Source: [23], HawARC/SARI = Hawassa Agricultural Research Center of South Agricultural Research Institute (SARI), nif = no information found.

2.5. Data collection and measurement

2.5.1. Growth, yield, and yield components

Growth parameters, including vine length, leaf area index, and above-ground fresh biomass, were recorded at 120, 150, 180, and 210 DAP. Vine length was measured from seven randomly selected plants and the average was recorded in cm. The LAI was determined using a CI-202 Area meter (CID, Inc. made in the USA) which calculates the leaf area and LAI of the sample plants. Using a weighing balance (CAMRY Mechanical Hanging Scale with a weight capacity of 100 kg), above-ground fresh biomass was gathered from the three middle rows of a plot by cutting the vegetative sections of the plant back to 2 cm at harvest time.

Root parameters like root fresh weight, root length and diameter, marketable and non-marketable root number, marketable, un-marketable, total root yield, and weevil damage were also measured at each harvesting time from both sites. From each of the seven sample plants, three roots were taken, and the average fresh weight of the roots was determined at harvest time using a sensitive balance and presented in grams. Similarly, from these three roots of the seven sample plants, root diameter at the center of its broad region (using a caliper) and root length (using a centimeter) were measured and the average was recorded. Marketable root numbers per plant/hill were calculated by detecting and averaging insect and disease-free roots, under and over-sized roots, and damaged roots from the seven sample plants. All diseased, infected, under and over-sized roots were considered under non-marketable root number per plant. After sorting harvested roots into clean and uninfected ones weighing 100–500 g, marketable root yields (t ha^{-1}) were measured using a weighing scale and expressed on a hectare basis. Those roots not considered under marketable root yield were taken to non-marketable root yield and expressed on a hectare basis. Total root yield (t ha^{-1}) was computed and expressed in hectares by combining marketable and non-marketable root yields. The degree of weevil infestation was assessed by rating the harvested storage roots in each plot on a scale from 1 to 9 as stated by Ref. [25].

2.5.2. Nutritional composition and quality parameters

The samples of sweet potato roots from both sites and each plot at each harvesting time (120, 150, 180, and 210 DAP) were carefully harvested, labeled, covered with plastic, and taken to the laboratory for further physicochemical analysis. In the laboratory, the sample roots were washed with tap water twice, piled, and sliced into pieces.

The dry matter content (%) of storage roots of each variety at various harvesting stages was determined as stated by Ref. [26]. According to Ref. [27], Atomic Absorption Spectro-photometric analysis was used to determine the analysis of Fe and Zn contents. The gravimetric method as reported by Ref. [28] was used to determine the crude fiber content. The UV Spectrophotometric technique, as reported by Ref. [29], was used to determine the reducing sugars. Using high-pressure liquid chromatography (HPLC) following [30] guidelines, the beta-carotene content of each cultivar was assessed.

2.6. Data analysis

The data was subjected to a two-way analysis of variance (ANOVA) using SAS Version 9.4 statistical software [31]. Fisher's Least Significant Differences (LSD) for main factors effects and The Tukey honestly significant difference (HSD) test were used to compare treatment means of interaction effects at a 5 % ($p < 0.05$) level significance. Path coefficient analysis was carried out to determine the direct and indirect effects of growth and yield-related parameters on marketable root yield at 150 DAP.

3. Results and discussion

3.1. Effect of sweet potato varieties and harvesting time on growth parameters

The combined analysis of variance over the two locations showed a significant ($p < 0.05$) impact on major growth parameters like vine length, leaf area index, and above-ground fresh biomass due to the interaction effect of variety with the harvesting stage (Table 3). The interaction effect of variety by location also had a significant effect on leaf area index (Table 2).

Table 2
The interaction effect of variety over location on LAI of sweet potato at Rare and Babile in East Hararghe during the 2022 main cropping season.

Treatment	Location	
Variety	Rare	Babile
Alamura	2.92^{b}	2.99^{b}
Kabode	1.75^{c}	1.31^{d}
Bakule (local)	3.31^{a}	3.12^{ab}
LSD (5 %)	0.27	
CV (%)	12.72	

The means in this table that are followed by the same letter do not differ statistically at the 5 % level of significance.

3.1.1. Vine length (cm)

The interaction effect of location, variety, and harvesting time on vine length was non-significant ($p \geq 0.05$), however, the interaction effect of variety and harvesting time was significant ($p < 0.05$) for vine length (Appendix Table 1). At 210 and 180 DAPs, the local cultivar *Bakule* had the longest vine lengths of 214.19 and 207.39 cm, respectively (Table 3). The *Kabode* variety had the shortest vine length (44.69, 43.27, 37.12, and 32.59 cm) at early to last harvesting times, respectively. This finding corresponded with the reports of [32], where the local variety measured the longest vine (149.94 cm) from a trial established in Ethiopia's southern region. According to Ref. [33], substantial variations in vine length were identified across the examined OFSP cultivars at Malawi and Bangladesh Agricultural Research Institute (BARI), Pahartali, and Chittagong, respectively. Variations in vine length could be related to variations in genotypes due to genetic variations and their interaction with the environment [34].

3.1.2. Leaf area index (LAI)

The interaction effect of variety with location and variety by harvesting time interaction showed a significant ($p < 0.05$) difference for LAI (Appendix Table 1). As a result, the Bakule variety had the highest LAI (3.31 and 3.12), at Rare and Babile respectively (Table 2). Similarly, the *Bakule* variety at 180 and 210 DAP and the *Alamura* variety at 150 and 180 DAP measured the highest LAI (3.59, 3.80, and 3.33, 3.19), respectively (Table 3). On the other hand, the lowest LAI (1.31) was measured from the *Kabode* variety at the Babile site. The lowest LAI (1.11, 1.39, and 1.70) was also measured from *Kabode* at 210, 180, and 150 DAP, respectively. The difference in LAI of these varieties is due to the *Alamura* and *Bakule* varieties having broader leaves than the *Kabode* variety. The result is supported by the finding of [35] that the optimum LAI (4.40–7.23) was observed after the entrance of 3 MAP and the variations are due to morphological characteristics of the varieties in sweet potato, especially the shape and size of the leaves can affect the LAI.

3.1.3. Above-ground fresh biomass (t ha^{-1})

The combined analysis of the two locations (Rare and Babile) showed that the interaction effect of harvesting time and varieties was significant for above-ground fresh biomass (Appendix Table 1). *Bakule* variety at 180 and 210 DAP and *Alamura* variety at 150 and 180 DAP gave the highest above-ground fresh biomass (30.33, 30.31 and 28.99, 27.09 t ha^{-1}), respectively. The combined result of three sites studied for two years at Gedeo Zone Southern Ethiopia also showed that the *Alamura* variety yielded (29.90 t ha^{-1}) similar above-ground biomass [36]. The lowest above-ground fresh biomass yield (7.56 and 8.78 t ha^{-1}) was recorded from *Kabode* at the late harvesting stage (210 and 180 DAP), respectively (Table 3). This indicates that the above-ground fresh biomass yields of the *Kabode* variety decrease as the harvest time extends due to thin and narrow leaves drying faster than the broad leaves of the other two varieties. The decrease in above-ground fresh biomass with delayed harvest stages is the consequence of senescence and leaf abscission, plant death, and reverse allocation of photoassimilates from tuberous roots to shoots at later harvest stages than at earlier harvest stages [37].

3.2. Effect varieties and harvesting time on root yield and related traits

3.2.1. Root length (cm)

The analysis of variance showed that the three-way interaction effect of location, variety, and harvesting stage was not significant ($p \geq 0.05$) for root length. However, the interaction effect of variety with location, harvesting time with location, and variety with harvesting time showed significant differences ($p < 0.05$) (Appendix Table 2). *Alamura* variety at both Rare and Babile sites measured the longest root length (19.14 and 19.94 cm) whereas the *Bakule* variety at both sites and *Kabode* at Rare site measured the shortest root

Table 3
Interaction effect of variety and harvesting time on vine length, LAI, and above-ground fresh biomass of sweet potato at Rare and Babile in East Hararghe Zone, Ethiopia.

Factors		Growth traits		
Variety	HT (DAP)	Vine length (cm)	LAI (%)	AGFB (t ha^{-1})
Alamura	120	96.06^{e}	2.64^{cd}	20.27^{b}
	150	122.10^{cd}	3.33^{ab}	28.99^{a}
	180	119.80^{cd}	3.19^{abc}	27.09^{a}
	210	106.94^{de}	2.66^{cd}	21.05^{b}
Kabode	120	44.69^{f}	1.92^{ef}	14.93^{c}
	150	43.27^{f}	1.70^{fg}	13.83^{c}
	180	37.12^{f}	1.39^{fg}	8.78^{d}
	210	32.59^{f}	1.11^{g}	7.56^{d}
Bakule (Local)	120	139.61^{b}	2.35^{de}	13.88^{c}
	150	179.27^{b}	3.11^{bc}	21.90^{b}
	180	207.39^{a}	3.59^{ab}	30.33^{a}
	210	214.19^{a}	3.80^{a}	30.31^{a}
Tukey (5 %)		21.01	0.65	4.25
CV (%)		9.45	12.72	10.74

The same letter in the column does not differ statistically at the 5 % level of significance, HT = Harvesting time, DAP = days after planting, LAI = Leaf area index, AGFB = Above-ground fresh biomass.

length (Table 4). Similar root lengths were measured at all harvesting stages and both sites except for the Rare site at 120 DAP which was significantly lower than the others (Table 5). *Alamura* variety resulted in the longest root length (21.01 and 20.19 cm) at 150 and 180 DAP, respectively. However, the shortest root length was measured from *Bakule* at 120 and 150 DAP (14.09 and 16.17 cm) from *Kabode* variety at 210 DAP (15.70 cm) (Table 9). This result is consistent with the reports of [38] that there is an increasing linear correlation concerning harvesting age to commercial root length reaching 15.27 cm at 150 DAP, indicating that the increase of the field period promoted greater root growth.

3.2.2. Root diameter (cm)

The interaction effect of location, variety, and harvesting time showed a significant difference ($p < 0.05$) for root diameter (Appendix Table 2). As a res ult, the wider root diameter (from 12.20 to 14.93 cm) was measured from the *Alamura* variety harvested at 150 and 180 DAP from both sites which were not significantly different from *Alamura* at 210 DAP from Rare and 120 DAP from Ref. [38] Babile. *Kabode* at 120 DAP from both sites and *Bakule* variety at late harvesting time (180 and 210 DAP) at both sites were also statistically similar to the above result in root diameter (Table 6). The smallest root diameter (8.60–10.34 cm) was measured for the *Kabode* variety at late harvesting time (180 and 210 DAP) and for the *Bakule* variety at early harvesting time (120 and 150 DAP) at both sites. This result is in agreement with the findings of [38], where the diameter of roots increased with delay in the harvest stage from 90 to 150 DAP.

3.2.3. Marketable root number

The interaction effect of harvesting time and variety had a substantial effect on the marketable root number per plant (Appendix Table 2). At 150 and 180 DAP, *Alamura* (8.43 and 6.80), respectively, had the greatest number of marketable roots per plant followed by *Kabode* variety at 120 and 150 DAP *Alamura* at 120 DAP. However, the local variety (*Bakule*) at 120 and 150 DAP and *Kabode* at 210 and 180 DAP gave the lowest number of marketable roots (3.16–3.80) (Table 9). Similarly, a significant marketable root number was observed from the finding of [39] conducted at the Daro Labu and Habro districts during the 2016–2017 cropping season with the highest mean value (6.67) of root number per plant.

3.2.4. Non-marketable root number

The interaction effect of variety and harvesting time showed a significant ($p < 0.05$) difference in non-marketable root numbers (Appendix Table 2). *Bakule* variety at 120 and 150 DAP and *Kabode* variety at 210 DAP resulted in the highest number of non-marketable roots (11.71, 10.17, and 10.19), respectively (Table 9). The lowest number of non-marketable roots (5.37–7.42) was recorded from the *Alamura* variety at 150 DAP which was statistically non-significant with this variety at 180 and 120 DAP, *Kabode* at 120 and 150 DAP and *Bakule* at 180 and 210 DAP. The finding of [40] revealed that a higher number of non-marketable roots per plant was recorded at early harvest stages due to a greater number of immature tuberous roots and at later harvest stages due to weevil damage and oversized tuberous roots.

3.2.5. Total root number per plant

The interaction effect of variety and harvesting time over location showed significant differences ($p < 0.05$) for the total root number per plant (Appendix Table 2). Hence, the highest value (12.14–14.87) was recorded from *Alamura* and *Kabode* varieties at all harvest stages and *Kabode* at 120, 150, and 180 DAP. This implies that varieties harvested at different stages having higher marketable root numbers gave lower non-marketable root numbers showing comparable total root numbers per plant. Whereas the *Kabode* variety harvested at 210 DAP resulted relatively lower number of total roots (11.84) per plant (Table 9) [23]. also reported that there was significant differences were among OFSP varieties tested in the total number of roots per plant.

3.2.6. Root fresh weight (g)

The interaction effect of variety with location and variety with harvesting time was significant ($p < 0.05$) for root fresh weight (Appendix Table 3). *Alamura* variety at both the Rare and Babile sites and the *Kabode* variety at the Babile site gave the highest root fresh weight (871.73, 872.00, and 820.57 g), respectively (Table 7). On the other hand, the *Alamura* variety harvested at 150 and 180 DAP (1011.40 and 899.30 g) and the *Kabode* variety harvested at 120 DAP (868.30 g) recorded the highest root fresh weight.

Table 4
Interaction effect of variety and location on root length of sweet potato at Rare and Babile in East Hararghe during 2022 main cropping season.

Treatment	Location	
Variety	Rare	Babile
Alamura	19.14^{ab}	19.94^{a}
Kabode	16.72^{c}	18.38^{b}
Bakule (local)	16.63^{c}	16.55^{c}
LSD (5 %)	1.36	
CV (%)	6.25	

The same letter in this means does not differ statistically at the 5 % level of significance.

Table 5
The interaction effect of harvesting time over location on root length of sweet potato at Rare and Babile in East Hararghe during the 2022 main cropping season.

Treatment	Location	
HT(DAP)	Rare	Babile
120	16.16[b]	18.50[a]
150	17.92[a]	19.11[a]
180	18.31[a]	18.04[a]
210	17.59[ab]	17.51[a]
LSD (5 %)	1.67	
CV (%)	6.25	

The means in this table that are followed by the same letter do not differ statistically at the 5 % level of significance, HT = Harvesting time, DAP = days after planting.

Table 6
Mean of root diameter as affected by interaction effects of variety, harvesting time, and location at Rare and Babile during the 2022 main cropping season.

Location	Rare				Babile			
Treatment	HT(DAP)							
Variety	120	150	180	210	120	150	180	210
Alamura	11.25[b-h]	14.93[a]	14.80[a]	12.20[a-e]	12.98[a-c]	14.84[a]	12.62[a-d]	11.72[b-f]
Kabode	12.20[a-e]	11.20[b-h]	9.07[f-i]	8.60[hi]	12.28[a-e]	11.44[b-g]	10.34[c-i]	9.66[e-i]
Bakule (local)	7.97[i]	9.60[e-i]	12.84[a-c]	13.36[ab]	8.74[g-i]	10.03[d-i]	13.35[ab]	13.67[ab]
Tukey (5 %)	2.80							
CV (%)	7.61							

Means that are followed by the same letter do not differ statistically at the 5 % level of significance, HT = Harvesting time, DAP = days after planting.

According to Ref. [13], variations in root fresh weight of sweet potato could be due to genetic variations of the varieties and environmental effects. The lowest root fresh weight was observed from the *Bakule* variety at the early stage (120 and 150 DAP) and from the *Kabode* variety at the late harvest stage (210 DAP) (Table 9).

The interaction effect of location, variety, and harvesting time showed a non-significant ($p \geq 0.05$) difference for marketable root yield (Appendix Table 3). However, the interaction effect of variety and harvesting time resulted in a significant ($p < 0.05$) difference in marketable root yield. As a result, the *Alamura* variety gave the highest marketable root yield at 150 DAP (36.40 t ha^{-1}) followed by the *Kabode* variety at 120 DAP (32.45 t ha^{-1}) and *Alamura* at 180 DAP (32.22 t ha^{-1}). The lowest marketable root yield was recorded from *Bakule* harvested at 120 DAP (19.67 t ha^{-1}) (Table 9). This result is consistent with the findings of [15], who discovered that tuberous root yields were lower at 90 DAP compared to 120, 150, and 180 DAP. According to Ref. [41], the highest marketable root yield was recorded from BD45, BD-38, and BD-15 sweet potato clones, with no differences among themselves, but higher than the other clones at 150 days of harvest.

Non-marketable root yield (t ha^{-1})

Interaction effects of location with variety and variety with harvesting time showed significant ($p < 0.05$) differences in non-marketable root yield (Appendix Table 3). The highest non-marketable root yields (2.07–2.42 t ha^{-1}) were recorded from the *Bakule* and *Kabode* varieties at both sites. However, the lowest non-marketable root yields (1.56 and 1.78 t ha^{-1}) were obtained from the *Alamura* variety at both Babile and Rare sites, respectively (Table 8). This indicates that the *Alamura* variety showed consistency

Table 7
The interaction effect of variety and location on root fresh weight of sweet potato at Rare and Babile in East Hararghe during the 2022 main cropping season.

Treatment	Location	
Variety	Rare	Babile
Alamura	871.73[a]	872.00[a]
Kabode	657.83[b]	820.57[a]
Bakule (local)	636.37[b]	657.40[b]
LSD (5 %)	90.96	
CV (%)	9.96	

Means that are followed by the same letter do not differ statistically at the 5 % level of significance.

Marketable root yield (t ha^{-1}).

and the least non-marketable root yield at both sites. *Bakule* variety at 120 and 150 DAP and *Kabode* at 180 and 210 DAP showed higher non-marketable root yield (2.43–2.97 t ha^{-1}). However, the lowest non-marketable root yields (1.39–1.90 t ha^{-1}) were recorded from *Alamura* at 120, 150, and 150 DAP, from *Kabode* at 120 and 150 DAP, and *Bakule* at 180 and 210 DAP (Table 9). It is supported by Ref. [15] results that combined analysis of data across the harvesting periods showed that genotype had a highly significant effect on both commercial and non-commercial root yield.

The combined analysis of variance revealed that the interaction effect of variety with harvesting time had a significant ($p < 0.05$) impact on total root yield (Appendix Table 3). Across harvesting times compared for the three varieties, the *Alamura* variety at 150 DAP (37.79 t ha^{-1}) gave the highest total root yields followed by the *Kabode* variety at 120 DAP (33.97 t ha^{-1}) and *Alamura* at 180 DAP (33.91 t ha^{-1}). However, the lowest total root yield (22.65 and 24.91 t ha^{-1}) was recorded from the *Bakule* variety at 120 and 150 DAP (Table 9). Similar average attainable fresh root yields ranging from 18 to 32 t ha^{-1} were reported for different varieties [11] and when grown in different conditions [42]. In general, *Alamura* variety at 150 DAP gave higher marketable and total root yields showing consistency at both sites with minimum non-marketable root yield.

3.3. Path coefficient analysis

The path coefficient analysis of growth and yield-related parameters collected at 150 DAP was carried out to identify direct and indirect effects on the marketable root yield of the crop. As a result, the marketable root number per plant has the maximum direct positive effect (0.90) on marketable root yield. This is followed by non-marketable root number per plant (0.64), LAI (0.33), root length (0.20), root fresh weight (0.20), above-ground biomass (0.16), and non-marketable root yield per hectare. Total root number per plant (−0.57), vine length (−0.48), and root diameter (−0.03) have a negative direct effect on marketable root yield. Marketable root number per plant, root diameter and length, and root fresh weight showed higher indirect positive effects on marketable root yield through other characters except root diameter, non-marketable root number, and yield. The indirect effects of vine length, LAI, above-ground biomass, non-marketable and total root number per plant, and non-marketable root yield on marketable root yield through most parameters are observed to be negative (Table 10). The result obtained from this path analysis strongly indicates that marketable root number per plant, root diameter and length, and root fresh weight should be considered as indices for selecting a high-yielding sweet potato variety.

3.3.1. Weevil damage

The three and two-way interaction effect of location, variety, and harvesting time showed a non-significant ($p \geq 0.05$) difference for weevil damage. However, the main effects of location, variety, and harvesting time showed significant ($p < 0.05$) differences (Appendix Table 3). A higher sweet potato weevil infestation (4.56) was recorded at the Babile site than at Rare (Table 11). This could be because Babile has warmer weather conditions than Rare, which favors weevil multiplication and infestation. On the other hand, the *Alamura* variety showed a lower weevil damage record (3.50) as compared to the *Kabode* and *Bakule* varieties. This result is in line with the finding of [43] where sweet potato roots are highly affected as harvesting time is delayed and at the early harvesting stage less damage to roots by sweet potato weevils. As harvesting time extends from 120 to 210 DAP, the incidence of weevil damage increased from no damage (1) to heavy damage (7.67), respectively (Table 11). Harvesting time had a major impact on weevil damage to sweet potato roots, especially at the Babile site. The results concur with those of [15], who discovered that sweet potato root injury increases with harvesting time increase from 90 to 180 DAP, which leads to an increase in non-marketable root yield.

3.4. Varietal and harvesting time effects on root nutritional compositions

3.4.1. Dry matter content (%)

The three-way interaction effect of location, variety, and harvesting time showed a non-significant ($p \geq 0.05$) difference for root dry matter content. However, the interaction between location and variety, location and harvesting time, and variety and harvesting time had a significant ($p < 0.05$) impact on the root dry matter content (Appendix Table 4). The highest root dry matter content (30.48 and 29.52 %) was measured from the *Alamura* variety at both the Babile and Rare sites. The lowest root dry matter was recorded from the

Table 8
The interaction effect of variety and location on non-marketable root yield of sweet potato at Rare and Babile during the 2022 main cropping season.

Treatment	Location	
Variety	Rare	Babile
Alamura	1.78^{bc}	1.56^{c}
Kabode	2.14^{ab}	2.07^{ab}
Bakule (local)	2.16^{a}	2.42^{a}
LSD (5 %)	0.36	
CV (%)	14.59	

This means that are followed by the same letter do not differ statistically at the 5 % level of significance.
Total root yield (t ha^{-1}).

Table 9
Interaction effect of variety and harvesting time on root length, marketable, non-marketable, and total root number, root fresh weight, marketable, non-marketable, and total root yield of sweet potato at Rare and Babile in East Hararghe Zone, Ethiopia.

Factors		Root Yield and Related Traits							
Variety	HT (DAP)	RL (cm)	MRN	NnMRN	TRN	RFW (g)	MRY (t ha^{-1})	NnMRY (t ha^{-1})	TRY (t ha^{-1})
Alamura	120	18.50^{b-d}	6.35^{b-d}	6.43^{de}	12.78^{ab}	775.50^{b-e}	29.76^{cd}	1.47^{e}	31.23^{cd}
	150	21.01^{a}	8.43^{a}	5.37^{e}	13.81^{ab}	1011.40^{a}	36.40^{a}	1.39^{e}	37.79^{a}
	180	20.17^{ab}	6.80^{ab}	6.86^{de}	13.66^{ab}	899.30^{ab}	32.22^{bc}	1.69^{de}	33.91^{bc}
	210	18.48^{b-d}	4.86^{d-f}	8.47^{b-d}	13.33^{ab}	801.20^{b-d}	27.02^{ef}	2.15^{b-d}	29.17^{de}
Kabode	120	19.40^{a-c}	6.57^{bc}	6.83^{de}	13.40^{ab}	868.30^{a-c}	32.45^{b}	1.52^{e}	33.97^{b}
	150	18.37^{b-e}	5.91^{b-d}	7.42^{c-e}	13.33^{ab}	799.50^{b-d}	29.18^{de}	1.71^{de}	30.89^{d}
	180	16.73^{d-f}	3.78^{e-g}	9.28^{bc}	13.06^{ab}	686.40^{d-f}	26.44^{fg}	2.43^{a-c}	28.86^{de}
	210	15.70^{fg}	3.42^{fg}	10.19^{ab}	13.61^{ab}	602.60^{fg}	24.25^{gh}	2.76^{a}	27.01^{ef}
***Bakule* (Local)**	120	14.09^{g}	3.16^{g}	11.71^{a}	14.87^{a}	487.00^{g}	19.67^{i}	2.97^{a}	22.65^{g}
	150	16.17^{e-g}	3.80^{e-g}	10.17^{ab}	13.97^{ab}	628.10^{e-g}	22.41^{h}	2.50^{ab}	24.91^{fg}
	180	17.63^{c-f}	5.11^{c-e}	7.03^{c-e}	12.14^{ab}	743.40^{c-f}	27.33^{d-f}	1.90^{c-e}	29.23^{de}
	210	18.47^{b-d}	5.43^{b-e}	6.41^{de}	11.84^{b}	729.00^{c-f}	28.65^{d-f}	1.79^{de}	30.44^{d}
Tukey (5 %)		2.22	1.67	2.40	2.94	148.83	2.59	0.59	2.73
CV (%)		6.25	15.81	15.08	11.12	9.96	4.67	14.59	4.59

The same letter in the column does not differ statistically at the 5 % level of significance, HT = Harvesting time, DAP = days after planting, RL = Root length, MRN = Marketable root number, NnMRN = non-marketable root number, TRN = Total root number, RFW = Root fresh weight, MRY = Marketable root yield, NnMRY = non-marketable root yield, TRY = Total root yield.

Table 10
Path coefficients showing direct and indirect effects for marketable root yield.

S. No.	Character	r with MRY	Direct effect	Indirect effect									
				VL	LAI	AGBM	RL	RD	MRN	NMRN	TRN	RFW	NMRY
1	**VL**	−0.38	−0.48	−0.48	0.25	0.08	−0.06	0.006	−0.28	0.24	−0.10	−0.06	0.03
2	**LAI**	0.12	0.33	−0.37	0.33	0.12	0.02	−0.008	0.10	0.05	−0.13	0.01	0.002
3	**AGBM**	0.44	0.16	−0.25	0.25	0.16	0.08	−0.015	0.32	−0.20	0.02	0.09	−0.01
4	**RL**	0.89	0.20	0.15	0.03	0.06	0.20	−0.03	0.74	−0.49	0.10	0.17	−0.04
5	**RD**	0.88	−0.03	0.09	0.09	0.08	0.17	−0.03	0.77	−0.46	0.05	0.16	−0.04
6	**MRN**	0.88	0.90	0.15	0.04	0.06	0.16	−0.03	0.90	−0.44	−0.07	0.15	−0.04
7	**NMRN**	−0.79	0.64	−0.18	0.03	−0.05	−0.15	0.02	−0.62	0.64	−0.36	−0.15	0.03
8	**TRN**	−0.13	−0.57	−0.08	0.08	−0.005	−0.03	0.002	0.12	0.40	−0.57	−0.05	0.001
9	**RFW**	0.89	0.20	0.15	0.02	0.08	0.17	−0.02	0.68	−0.49	0.14	0.20	−0.04
10	**NMRY**	−0.80	0.05	−0.24	0.01	−0.04	−0.15	0.02	−0.70	0.40	−0.01	−0.14	0.05

Where, VL = Vine length, LAI = Leaf area index, AGBM = Above-ground biomass, RL = Root length, RD = Root diameter, MRN = Marketable root number, NMRN = non-marketable root number, TRN = Total root number, RFW = Root fresh weight, NMRY = non-marketable root yield, MRY = Marketable root yield.

Table 11
Main effect of location, variety, and harvesting time on weevil infestation of sweet potato roots at Rare and Babile during the 2022 main cropping season.

Treatment	Sweet potato weevil infestation	
	Levels	Mean
Location	Rare	3.83^{b}
	Babile	4.56^{a}
	LSD (5 %)	0.47
Variety	*Alamura*	3.50^{b}
	Kabode	4.42^{a}
	Bakule (Local)	4.67^{a}
	LSD (5 %)	0.57
HT (DAP)	120	1.00^{d}
	150	2.67^{c}
	180	5.44^{b}
	210	7.67^{a}
	LSD (5 %)	0.66
	CV (%)	23.46

This means that is followed by the same letter and does not differ statistically at a 5 % level of significance for each factor, HT = Harvesting time, DAP = days after planting.

Bakule variety at both sites and *Kabode* at the Babile site (Table 12). The highest root dry matter contents of 28.32 and 27.69 % were recorded at 150 and 180 DAP from the Rare site, respectively, whereas starting from 120 DAP to 180 DAP resulted in significantly higher root dry matter at the Babile site. Conversely, the lowest root dry matter (25.17–27.01 %) was measured from Rare at 210 and 120 DAP and from the Babile site at 210 and 180 DAP (Table 13). *Alamura* variety harvested at 150 and 120 DAP resulted in the highest dry matter content (33.01 and 30.58 %), respectively. However, the lowest root dry matter content was recorded from the *Bakule* variety at 120 and 150 DAP (21.53 and 23.86 %) and from the *Kabode* variety at 210 DAP (22.58 %) (Table 14). This outcome is consistent with the research conducted by Ref. [15], who found that the dry matter content rose from planting to harvest up to 150 DAP but not to 180 DAP. Similarly [38], also revealed that as harvesting time increased from 90 to 150 DAP, the total dry mass of roots showed rising responses with delay in the harvest stage.

3.4.2. *Crude fibre content (%)*

The interaction effect of variety and harvesting time gave a highly significant ($p < 0.01$) difference in crude fiber content (Appendix Table 4). The larg est amount of crude fiber (2.59–3.18 %) was recorded for the *Alamura* variety harvested at 150, 180, and 210 DAP and from the *Kabode* variety harvested at all harvesting times. However, the lowest fiber concentration was found for the *Bakule* variety harvested at 120 and 150 DAP (1.51 and 1.89 %) (Table 14). This result is consistent with [44], who reported that there was an increase in fiber content with a delay in harvesting stages from 90 to 150 DAP for all sweet potato cultivars examined. Similarly [45], also noted that the dietary fiber of OFSP roots was higher as harvesting time extended 90 DAP. The increase in fiber content as harvesting time extends is due possibly to the conversion of other nutrients with time. The variation in dietary fiber is caused by several factors, such as nutritional composition, maturity, and genotype [15].

3.4.3. *Reducing sugar (g/100g)*

Similar to crude fiber, the interaction effect of variety and harvesting time showed a highly significant ($p < 0.01$) difference for reducing sugar content (Appendix Table 4). The highest amount of reducing sugar (10.60 and 9.92 g/100g) was recorded for the *Alamura* variety harvested at 150 and 180 DAP, respectively, followed by the *Kabode* variety at 120 DAP and the *Alamura* variety at 210 DAP. Whereas, the lowest reducing sugar (2.22 and 2.63 g/100g) was found for the *Bakule* variety harvested at 120 and 150 DAP (Table 14). [46], also reported that the reduced sugar contents of two sweet potato varieties increased at the 16th week's harvest compared to the roots harvested at the 12th week.

3.4.4. *Zinc contents (mg/100g)*

The effect of variety by harvesting time interaction was a highly significant ($p < 0.01$) difference in the zinc content of sweet potato roots (Appendix Table 5). The highest zinc content was found for *Alamura* harvested at 150, 180, and 210 DAP (3.79, 3.48, and 3.28 mg/100g) and for *Kabode* harvested at 120, 150, and 180 DAP (3.23, 3.37, and 2.98 mg/100g), respectively. The lowest amount of zinc (0.97–1.62 mg/100g) was recorded from *Bakule* harvested at 120, 150, and 180 DAP (Table 14). This result is also closely related to the observation of [15], where root zinc content stabilized from 120 to 180 DAP.

3.4.5. *Iron contents (mg/100g)*

The interaction effect of variety with harvesting time showed a highly significant ($p < 0.01$) difference in root iron content (Appendix Table 5). Root iron content also followed a similar trend with zinc with the highest amount found for the *Alamura* variety harvested at 150, 180, and 210 DAP and for the *Kabode* variety harvested at 120 and 150 DAP ranging from 13.01 to 14.47 mg/100g. The lowest amount of iron (3.42 and 3.64 mg/100g) was recorded from the *Bakule* variety at 120 and 150 DAP, respectively, (Table 14). This finding reveals that the local white-fleshed variety (*Bakule*) contains less zinc and iron content than the two orange-fleshed varieties. Furthermore, the results are consistent with the findings of [15], that the root iron contents were stabilized as harvesting times were delayed.

3.4.6. *Beta-carotene (μg/100g)*

The effect of location with variety and harvesting time was non-significant ($p \geq 0.05$) for β-carotene contents of roots (Appendix Table 5). However, the interaction of variety with harvesting time showed a significant ($p < 0.05$) difference in root β-carotene level. As a result, the highest amount of root β-carotene level (11809 μg/100g) was measured for the *Alamura* variety harvested at 150 DAP, which was followed by this variety at 180 DAP (10478 μg/100g). As expected, the lowest β-carotene levels were found for the white-fleshed local variety, *Bakule*, harvested at 120 and 150 DAP (1222 and 1457 μg/100g), respectively, (Table 14). The two OFSP (*Alamura* and *Kabode*) varieties showed higher β-carotene contents than the local variety and can overcome the problem of VAD identified in the study area. Therefore, harvesting the *Alamura* variety at 150 DAP produces better β-carotene content with consistently higher tuberous root yield at both sites. This result is in line with the finding of [15], that the β-carotene content of OFSP varieties remained constant from 90 DAP to 150 DAP and then increased to 180 DAP (15.3–19.0 mg/100g). According to Ref. [33], report, the highest vitamin A (919.2 μg/100 g RAE) or (11,030 μg/100g of β-carotene) fresh weight basis was recorded in CIP 440267.2 variety and recommended in Bangladesh based on yield and quality. [47], also discovered that OFS from Kelantan contained a relatively high concentration of β-carotene followed by α-carotene and zeaxanthin. According to Ref. [48], the amount of β-carotene found in sweet potatoes ranged from 9195 μg/100g DW (dry weight) in white-fleshed to 37,603 μg/100g DW in orange-fleshed sweet potato cultivars. However, the value of this result is slightly lower than what was reported by researchers might be due to environmental effects and varietal differences. The β-carotene content of *Alamura* and *Kabode* varieties tends to decrease as harvesting time extends beyond 150 DAP possibly due to relatively early maturing varieties and conversion of carotenoids into other nutrients as

Table 12
Interaction effect of variety and location on dry matter content of sweet potato roots at Rare and Babile in East Hararghe during the 2022 main cropping season.

Treatment	Location	
Variety	Rare	Babile
Alamura	29.52^{a}	30.48^{a}
Kabode	26.93^{b}	25.68^{bc}
Bakule (local)	24.24^{c}	25.73^{bc}
LSD (5 %)	1.54	
CV (%)	4.68	

Means that are followed by the same letter do not differ statistically at the 5 % level of significance.

Table 13
The interaction effect of harvesting time and location on dry matter content of sweet potato roots at Rare and Babile during the 2022 main cropping season.

Treatment	Location	
HT(DAP)	Rare	Babile
120	26.40$^{b\text{-}d}$	28.11^{ab}
150	28.32^{a}	28.25^{ab}
180	27.69$^{a\text{-}c}$	27.01$^{a\text{-}d}$
210	25.17^{d}	25.81^{cd}
LSD (5 %)	1.90	
CV (%)	4.68	

Means that are followed by the same letter do not differ statistically at the 5 % level of significance.

Table 14
Interaction effect of variety and harvesting time on dry matter content, crude fiber, reducing sugar, zinc, iron, and β-carotene content of sweet potato root at Rare and Babile in East Hararghe Zone, Ethiopia.

Factors		Root Nutritional Compositions					
Variety	HT (DAP)	DMC (%)	Crude fiber (%)	RS (g/100g)	Zn (mg/100g)	Fe (mg/100g)	β-carotene (μg/100g)
Alamura	120	30.58^{ab}	2.19^{cd}	5.27^{ef}	2.54^{cd}	9.91^{d}	7895^{c}
	150	33.01^{a}	3.18^{a}	10.60^{a}	3.79^{a}	14.47^{a}	11809^{a}
	180	29.80^{bc}	3.05^{ab}	9.92^{ab}	3.48^{ab}	13.68^{a}	10478^{b}
	210	26.60^{ef}	2.88^{ab}	8.83^{b}	3.28$^{a\text{-}c}$	13.36^{ab}	7614^{cd}
Kabode	120	29.66$^{b\text{-}d}$	2.67$^{a\text{-}c}$	8.57^{bc}	3.23$^{a\text{-}c}$	13.01$^{a\text{-}c}$	8179^{c}
	150	27.99$^{c\text{-}e}$	2.73$^{a\text{-}c}$	7.13^{cd}	3.37^{ab}	13.09$^{a\text{-}c}$	7391^{cd}
	180	24.99^{fg}	2.62$^{a\text{-}c}$	5.73$^{d\text{-}f}$	2.98$^{a\text{-}c}$	11.84^{bc}	6772^{d}
	210	22.58^{gh}	2.59$^{a\text{-}c}$	4.49^{f}	2.83^{bc}	11.76^{c}	5487^{e}
Bakule (Local)	120	21.53^{h}	1.51^{e}	2.22^{g}	0.97^{f}	2.42^{f}	1222^{g}
	150	23.86^{gh}	1.89^{de}	2.63^{g}	1.44^{ef}	3.64^{f}	1457^{g}
	180	27.27$^{d\text{-}f}$	2.46$^{b\text{-}d}$	5.57$^{d\text{-}f}$	1.62^{ef}	5.84^{e}	2492^{f}
	210	27.29$^{c\text{-}f}$	2.44$^{b\text{-}d}$	6.73^{de}	1.83^{de}	5.82^{e}	2956^{f}
Tukey (5 %)		2.52	0.61	1.69	0.82	1.60	983.01
CV (%)		4.68	12.29	13.13	15.79	8.11	8.05

The same letter in the column does not differ statistically at the 5 % level of significance, HT = Harvesting time, DAP = days after planting, DMC = Dry matter content.

colour changes.

4. Conclusion

The combined analysis of variance over the two sites showed that the interaction effect of variety with harvesting time had a significant ($p < 0.05$) impact on growth, yield, and yield-related traits as well as on nutritional components of sweet potato crops. As a result, the two OFSP varieties (*Alamura* and *Kabode*) gave higher root yields at an earlier harvesting stage than *Bakule* (local) with higher micronutrients (Zn and Fe) and other nutritional components. More specifically, the *Alamura* variety harvested at 150 DAP is even better than the *Kabode* variety in many components. Having the advantages of root yields and physicochemical compositions, the

Alamura variety yields comparable vine and above-ground fresh biomass to the local cultivar that is used for animal feed. Path coefficient analysis showed that marketable root number per plant, root diameter and length, and root fresh weight have a strong positive direct effect on selecting a higher marketable root-yielding variety. Thus, from this result, the *Alamura* variety harvested at 150 DAP gave better above-ground fresh biomasses, marketable root yield, and physicochemical composition than *Kabode* and local varieties. Therefore, it has a high potential to combat malnutrition and food insecurity problems that are prevalent in eastern parts of the country with its higher root yield, beta-carotene content, and other essential micronutrients.

Data availability statement

Agronomic and nutritional data are included in the supplementary file submitted with the manuscript.

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CRediT authorship contribution statement

Chala Begna Bedassa: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Setegn Gebeyehu:** Writing – review & editing, Visualization, Validation, Supervision, Methodology, Conceptualization. **Wassu Mohammed:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Dandena Gelmesa:** Writing – review & editing, Visualization, Validation, Supervision, Methodology, Conceptualization. **Getachew Neme:** Writing – review & editing, Supervision, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix Tables

ANOVA Table for Yield, Yield-related, and Physicochemical Parameters

Appendix Table 1
Combined mean square of ANOVA for vine length, LAI, and fresh biomass of sweet potato at Rare and Babile

Source	Df	Vine Length (cm)	LAI	Biomass (t/ha)
Loc	1	323^{ns}	0.61*	0.80^{ns}
Var	2	127374***	19.72***	1342.53***
HT (DAP)	3	2857***	0.71***	120.50***
Loc*Var	2	124^{ns}	0.39*	9.23^{ns}
Loc*DAP	3	144^{ns}	0.08^{ns}	1.32^{ns}
Var*DAP	6	2552***	1.65***	222.93***
Loc*Var*DAP	6	80^{ns}	0.14^{ns}	3.47^{ns}
Error	46	112	0.11	4.57

Where *** = significant at 0.001, ** = significance at 0.01, * = significant at 0.05, ns = non-significant, Df = degree of freedom, Loc = location, LAI = Leaf Area Index, DAP = Days after planting, Var = Variety, and HT = Harvesting Time.

Appendix Table 2
Combined mean square of ANOVA for root length, root diameter, marketable root number, non-marketable root number, and total root number of sweet potato at Rare and Babile

Source	Df	RL (cm)	RD (cm)	MRN	NMRN	TRN
Loc	1	11.46**	1.66^{ns}	0.002^{ns}	125.27***	126.35***
Var	2	54.38***	43.37***	32.71***	28.30***	0.24^{ns}

(*continued on next page*)

Appendix Table 2 (*continued*)

Source	Df	RL (cm)	RD (cm)	MRN	NMRN	TRN
HT (DAP)	3	5.40**	5.82***	6.60***	2.58^{ns}	3.40^{ns}
Loc*Var	2	4.52*	1.46^{ns}	0.26^{ns}	2.37^{ns}	4.21^{ns}
Loc*DAP	3	6.71**	0.77^{ns}	0.74^{ns}	0.67^{ns}	0.66^{ns}
Var*DAP	6	21.29***	28.07***	13.90***	30.25***	5.43*
Loc*Var*DAP	6	0.36^{ns}	1.83*	1.37^{ns}	0.82^{ns}	1.93^{ns}
Error	46	1.25	0.79	0.70	1.46	2.19

Where *** = significant at 0.001, ** = significance at 0.01, * = significant at 0.05, ns = non-significant, Df = degree of freedom, RL = Root length, RD = Root diameter, Loc = location, DAP = Days after planting, Var = Variety, and HT = Harvesting Time, MRN = Marketable root number, NMRN = Non-marketable root number, TRN = Total root number.

Appendix Table 3

Combined mean square of ANOVA for root fresh weight, marketable, non-marketable, and total root yield per hectare, and weevil damage of sweet potato at Rare and Babile

Source	Df	RFW (g)	MRY (t/ha)	NMRY (t/ha)	TRY (t/ha)	Weevil damage
Loc	1	67735**	28.51***	0.03^{ns}	30.29***	9.39**
Var	2	306950***	280.48***	2.39***	232.65***	9.06***
HT (DAP)	3	46446***	27.35***	0.42**	21.96***	156.94***
Loc*Var	2	46913***	0.60^{ns}	0.36*	0.93^{ns}	1.39^{ns}
Loc*DAP	3	561^{ns}	1.01^{ns}	0.03^{ns}	1.16^{ns}	1.39^{ns}
Var*DAP	6	94976***	124.49***	2.08***	97.26***	1.50^{ns}
Loc*Var*DAP	6	5988^{ns}	1.87^{ns}	0.05^{ns}	1.85^{ns}	0.50^{ns}
Error	46	5616	1.71	0.09	1.89	0.97

Where *** = significant at 0.001, ** = significance at 0.01, * = significant at 0.05, ns = non-significant, Df = degree of freedom, RFW = Root fresh weight, MRY = Marketable root yield, NMRY = Non-marketable root yield, TRY = Total root yield, Loc = location, DAP = Days after planting, Var = Variety, and HT = Harvesting Time.

Appendix Table 4

Combined mean square of ANOVA for root dry matter, crude fiber, and reducing sugar content of sweet potato at Rare and Babile

Source	Df	Dry matter (%)	Crude fiber (%)	Reducing Sugar (g/100g)
Loc	1	2.89^{ns}	0.58*	0.76^{ns}
Var	2	162.03***	3.67***	114.34***
HT (DAP)	3	24.50***	1.30***	10.57***
Loc*Var	2	12.70**	0.13^{ns}	0.06^{ns}
Loc*DAP	3	4.75*	0.02^{ns}	0.38^{ns}
Var*DAP	6	62.12***	0.59***	35.49***
Loc*Var*DAP	6	2.01^{ns}	0.09^{ns}	0.97^{ns}
Error	46	1.61	0.10	0.72

Where *** = significant at 0.001, ** = significance at 0.01, * = significant at 0.05, ns = non-significant, Df = degree of freedom, Loc = location, DAP = Days after planting, Var = Variety, and HT = Harvesting Time.

Appendix Table 5

Combined mean square of ANOVA for root zinc, iron, and beta-carotene contents of sweet potato at Rare and Babile

Source	Df	Zn (mg/100g)	Fe (mg/100g)	β-carotene (μg/100g)
Loc	1	1.76**	6.33**	2893171**
Var	2	23.91***	540.34***	3.419E+08***
HT (DAP)	3	1.24***	17.07***	9066119***
Loc*Var	2	0.37^{ns}	0.40^{ns}	88354.4^{ns}
Loc*DAP	3	0.03^{ns}	0.55^{ns}	136259^{ns}
Var*DAP	6	0.81***	13.87***	1.380E+07***
Loc*Var*DAP	6	0.06^{ns}	0.71^{ns}	53048.1^{ns}
Error	46	0.17	0.65	245006

Where *** = significant at 0.001, ** = significance at 0.01, * = significant at 0.05, ns = non-significant, Df = degree of freedom, Loc = location, DAP = Days after planting, Var = Variety, and HT = Harvesting Time.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e37153.

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