International Journal of Horticultural Science and Technology
Journal homepage: https://ijhst.ut.ac.ir

Nutritional, Anti-Nutritional, and Functional Characteristics of Orange-Fleshed Sweetpotato Varieties in Response to Soil Nutrition

Miheret Hendebo Lemma[1,4], Ali Mohammed Ibrahim[2], Fekadu Gurmu[3], Ashenafi Haile[4], Hussien Mohammed Beshir[4]*

1 Department of Horticulture, Dilla University, Dilla, Ethiopia
2 Departments of Postharvest Management, Jimma University, P.O. Box 307, Jimma, Ethiopia
3 Ethiopian Agricultural Research Institute, P.O. Box 8115, Addis Ababa, Ethiopia
4 School of Plant and Horticultural Sciences, Hawassa University, P.O. Box 05, Hawassa, Ethiopia

ARTICLE INFO

Article history:

Received: 4 September 2024,
Received in revised form: 24 May 2025,
Accepted: 25 May 2025,

Article type:

Research paper

Keywords:

Bioavailability,
Fertilizer application rate,
Mineral content,
Proximate composition,
Varietal performance,
Vitamin A deficiency

*Corresponding author's email: muzeyenyesuf2003@yahoo.com

ABSTRACT

Orange-fleshed sweet potatoes have gained recognition as a regular component of the human diet, particularly for their potential to enhance nutritional food security, with a focus on addressing vitamin A deficiency. This study aimed to identify the optimal combination of nitrogen (0, 23, and 46 kg N ha^{-1}) and phosphorus (0 and 46 kg ha^{-1} P_2O_5) fertilizer levels to improve the nutritional, anti-nutritional, and vitamin profiles of five orange-fleshed sweet potato varieties: NASPOT-12, Kulfo, Kabode, Alamura, and Dilla. Among these, the Alamura variety, cultivated with 23 kg ha^{-1} N and 46 kg ha^{-1} P_2O_5, yielded the highest levels of calcium, vitamin E, zinc, and tannins. The Kabode variety recorded the highest protein content, while Alamura and Kulfo showed elevated levels of anti-nutritional factors, specifically tannins and phytates, respectively. NASPOT-12, grown under 23 kg ha^{-1} N and 46 kg ha^{-1} P_2O_5, exhibited superior performance in proximate composition (fat, ash, carbohydrates, and energy), mineral content (magnesium and iron), vitamin content (β-carotene and vitamin C), and functional properties (water absorption and gelatinization temperature). The findings highlight the critical role of nutrient management, as fertilization can influence both beneficial and adverse aspects of food quality, including mineral composition and protein digestibility. Additionally, the study underscores the importance of varietal selection in maximizing the nutritional value of orange-fleshed sweet potatoes, thereby contributing to efforts aimed at combating malnutrition and improving food security.

Introduction

Sweet potatoes (*Ipomoea batatas*) are highly nutritious root crops with considerable economic importance, particularly in nutrient-poor soils (Pardales and Roa, 2002; Uwah et al., 2013). Among these, orange-fleshed sweet potato (OFSP) varieties are especially valuable due to their high β-carotene content—a precursor of vitamin A that is critical in addressing deficiencies affecting over 700 million people in developing countries (Mehansho, 2006). While the roles of nitrogen (N) and phosphorus (P) fertilizers in enhancing root crop yields are well documented, their specific effects on the nutritional and functional qualities of OFSP remain underexplored, despite the vital roles N and P play in plant metabolism (Souri and Hatamian, 2019).

Nitrogen deficiency can adversely affect crop quality, whereas appropriate N application has been shown to improve sweet potato growth and nutritional value (Essilfie, 2015; Jennings, 2009). Similarly, phosphorus is essential for root development and energy transfer (Ishfaq et al., 2023), yet its varietal-specific interactions within

OFSP cultivation remain poorly understood, underscoring the need for targeted research. Insights from related crops reinforce the broader significance of nutrient management. For example, Pagard et al. (2024) found that fertigation and boron foliar sprays improved yield and physiological traits in bell pepper, while Pakrah et al. (2021) demonstrated how factors such as maturity stage and drying methods influenced the nutritional quality of Persian walnuts—findings that mirror the potential impact of fertilizer strategies on OFSP.

Research on other root crops, including cassava and yams, further illustrates the importance of balanced fertilization. Kumar et al. (2023) reported enhanced tuber yield and quality with adequate N and P application, while studies by Chandrasekara and Kumar (2016) and Tewodros et al. (2017) showed that proper nutrient supply can reduce anti-nutritional compounds such as tannins and phytates. Alexopoulos et al. (2016) also emphasized the combined effects of varietal selection and nutrient management on functional traits in root crops. Moreover, nitrogen application has been associated with increased β-carotene accumulation and vitamin C biosynthesis, both vital for alleviating micronutrient malnutrition (Islam et al., 2009; Souri and Hatamian, 2019). Phosphorus contributes to enhanced mineral content, antioxidant activity, and potential reductions in anti-nutritional factors, thereby improving nutrient bioavailability (Alexopoulos et al., 2016).

In addition to nutritional traits, functional properties such as water absorption, gelatinization temperature, and texture (critical for both industrial and household use) are influenced by nutrient availability (Ishfaq et al., 2023). Although sweet potatoes can perform reasonably well in marginal soils (Uwah et al., 2013), supplemental fertilization significantly improves both yield and quality (Esan et al., 2021). Nitrogen is particularly important for dry matter accumulation and root development, while both N and P influence the crop's nutritional composition and functional properties (Jennings, 2009; Essilfie, 2015; Chandrasekara and Kumar, 2016; Alexopoulos et al., 2016). Effective soil fertility management is therefore, essential not only for improving agronomic performance but also for addressing food and nutritional security in developing regions (Bouis and Saltzman, 2017).

Accordingly, this study determined the effects of nitrogen and phosphorus fertilization on the biochemical, nutritional, and functional properties of selected OFSP varieties. It aims to enhance essential nutrient levels, reduce anti-nutritional compounds, evaluate key functional traits, and explore variety-specific responses to support improved OFSP quality and sustainable agricultural practices.

Materials and Methods

Study area description

The experiment was conducted at Hawassa Research Center, South Agricultural Research Institute, Sidama Regional State, Ethiopia, in two cropping years (2019 and 2020, April to October). The area is situated at 7° 3' 54" N, 38° 28' 59" E, and altitude of 1708 m.a.s.l. which is about 275 km south of Addis Ababa (EFDD Hawassa, 2019). The annual temperature and rainfall data were presented in Table 1. The soil at the experimental field was loamy, and its physicochemical characteristics were tested during both cropping years (Table 1).

Table 1. Soil physicochemical characteristics before planting, annual rainfall and mean temperatures of the experimental site in 2019 and 2020.

	Years	
Soil properties	**2019**	**2020**
Soil depth (cm)	0-30	0-30
pH water (1:2.5)	5.65	5.94
Organic Carbon (%)	2.24	1.50
Organic Matter %	5.31	5.31
Total N (%)	0.15	0.166
Available P (mg kg^{-1} or ppm)	8.11	7.27
CEC (meq. 100 g^{-1} soil)	25.30	28.40
Bulk density (g cm^{-3})	1. 30	1.28
Sand (%)	63.00	56.00
Clay (%)	26.00	28.00
Silt (%)	15.00	21.00
Annual mean Temperatures and Rain fall		
Maximum temperature (°C)	28.08	27.53
Minimum temperature (°C)	14.06	14.14
Annual rain fall (mm)	1046.9	1277.5

Experimental materials, treatment, and design

In this study, five orange-fleshed sweet potato (OFSP) varieties (NASPOT-12, Kulfo, Kabode, Alamura, and Dilla) were sourced from the Southern Agricultural Research Institute (SARI). NASPOT-12, originally introduced from Uganda, was evaluated alongside four Ethiopian varieties: Kulfo (LO-323), Kabode (SPK 004/6/6), Alamura (Ukr/Eju-10), and Dilla (Ukr/Eju-13). Among these, NASPOT-12, Kabode, and Dilla represent recent introductions intended for production in Ethiopia, whereas Kulfo and Alamura are widely cultivated in Southern Ethiopia. The inclusion of both newly introduced and commonly grown varieties was essential to enable comparative evaluation and inform future recommendations for variety selection. The experimental design incorporated three nitrogen levels (0, 23, and 46 kg N ha^{-1}) and two phosphorus levels (0 and 46 kg P_2O_5 ha^{-1}). These fertilizer rates fall within the blanket recommendations for root and tuber crops in Ethiopia, providing a relevant basis for treatment selection. A 5 × 3 × 2 factorial arrangement was employed using an alpha-lattice design with three replications. Each experimental plot measured 2.4 × 2.4 m (4.8 m^2), with plant spacing set at 60 cm between rows and 30 cm between plants. Each plot comprised four rows with eight plants per row, totaling 32 plants per plot. Semi-hardwood vine cuttings, each 30 cm in length, were used for planting. Fertilizer application was conducted in two phases: an initial application at planting, followed by a top-dressing of nitrogen 45 d later. Standard agronomic practices were implemented according to the Ethiopian Agricultural Research Organization (EARO) guidelines (EARO, 2004).

Methods for flour production

Following harvest, three plants with medium-sized, uniform, and undamaged roots were selected from each plot. These roots were immediately transported to the laboratory for chemical analysis. Orange-fleshed sweet potato flour was prepared following the method described by Dako et al. (2016). To ensure representation across all sizes and varieties within 24 hours of harvest, root samples from the three selected plants were carefully sorted and processed separately in the laboratory.

The roots were manually washed with clean water to remove soil and other adhering materials. To prevent enzymatic browning, the samples were manually peeled, immersed in water, and then sliced to a uniform thickness of 2.00 mm using a stainless-steel knife. The slices were blanched in hot water at 80 °C for five min and immediately cooled in cold water to prevent overcooking, as described by Eluagu and Onimawo (2010). After cooling, the slices were drained on a perforated plastic tray and then dried overnight in a hot air oven (model DHG-9055A) at 60 °C until they became brittle and suitable for milling.

The dried samples were ground using a high-speed electric grinder (Sampling Machine Model FW100) into a fine powder capable of passing through a 0.425-mm sieve.

Determination of OFSP chemical composition

Proximate analysis

Moisture

The moisture content of the samples was determined in accordance with the AOAC (2005) method. A 5 g portion of the sample (W1) was placed into a pre-weighed crucible (W0) and dried in a hot-air oven at 130 °C for approximately 1 h. Following drying, the crucible was removed from the oven and transferred to a desiccator, where it was allowed to cool for 30 min. The cooled sample was then weighed (W2). The weight of the dried sample alone (W3) was obtained by subtracting the initial weight of the empty crucible (W0) from the final weight (W2). The moisture content was calculated using the following equation:

$$\text{Moisture } (\%) = \frac{W1 - W3}{W1} x\ 100 \quad (1)$$

Where: W0 = mass of empty crucible (g); W1 = mass of sample before drying (g); W2 = mass of sample and crucible after drying (g); W3 = mass of dried sample alone (the difference between W2 and W0).

Ash

The ash content was determined in accordance with the AOAC (2005) method. A 20 g portion of the sample was prepared in triplicate, each portion placed into a porcelain crucible. The crucibles were cooled in a desiccator, carbonized, weighed, and then transferred to a cool electric muffle furnace. Ashing was conducted overnight at a temperature of 550 °C to ensure complete combustion. Upon completion, the crucibles containing ash were placed directly into a desiccator, cooled for 30 min, and promptly weighed. The ash content was calculated and expressed as a percentage using the following equation:

$$\text{Ash } (\%) = \frac{W3 - W1}{W2 - W1} x\ 100 \quad (2)$$

Where: W1 is mass of crucible (g), W2 is sampled mass with crucible (g), and W3 is final mass of sample with crucible (g).

Crude protein

Crude protein content was determined using the Kjeldahl method, following AOAC method 978.02, with the nitrogen content multiplied by 6.25 to obtain

the percentage of protein. Fat content was determined according to AOAC method 920.39.

For crude protein determination, 1 g of sample was placed in a digestion flask with 5 mL of H_2SO_4. Anhydrous Na_2SO_4 was added to elevate the boiling point of H_2SO_4, while $CuSO_4$ served as a catalyst to accelerate the reaction in the presence of the digestion mixture. Digestion was carried out for 6 h, or until the flask contents became clear. The digested samples were then diluted with water, followed by the addition of 40% NaOH to neutralise the acid and render the solution slightly alkaline.

The liberated ammonia was distilled into a receiving flask containing 4% boric acid solution, with methyl red used as an indicator to determine the nitrogen content. Boric acid served for indirect titration, with the ammonia-bound borate ions titrated directly using 0.1 N HCl. The crude protein percentage was calculated according to the following equation:

$$\text{N (\%)} = \frac{\text{V HCl in L x N HCl x (ca.0.1) x 14}}{\text{Sample weight in g on dry matter basis (db)}} x\ 100 \quad (3)$$

Where: V is volume of HCl in L consumed to the end point of the titration, N is the normality of HCl, and 14 is the molecular weight of nitrogen. Protein (%) was calculated by multiplying N (%) with factor 6.25.

Crude fat

Crude fat content was determined using the Soxhlet extraction method in accordance with AOAC (2005). A 5 g portion of the sample was weighed into an extraction thimble, and a flat-bottom flask was also weighed. The thimble was positioned midway within the extractor, and the weighed sample was transferred into it. The thimble was then plugged with cotton wool and extracted with 200 mL of petroleum ether for 6 h. Following extraction, the solvent-free fat in the flask was dried in an oven at 105 °C for 1 h, cooled in a desiccator, and weighed. The crude fat content was calculated using the following equation:

$$\text{Crude fat (\%)} = \frac{\text{We+Wf)} - \text{Wf}}{\text{Ws}} x\ 100 \quad (4)$$

Where: We = Weight of extract, Wf = Weight of flux, and Ws = Weight of sample.

Crude fiber

Crude fiber content was determined in accordance with AOAC (2005) procedures. A 20 g portion of the sample was placed in the extraction unit, and 200 mL of hot 0.2 N H_2SO_4 was added. The sample was digested for 30 min, after which the acid was drained and the residue washed thoroughly with hot distilled water. The fiber was extracted and partially dried by moistening the residue with a small quantity of acetone, which was then allowed to drain. The sample was subsequently incinerated in a furnace at 550 °C for 3 h, until all carbonaceous matter was completely combusted. The crucible containing the remaining ash was cooled in a desiccator and weighed. The crude fiber percentage was calculated using the following equation:

$$\text{Crude fiber (\%)} = \frac{\text{Weight of residue} - \text{Weight of ash}}{\text{Weight of sample}} x\ 100 \quad (5)$$

Total carbohydrate (CHO)

The carbohydrate content of the milled sweet potatoes was determined as described by Ihekoronye and Ngoddy (1985) and calculated using the following equation:

$$\text{CHO (\%)} = 100 - \text{\% (ash + protein + fat + crude fiber + moisture)} \quad (6)$$

Determination of OFSP mineral composition

The dietary mineral content—magnesium, iron, calcium, and zinc—was determined using the dry ashing method as described in AOAC (2000) and quantified with an atomic absorption spectrophotometer (Model 200, Germany), employing air-acetylene as the atomization energy source. The absorbance of iron, zinc, and calcium was measured at wavelengths of 248.3, 213.8, and 422.7 nm, respectively. Mineral concentrations were estimated from calibration curves prepared using standard solutions of iron wire, zinc oxide (ZnO), and calcium carbonate ($CaCO_3$) at concentration ranges of 1–5, 0.5–2.5, and 2–10 mg kg^{-1}, respectively. Potassium and sodium levels were determined by flame photometry (AOAC, 1984), while phosphorus content was measured colorimetrically using the Vanado–molybdate method (AOAC, 1984).

$$\text{Phosphorus (mg/100g)} = \text{C} \times \text{V} \times \text{df W} \quad \ldots\ldots\ldots \quad (7)$$

Where C = the concentration of the element in the sample solution in mg L^{-1}; V = the volume of the undiluted sample solution in mL; W = the sample weight in grams; and df = the dilution factor.

Determination of OFSP functional properties

pH

The pH of the flour samples was determined by mixing approximately 10 g of each sample with 100 mL of distilled water. The mixture was allowed to stand at room temperature for 30 min to facilitate proper extraction. The pH of the resulting supernatant was then measured using a pH meter previously calibrated with buffer solutions of pH 4.0 and 7.0.

Water absorption capacity

Water absorption capacity was determined by weighing approximately 1 g of flour into a conical graduated centrifuge tube and dispersing it in 10 mL of distilled water. The mixture was thoroughly shaken for 1 min at room temperature and allowed to stand for 30 min. It was then centrifuged at 4,000 rpm for 30 min. The volume of free water was recorded directly from the centrifuge tube. The amount of absorbed water was calculated by subtracting the free water volume from the total water volume, then multiplying by the density of water (1 g mL^{-1}). Results were expressed as grams of absorbed water per 100 g of flour.

Bulk density

Bulk density was determined following the method of Konak et al. (2002). Approximately 50 g of flour was weighed into a 100 mL graduated measuring cylinder. The cylinder was gently tapped continuously until the flour was compacted. Bulk density was calculated as the ratio of the flour weight (g) to its packed volume (cm^3).

Oil absorption

Oil absorption capacity was measured by weighing 1 g of the sample into a 25 mL centrifuge tube and adding 5 mL of refined vegetable oil. The mixture was agitated for 2 min using a vortex mixer, then centrifuged at 4,000 rpm for 20 min. The supernatant was decanted and discarded, and adhering oil was removed. The tube was reweighed, and oil absorption capacity was calculated based on the weight change after the process.

Determination of anti-nutritional and vitamins composition

Phytate

Phytate content was determined according to the method of Vaintraub and Lapteva (1988). Samples were extracted with 2.4% HCl for 1 h, followed by centrifugation. A 3 mL aliquot of the supernatant was reacted with 1 mL of Wade reagent (0.03% $FeCl_3 \cdot 6H_2O$ and 0.3% sulfosalicylic acid in distilled water). Absorbance was measured at 500 nm using a UV–Vis spectrophotometer (Model DU-64, Beckman Coulter, Houston, TX, USA). The absorbance reading was adjusted by subtracting the blank value, and phytate concentration (mg 100 g^{-1} sample) was calculated from a phytic acid standard curve (5–36 mg kg^{-1}).

Tannin

Tannin content was determined using the modified vanillin–HCl–methanol method (Price et al., 1978; Siwela et al., 2007). Approximately 0.2 g of sweet potato flour was extracted with 10 mL of 1% HCl for 24 h. A 1 mL aliquot of the extract was mixed with 5 mL of vanillin–HCl reagent, prepared by combining 8% concentrated HCl in methanol with 4% vanillin in methanol (50:50, v/v). The mixture was incubated for 20 min at 30 °C, and absorbance was read at 450 nm using a UV–Vis spectrophotometer (DU-64, Beckman Coulter). Tannin concentration was determined from a catechin calibration curve and expressed as mg catechin g^{-1} sample.

Vitamin C

Vitamin C content was determined following a modified method by Abushita et al. (1997). A 10 g sample was homogenized with an extraction solution of 0.3 M meta-phosphoric acid and 1.4 M acetic acid at a 1:1 sample-to-solution ratio. The mixture, placed in a conical flask wrapped in aluminum foil, was agitated at 100 rpm on an orbital shaker for 15 min at room temperature. It was then filtered through Whatman No. 4 filter paper to obtain a clear extract. All determinations were performed in triplicate.

β-Carotene

β-Carotene was extracted using a modified method from Tee et al. (1996). A 10 g sample was homogenized with 40 mL of 99.8% ethanol and 10 mL of 100% (w/v) potassium hydroxide for 3 min. The mixture was saponified by heating for 30 min under reflux, then cooled to room temperature with intermittent stirring to prevent aggregation. The mixture was transferred to a separation funnel, and 50 mL of n-hexane was added. After vigorous shaking and separation, the upper hexane layer was collected. The aqueous layer was extracted twice more with 50 mL of n-hexane each time, and the hexane layers were pooled. The combined extract was washed with distilled water until free of alkali, as confirmed by phenolphthalein (1%). Residual water was removed by filtration through anhydrous sodium sulfate. The solvent was evaporated under reduced pressure at 45 °C using a rotary evaporator, and the residue was diluted with n-hexane to 10 mL. All analyses were conducted in triplicate.

Data analysis

Data were analyzed using the PROC MIXED procedure in SAS software version 9.2 (SAS Institute, 2008). ANOVA assumptions, including homogeneity of variance and normality of residuals, were verified prior to analysis. Data from the two years of the study were pooled. Fixed effects included variations and treatments involving nitrogen and phosphorus. Random effects included year, block nested within year, nitrogen treatment, phosphorus treatment, variety, and all two- and three-way interactions. Significant interactions—variety × phosphorus, variety × nitrogen, nitrogen × phosphorus, and variety × nitrogen × phosphorus—were reported only when statistically significant.

Results

Proximate composition

The interaction effects of nitrogen (N), phosphorus (P_2O_5), and variety significantly influenced the proximate composition of orange-fleshed sweet potato (OFSP) tubers (Table 2). Moisture content varied markedly among treatments and varieties, with the highest value (7.23%) recorded in the Kulfo variety at 23 kg ha^{-1} N and 46 kg ha^{-1} P_2O_5, and the lowest (4.26%) in the Dilla variety under the control (unfertilized) treatment. These results indicate that both genetic background and nutrient management play critical roles in determining moisture retention in OFSP tubers.

Protein content was likewise significantly affected by the N × P × variety interaction. The highest values were observed in Dilla (4.29%), Kabode (4.25%), and NASPOT-12 (4.08%) at moderate fertilization levels (23/46 kg ha^{-1} N/P_2O_5), whereas the lowest (~2.39%) occurred in unfertilized Alamura and Dilla. This pattern suggests that moderate nutrient inputs enhance protein synthesis, underscoring the synergistic effects of genotype and fertilizer regime.

Fat content also responded positively to increased fertilization, with peak values recorded in NASPOT-12 (2.52%) and Kulfo (2.40%) under the highest fertilization rate (46/46 kg ha^{-1} N/P_2O_5). In contrast, substantially lower fat concentrations (0.99–1.22%) were recorded in the control plots, highlighting the role of nutrient availability in promoting lipid accumulation.

However, this positive response to fertilization did not extend to all nutritional traits. Fiber content exhibited an inverse trend, declining with higher fertilizer levels. The maximum fiber concentration (4.06%) was found in unfertilized Kulfo, whereas the minimum (1.93%) occurred in Dilla at the highest fertilization rate. This reduction may reflect a dilution effect or a shift in assimilate allocation toward starch and other storage compounds. Collectively, these findings highlight the interactive influence of genotype and nutrient inputs on key nutritional attributes of OFSP tubers. While moderate nitrogen and phosphorus levels improve protein and fat contents, they may simultaneously reduce fiber concentration, suggesting a trade-off in quality traits that should be considered when designing fertilizer management strategies.

Ash, carbohydrate, and energy content

Ash content—an indicator of total mineral concentration—was significantly influenced by the interaction between nitrogen (N), phosphorus (P_2O_5), and variety (Table 3). The highest ash content (4.01%) occurred in NASPOT-12 under the highest fertilizer rate (46/46 kg ha^{-1} N/P_2O_5), whereas the lowest value (1.84%) was recorded in unfertilized Alamura. This consistent pattern across varieties suggests that nutrient application enhances mineral accumulation, likely through improved root development and greater nutrient uptake efficiency facilitated by fertilization.

Similarly, carbohydrate content responded markedly to fertilization. NASPOT-12 again recorded the highest carbohydrate concentration (88.99%) at the moderate application rate of 23/46 kg ha^{-1} N/P_2O_5, while the lowest concentration (83.16%) was observed in the same variety under control conditions. This trend indicates that an optimal nutrient supply supports carbohydrate biosynthesis, potentially via enhanced photosynthetic activity and increased starch deposition in the tubers.

Energy content—primarily derived from carbohydrates and fats—also increased with fertilization. The highest caloric value (381.15 kcal/100 g) was obtained in NASPOT-12 at 23/46 kg ha^{-1} N/P_2O_5, compared with the lowest value (364.94 kcal 100 g^{-1}) in unfertilized Alamura.

Collectively, these results underscore the critical role of balanced N and P inputs in improving both the nutritional and energy density of OFSP tubers. The findings further demonstrate that the interactive effects of nitrogen, phosphorus, and genotype significantly influence ash, carbohydrate, and energy contents. Among the tested varieties, NASPOT-12 consistently exhibited superior responsiveness to fertilization, highlighting its potential as a high-performing cultivar for enhancing sweet potato nutritional quality through targeted nutrient management strategies.

Mineral composition

The concentration of essential minerals, calcium, magnesium, iron, and zinc, in orange-fleshed sweet potato (OFSP) tubers was significantly influenced by the interaction between nitrogen (N), phosphorus (P_2O_5), and variety (Table 4). Calcium content was highest in the Alamura variety (25.27 mg 100 g^{-1}) under the application of 23 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1}, representing a substantial increase compared to the lowest value (17.61 mg 100 g^{-1}) recorded in the unfertilized Kabode variety. A similar trend was observed for magnesium, with NASPOT-12 achieving the highest concentration (24.68 mg 100 g^{-1}) under the same fertilization rate, while the lowest level (15.45 mg 100 g^{-1}) occurred in the control plot of Dilla. Iron content also responded strongly to fertilization, particularly in NASPOT-12, which accumulated the highest level (3.38 mg 100 g^{-1}) at the 23/46 N/P_2O_5 treatment which is over four times greater than its concentration in the unfertilized condition (0.83 mg 100 g^{-1}).

Zinc concentration varied considerably across treatments and genotypes, peaking in the Alamura

variety (0.74 mg 100 g^{-1}) under the highest nitrogen application rate (46 kg N ha^{-1}), regardless of phosphorus input, whereas the lowest value (0.22 mg 100 g^{-1}) was recorded in unfertilized NASPOT-12.

Table 2. Interaction effects of orange-fleshed sweet potato varieties and nitrogen-phosphorus fertilization on proximate composition.

Variety	Nitrogen (kg ha^{-1})	Phosphorus (P_2O_5 kg ha^{-1})	Flour moisture (%)	Protein%	Fat%	Fiber%
Kulfo	0	0	6.48^{f}	3.49^{f}	1.22^{q}	4.06^{a}
		46	6.69^{e}	3.44^{f}	1.22^{q}	3.49^{b}
	23	0	5.24^{n}	4.11^{bcd}	1.36^{n-q}	3.47^{b}
		46	7.23^{a}	4.11^{bcd}	1.31^{pq}	2.46^{ij}
	46	0	7.05^{bc}	2.96^{g}	2.33^{bc}	2.93^{c}
		46	6.97^{cd}	2.92^{gh}	2.40^{ab}	2.43^{i}
Kabode	0	0	6.48^{f}	2.84^{gh}	1.40^{m-p}	2.65^{efg}
		46	6.51^{f}	2.84^{gh}	1.35^{opq}	2.67^{ef}
	23	0	6.90^{d}	4.08^{cd}	1.67^{hij}	2.53^{hi}
		46	7.04^{c}	4.25^{abc}	1.65^{h-k}	2.47^{ij}
	46	0	4.98^{o}	2.95^{g}	1.49^{lmn}	2.26^{k}
		46	4.96^{o}	2.92^{gh}	1.51^{klm}	2.26^{k}
Alamura	0	0	5.90^{hij}	2.39^{l}	1.04^{r}	2.59^{fgh}
		46	5.84^{ijk}	2.39^{l}	0.99^{r}	2.58^{gh}
	23	0	5.60^{l}	2.57^{jk}	1.88^{fg}	2.09^{m}
		46	5.45^{m}	2.59^{j}	2.01^{ef}	$2.15l^{m}$
	46	0	5.94^{h}	2.76^{hi}	1.62^{i-l}	1.98^{n}
		46	6.08^{g}	2.80^{ghi}	1.54^{j-m}	1.97^{n}
Dilla	0	0	4.26^{q}	2.77^{hi}	2.10^{de}	2.73^{de}
		46	4.28^{q}	2.64^{ij}	2.07^{e}	2.00^{n}
	23	0	6.08g	4.12^{bcd}	1.75^{ghi}	2.27^{k}
		46	5.91^{hi}	4.29^{a}	1.77^{gh}	2.25^{k}
	46	0	4.81^{p}	2.52^{jkl}	1.99^{ef}	2.75^{d}
		46	5.04^{o}	2.40^{kl}	1.98^{ef}	1.93^{n}
NASPOT-12	0	0	5.75^{k}	2.50^{jkl}	1.47^{mno}	2.53^{hi}
		46	5.813^{jk}	2.50^{jkl}	1.48^{l-o}	2.45^{ij}
	23	0	5.17^{n}	3.76^{e}	2.28^{bc}	2.23^{k}
		46	7.13^{b}	3.80^{e}	2.22^{cd}	2.41^{j}
	46	0	5.43^{m}	4.00^{d}	2.34^{bc}	2.52^{hi}
		46	5.22^{n}	4.08^{cd}	2.52^{a}	2.20^{kl}
SE±			**0.25**	**0.23**	**0.04**	**0.13**

Means followed by the same letter within the same column are not significantly different at 5% level of significance.

Table 3. Interaction effects of orange-fleshed sweet potato varieties and nitrogen-phosphorus fertilization on ash, carbohydrate, and energy content.

Variety	Nitrogen (kg ha^{-1})	Phosphorus (P_2O_5 kg ha^{-1})	Ash%	CHO%	Energy Kcal 100 g^{-1}
Kulfo	0	0	2.53^{f}	86.07^{c-f}	369.36^{d-g}
		46	2.53^{f}	85.91^{def}	368.21^{efg}
	23	0	3.22^{d}	85.78^{def}	371.58^{b-g}
		46	3.28^{d}	85.84^{def}	371.70^{b-g}
	46	0	2.67^{f}	84.78^{f-i}	372.06^{b-g}
		46	2.58^{f}	84.93^{fgh}	371.01^{b-g}
Kabode	0	0	3.32^{d}	85.74^{ef}	367.65^{fg}
		46	3.36^{d}	85.74^{ef}	367.85^{fg}
	23	0	2.02^{h}	84.92^{fgh}	371.86^{b-g}
		46	1.99^{hi}	84.86^{f-i}	370.69^{c-g}
	46	0	3.24^{d}	87.13^{b-e}	371.83^{b-g}
		46	3.23^{d}	87.17^{b-e}	371.52^{b-g}
Alamura	0	0	1.84^{i}	87.17^{b-e}	364.94^{g}
		46	2.99^{e}	87.22^{b-e}	367.45^{fg}
	23	0	2.62^{f}	87.13^{b-e}	371.77^{b-g}
		46	3.01^{e}	87.17^{b-e}	372.91^{bcd}
	46	0	2.57^{f}	87.19^{b-e}	372.24^{b-e}
		46	2.04^{h}	83.24^{i}	368.91^{d-g}
Dilla	0	0	3.28^{d}	85.58^{efg}	373.06^{bc}
		46	3.37^{d}	85.55^{efg}	373.88^{b}
	23	0	3.23^{d}	86.09^{c-f}	370.79^{b-g}
		46	3.56^{bc}	86.07^{c-f}	371.37^{b-g}
	46	0	3.36^{d}	87.11^{b-e}	372.56^{bcd}
		46	3.65^{b}	86.86^{b-e}	372.96^{bcd}
NASPOT-12	0	0	2.23^{g}	83.16^{i}	372.69^{bcd}
		46	2.27^{g}	86.73^{b-e}	372.33^{b-g}
	23	0	3.37^{d}	86.83^{b-e}	370.93^{c-g}
		46	3.40^{cd}	88.99^{a}	381.15^{a}
	46	0	3.70^{b}	83.83^{hi}	371.08^{b-g}
		46	4.01^{a}	83.99^{ghi}	372.81^{bcd}
SE±			**0.05**	**0.53**	**1.83**

Means followed by the same letter within the same column are not significantly different at 5% level of significance.

Anti-nutritional factors

Phytate and tannin contents—two key anti-nutritional factors—were significantly influenced by the interaction between sweet potato genotype and nitrogen (N) and phosphorus (P_2O_5) fertilization levels (Table 5). The highest phytate content (0.39 mg 100 g^{-1}) was recorded in the Kulfo variety under 23 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1}, whereas the lowest value (0.15 mg 100 g^{-1}) occurred in Kabode at 23 kg N ha^{-1} with no phosphorus application (23/0 N/P). Phytates are known to chelate essential minerals such as calcium, iron, and zinc, thereby reducing their bioavailability. The elevated phytate levels observed in Kulfo under moderate nitrogen and high phosphorus suggest a genotype-specific response—particularly to phosphorus—in stimulating phytate biosynthesis.

Tannin content also varied significantly across fertilization regimes and genotypes. The highest tannin concentration (15.39 mg 100 g^{-1}) was found in the Alamura variety under the highest fertilizer input (46/46 kg ha^{-1} N/P_2O_5), while the lowest value (9.31 mg 100 g^{-1}) was observed in the unfertilized Dilla control. Tannins, as polyphenolic compounds, bind dietary proteins and inhibit their digestibility. The increased synthesis of tannins under high N and P conditions suggests that nutrient enrichment may inadvertently elevate levels of these anti-nutritional compounds in certain genotypes.

Overall, these findings highlight the dual impact of fertilization on the nutritional quality of sweet potato: while N and P applications can enhance mineral, protein, and energy content, they may also promote the accumulation of anti-nutritional factors such as phytates and tannins. Thus, optimizing fertilizer management in conjunction with strategic varietal selection is essential to balance productivity with nutritional quality in orange-fleshed sweet potato (OFSP) production.

Table 4. Interaction effects of orange-fleshed sweet potato varieties and nitrogen-phosphorus fertilization on mineral composition (mg 100 g^{-1}).

Varieties	Nitrogen (kg ha^{-1})	Phosphorus (P_2O_5 kg ha^{-1})	Calcium	Magnesium	Iron	Zinc
Kulfo	0	0	19.12^{r}	21.31^{n}	0.63^{i}	0.23^{lm}
		46	19.32^{q}	21.67^{l}	0.65^{i}	0.31^{ij}
	23	0	21.40^{k}	22.51^{i}	0.78^{f-i}	0.24^{klm}
		46	21.56^{j}	22.77^{h}	0.75^{ghi}	0.28^{ijk}
	46	0	22.21^{h}	21.96^{k}	1.16^{de}	0.50^{c}
		46	22.41^{fg}	22.06^{j}	1.38^{cd}	0.52^{c}
Kabode	0	0	17.61^{v}	17.69^{v}	0.62^{i}	0.24^{klm}
		46	19.44^{pq}	19.34^{s}	0.73^{ghi}	0.39^{gh}
	23	0	18.75^{s}	17.88^{u}	0.72^{hi}	0.25^{klm}
		46	19.62^{o}	19.75^{q}	0.63^{i}	0.43^{fg}
	46	0	17.88^{u}	20.22^{p}	1.29^{cd}	0.28^{ijk}
		46	18.59^{t}	20.59^{o}	1.38^{cd}	0.30^{ij}
Alamura	0	0	21.65^{j}	19.60^{r}	0.84^{f-i}	0.52^{c}
		46	21.60^{j}	19.24^{t}	0.91^{e-h}	0.49^{cd}
	23	0	22.53^{f}	23.18^{f}	0.97^{efg}	0.59^{b}
		46	25.27^{a}	23.41^{d}	2.28^{b}	0.58^{b}
	46	0	22.31^{gh}	17.45^{w}	2.19^{b}	0.74^{a}
		46	25.11^{b}	17.12^{x}	0.85^{f-i}	0.74^{a}
Dilla	0	0	21.81^{i}	15.45^{z}	0.90^{fgh}	0.42^{fg}
		46	20.99^{l}	21.62^{l}	1.38^{cd}	0.45^{def}
	23	0	20.89^{lm}	21.33^{n}	1.02^{ef}	0.44^{ef}
		46	23.78^{c}	21.67^{l}	1.28^{cd}	0.52^{c}
	46	0	19.33^{q}	15.82^{y}	1.43^{c}	0.37^{h}
		46	19.51^{op}	21.54^{m}	1.48^{c}	0.39^{gh}
NASPOT-12	0	0	21.67^{j}	24.35^{c}	0.83^{f-i}	0.22^{m}
		46	21.32^{k}	24.57^{b}	0.85^{f-i}	0.45^{def}
	23	0	20.44^{n}	24.55^{b}	3.35^{a}	0.30^{ij}
		46	20.77^{m}	24.68^{a}	3.38^{a}	0.48^{cde}
	46	0	23.41^{d}	23.29^{e}	0.71^{hi}	0.30^{ij}
		46	23.13^{e}	22.89^{g}	0.71^{hi}	0.32^{i}
SE±			**1.01**	**0.99**	**0.05**	**0.03**

Means followed by the same letter within the same column are not significantly different at 5% level of significance on, calcium, magnesium, iron and zinc.

Nutritional factors

As shown in Table 5, the concentrations of essential vitamins in orange-fleshed sweet potato (OFSP) tubers were significantly influenced by the interaction between nitrogen (N), phosphorus (P_2O_5), and variety. β-Carotene content—a key indicator of provitamin A activity—was highest in NASPOT-12 (19.64 mg 100 g^{-1}) under the 23/46 kg ha^{-1} N/P_2O_5 treatment, representing more than a four-fold increase compared with the control (4.42 mg 100 g^{-1}). This substantial enhancement reflects a strong varietal responsiveness to moderate nitrogen and high phosphorus application in promoting carotenoid biosynthesis.

Similarly, vitamin C content peaked in NASPOT-12 (3.66 mg 100 g^{-1}) under the same fertilization regime, whereas the lowest value (1.91 mg 100 g^{-1}) was recorded in unfertilized Alamura. The observed increase in ascorbic acid concentration with optimal N and P inputs suggests improved antioxidant metabolism, likely associated with enhanced photosynthetic activity and overall metabolic vigor.

Vitamin E content was highest in the Alamura variety (0.69 mg 100 g^{-1}) under both 23/46 and 46/46 kg ha^{-1} N/P_2O_5 treatments. In contrast, certain varieties, including Kabode and Dilla, exhibited undetectable vitamin E levels under specific nutrient regimes, indicating a pronounced genotype-by-environment interaction influencing tocopherol synthesis.

Overall, these results highlight the combined influence of genotype and fertilization on vitamin content in OFSP, underscoring the importance of balanced nutrient application and strategic varietal selection as complementary approaches for biofortification.

Table 5. Interaction effects of orange-fleshed sweet potato varieties and nitrogen-phosphorus fertilization on anti-nutritional, *β*-carotene and vitamin factors (mg 100 g^{-1}).

Variety	Nitrogen (kg ha^{-1})	Phosphorus (P_2O_5 kg ha^{-1})	Phytate	Tannin	*β*-carotene	Vitamin C	Vitamin E
Kulfo	0	0	0.27^{e-h}	9.99^{s}	3.38^{j}	2.73^{f}	0.33^{jk}
		46	0.25^{g-j}	10.06^{r}	3.80^{ij}	2.77^{ef}	0.48^{h}
	23	0	0.35^{ab}	11.26^{k}	7.20^{f-j}	2.81^{ef}	0.33^{jkl}
		46	0.39^{a}	11.48^{i}	14.07^{bc}	2.91^{e}	0.49^{gh}
	46	0	0.31^{c-e}	12.09^{g}	5.96^{f-j}	2.34^{hi}	0.35^{jk}
		46	0.30^{d-f}	12.26^{f}	6.38^{f-j}	2.34^{hi}	0.36^{j}
Kabode	0	0	0.34^{bc}	11.10^{m}	5.25^{g-j}	2.55^{g}	0.28^{m}
		46	0.34^{bc}	10.99^{n}	6.22^{f-j}	2.48^{gh}	0.55^{de}
	23	0	0.15^{o}	14.12^{d}	13.03^{b-e}	3.12^{d}	ND
		46	0.20^{l-n}	14.37^{c}	14.89^{bc}	3.16^{d}	ND
	46	0	0.25^{h-k}	12.01^{h}	8.33^{f-i}	2.76^{ef}	0.30^{lm}
		46	0.24^{i-l}	12.06^{g}	8.15^{f-j}	2.77^{ef}	0.54^{def}
Alamura	0	0	0.26^{f-i}	10.30^{p}	6.78^{f-j}	1.91^{j}	0.40^{i}
		46	0.29^{d-g}	10.38^{o}	7.40^{f-j}	1.94^{j}	0.41^{i}
	23	0	0.32^{b-d}	13.07^{e}	13.32^{bcd}	2.26^{i}	0.69^{a}
		46	0.29^{d-g}	13.04^{e}	14.21^{bc}	2.25^{i}	0.69^{a}
	46	0	0.19^{mn}	15.20^{b}	8.80^{e-h}	3.48^{b}	0.64^{b}
		46	0.19^{mn}	15.39^{a}	8.30^{e-i}	3.44^{b}	0.60^{c}
Dilla	0	0	0.22^{j-m}	9.31^{v}	6.37^{f-j}	2.40^{ghi}	0.53^{ef}
		46	0.24^{i-l}	9.46^{u}	7.18^{f-j}	2.39^{ghi}	0.52^{fg}
	23	0	0.29^{d-g}	9.69^{t}	10.70^{c-f}	3.25^{cd}	ND
		46	0.29^{d-g}	9.43^{u}	14.4^{bc}	3.35^{bc}	ND
	46	0	0.32^{b-d}	11.15^{l}	9.17^{d-h}	2.02^{j}	0.32^{kl}
		46	0.32^{b-d}	11.02^{n}	8.77^{d-h}	2.01^{j}	0.32^{kl}
NASPOT-12	0	0	0.21^{k-n}	10.08^{r}	4.42^{hij}	2.87^{ef}	ND
		46	0.19^{mn}	10.16^{q}	5.48^{g-j}	3.25^{cd}	ND
	23	0	0.24^{i-l}	12.27^{f}	9.34^{c-g}	2.86^{ef}	0.61^{bc}
		46	0.21^{k-n}	12.30^{f}	19.64^{a}	3.66^{a}	0.62^{bc}
	46	0	0.21^{k-n}	11.27^{k}	7.87^{f-j}	3.18^{d}	0.56^{de}
		46	0.18^{no}	11.35^{j}	8.27^{e-i}	3.66^{a}	0.56^{d}
SE±			**0.02**	**0.25**	**0.94**	**0.13**	**0.06**

Means followed by the same letter within the same column are not significantly different at 5% level of significance.

Functional properties

As presented in Table 6, the functional properties of orange-fleshed sweet potato (OFSP) flours—including pH, bulk density, water absorption capacity (WAC), gelatinization temperature, and oil absorption capacity (OAC)—were significantly affected by the interaction between nitrogen (N), phosphorus (P_2O_5), and genotype. The highest pH values were recorded in Kulfo (6.35) under the 46/46 kg ha^{-1} N/P_2O_5 treatment and in Kabode (6.35) under the 23/0 kg ha^{-1} N/P_2O_5 treatment, whereas the lowest pH (5.64) was observed in NASPOT-12 under the 46/46 kg ha^{-1} N/P_2O_5 regime. These findings indicated genotype-specific acid–base responses to fertilization, which are important determinants of shelf stability, microbial resistance, and sensory attributes in processed OFSP products.

Bulk density was highest in Dilla (0.66 g mL^{-1}) under the phosphorus-only application (46/0 kg ha^{-1} N/P_2O_5), underscoring phosphorus's prominent role in influencing this parameter. Higher bulk density enhances packaging efficiency and reduces storage space requirements, which is particularly advantageous in commercial flour processing. Water absorption capacity (WAC) reached its maximum in NASPOT-12 (2.67 g 100 g^{-1}) under the 23/46 kg ha^{-1} N/P_2O_5 treatment, followed by Dilla and Alamura under similar fertilization regimes. This suggests that moderate nitrogen combined with high phosphorus improves the flour's moisture retention capacity—an important quality attribute in baked, rehydrated, and dough-based food products.

The highest gelatinization temperature (49.5 °C) was observed in NASPOT-12 under the 46/46 kg ha^{-1} N/P_2O_5 regime, indicating increased thermal resistance of starch granules. Although higher gelatinization temperatures may prolong processing times, they confer improved structural integrity to products requiring thermal stability, such as instant or ready-to-cook foods. Oil absorption capacity (OAC) peaked in Dilla (105.80 mL 100 g^{-1}) under phosphorus-only application (46/0 kg ha^{-1} N/P_2O_5), representing a 17.46% increase over the control. Enhanced OAC contributes to improved flavor retention and palatability, particularly in fried and

snack products. This result further suggests that phosphorus, even in the absence of nitrogen, can markedly influence oil-binding properties in a genotype-dependent manner. Overall, these findings demonstrate that the functional properties of OFSP flours are both nutrient-responsive and genotype-specific. Tailoring N and P fertilization strategies to varietal characteristics can therefore enhance flour quality attributes for targeted food processing and culinary applications.

Table 6. Interaction effects of orange-fleshed sweet potato varieties and nitrogen-phosphorus fertilization on functional properties (%) of flour.

Variety	Nitrogen (kg ha^{-1})	Phosphorus (P_2O_5 kg ha^{-1})	pH	Bulk density g mL^{-1}	WABS (g 100 g^{-1})	Gelatinization Temp.	Oil *abs*. mL
Kulfo	0	0	6.15^{e}	0.41^{k}	1.47^{j}	46.50^{e}	98.21^{kl}
		46	5.95^{e}	0.43^{j}	1.48^{j}	44.50^{g}	98.30^{jk}
	23	0	6.25^{b}	0.53^{e}	1.92^{fg}	45.50^{f}	97.60^{m}
		46	6.15^{c}	0.53^{e}	1.93^{fg}	46.50^{e}	95.54^{n}
	46	0	5.95^{e}	0.38^{m}	1.60^{ij}	46.50^{e}	95.40^{n}
		46	6.35^{a}	0.39^{l}	1.62^{hij}	44.50^{g}	95.70^{n}
Kabode	0	0	6.15^{c}	0.41^{k}	1.51^{ij}	47.50^{c}	90.07^{o}
		46	5.95^{e}	0.41^{k}	1.51^{ij}	45.50^{f}	99.78^{hi}
	23	0	6.35^{a}	0.35^{p}	2.09^{c-f}	46.50^{f}	100.18^{g}
		46	6.15^{c}	0.34^{q}	2.05^{c-f}	44.50^{g}	100.08^{gh}
	46	0	6.15^{c}	0.34^{n}	2.25^{b-e}	48.50^{b}	90.21^{o}
		46	6.25^{b}	0.34^{n}	2.25^{b-e}	45.50^{f}	100.22^{g}
Alamura	0	0	5.95^{e}	0.32^{o}	1.90^{fg}	47.50^{c}	97.85^{lm}
		46	6.15^{c}	0.33^{o}	1.75^{ghi}	46.66^{d}	97.80^{lm}
	23	0	5.95^{e}	0.38^{e}	1.71^{g-j}	47.50^{c}	101.32^{e}
		46	6.15^{c}	0.38^{e}	1.70^{g-j}	45.50^{f}	101.40^{e}
	46	0	5.63^{h}	0.48^{f}	2.35^{b}	45.50^{f}	99.40^{i}
		46	5.95^{e}	0.48^{f}	2.30^{bcd}	44.50^{g}	99.53^{i}
Dilla	0	0	5.95^{e}	0.65^{b}	1.93^{fg}	44.50^{g}	102.11^{d}
		46	6.15^{c}	0.66^{a}	1.94^{fg}	45.50^{f}	103.02^{c}
	23	0	5.65^{h}	0.44^{i}	2.27^{b-e}	46.50^{e}	100.71^{f}
		46	5.85^{f}	0.45^{h}	2.35^{b}	44.50^{g}	101.06^{ef}
	46	0	5.85^{f}	0.45^{h}	2.05^{def}	48.50^{b}	105.80^{a}
		46	5.95^{e}	0.45^{h}	2.30^{bc}	45.50^{f}	105.42^{b}
NASPOT-12	0	0	6.05^{d}	0.46^{g}	2.03^{ef}	48.50^{b}	103.40^{c}
		46	6.05^{d}	0.53^{e}	1.87f^{gh}	46.50^{e}	101.00^{ef}
	23	0	5.75^{g}	0.53^{e}	1.70^{g-j}	47.50^{c}	98.74^{j}
		46	5.85^{f}	0.55^{d}	2.67^{a}	46.50^{e}	99.50^{i}
	46	0	5.55^{i}	0.56^{c}	1.57^{ij}	48.50^{b}	97.56^{m}
		46	5.55^{i}	0.55^{d}	1.60^{ij}	49.50^{a}	97.54^{m}
SE±			**0.25**	**0.02**	**0.11**	**2.51**	**1.8**

Means followed by the same letter within the same column are not significantly different at 5% level of significance.

Discussion

The application of nitrogen (N) and phosphorus (P) fertilizers significantly influences the nutritional quality of orange-fleshed sweet potato (OFSP) tubers, resulting in notable increases in moisture, protein, fat, ash, carbohydrate, and energy contents. However, these improvements are accompanied by a reduction in dietary fiber, indicating a nutritional trade-off.

Moisture content increased in several varieties, with Kulfo showing the highest levels under moderate N and P application. Enhanced moisture improves water retention during processing, which can benefit dough formation and texture, but may also reduce flour shelf life—a pattern consistent with previous findings by Gemechu et al. (2020) and Mitiku and Teka (2017). Protein content rose substantially in Dilla and Kabode varieties, demonstrating the effectiveness of targeted fertilization in promoting protein biosynthesis, in agreement with Ukom et al. (2009) and Etana et al. (2022). Similarly, fat content increased in NASPOT-12 and Kulfo, reflecting genotype-specific responses to nutrient availability, as also reported by Etana et al. (2022) and Ukom et al. (2009).

In contrast, dietary fiber content declined with increased fertilization, likely reflecting a physiological shift toward starch and storage compound accumulation at the expense of structural carbohydrate synthesis. While this may improve textural qualities, it reduces the health benefits associated with fiber intake, such as improved digestion and glycemic regulation (Ukom et al., 2009). Historical studies provide a benchmark for fiber levels in sweet potato: Oomen and Grubben (1977) reported 3.9% in fresh roots, while Huang et al. (1999) found a range of 2.01–3.87 g 100 g^{-1} across 18 Hawaiian varieties. The current findings build on these by demonstrating how fertilization actively modifies fiber content rather than presenting static values.

Fertilization also increased ash, carbohydrate, and energy contents, with NASPOT-12 showing the most pronounced and consistent response. Higher ash content in NASPOT-12 reflects enhanced mineral accumulation due to improved root development and nutrient uptake under optimized N and P levels, a trend also observed by Etana et al. (2022) with NPSB fertilizer. Carbohydrate content rose markedly at moderate fertilizer rates (23/46 kg ha^{-1} N/P_2O_5), highlighting the synergistic role of nitrogen in photosynthetic activity and phosphorus in energy transfer and carbohydrate translocation, which together promote starch and sugar accumulation. This, in turn, elevated energy content, with NASPOT-12 achieving the highest caloric value. These results are consistent with the findings of Etana et al. (2022) in the Tulla variety under NPSB fertilization. Overall, these results underscore the importance of genotype-specific fertilization strategies that balance nutritional enhancement with dietary fiber retention. NASPOT-12, with its high energy yield and consistent nutrient gains, emerges as a promising variety for nutrition-sensitive agriculture, particularly in food-insecure regions.

Variation in mineral content across orange-fleshed sweet potato (OFSP) varieties and fertilization regimes underscores the pivotal role of nitrogen (N) and phosphorus (P) in enhancing nutritional quality. The observed increase in calcium content in the Alamura variety under combined moderate N and high P application suggests that phosphorus facilitates calcium uptake by supporting root system development. Similarly, elevated magnesium levels in NASPOT-12 likely reflect improved chlorophyll synthesis and photosynthetic activity driven by N and P supplementation. Iron concentrations were significantly higher in NASPOT-12 under moderate N and P inputs, indicating that these nutrients enhance root architecture and enzymatic functions critical for iron acquisition. These findings align with Sanoussi et al. (2016), who reported that iron content in sweet potato is influenced by both genotype and environmental interactions. Zinc content also improved markedly, particularly in Alamura under high nitrogen input, likely due to nitrogen-enhanced root surface area and activation of zinc transporter proteins, which improve uptake and translocation. These genotype-specific responses highlight the need for tailored fertilizer strategies to optimize mineral biofortification in OFSP. Consistent with this, Agbede (2010) and Sanoussi et al. (2016) confirmed that mineral concentrations in sweet potato are strongly affected by fertilization regimes.

Phytates—known to chelate essential minerals such as calcium, iron, and zinc—can substantially reduce mineral bioavailability in the human diet. In this study, phytate levels were highest in the Kulfo variety under moderate nitrogen combined with either high or no phosphorus applications, suggesting that fertilization influences metabolic pathways associated with phytate biosynthesis. This observation supports the findings of Ooko Abong' et al. (2020), who reported that phytate content varies according to genotype and agronomic practices. Tannin concentrations also increased under nutrient enrichment, with the highest values observed in the Alamura variety under high nitrogen and phosphorus treatments. As polyphenolic compounds, tannins bind proteins and minerals, thereby reducing their digestibility and bioavailability. These results are consistent with Mitiku and Teka (2017), who documented substantial varietal variation in tannin accumulation, notably with the Adu variety exhibiting particularly high levels. Together, these findings emphasize that both genetic and fertilization factors shape the levels of anti-nutritional compounds, reinforcing the need for careful variety selection and optimized fertilizer management to improve overall nutritional quality.

Nitrogen and phosphorus fertilization also significantly enhanced key vitamins in OFSP, underscoring the key role of soil fertility management in biofortification strategies. In particular, β-carotene content in NASPOT-12 increased by approximately 300% under moderate nitrogen (23 kg ha^{-1}) and high phosphorus (46 kg ha^{-1}) application, highlighting the sensitivity of carotenoid biosynthesis to targeted nutrient supply. This is consistent with Vosawai et al. (2015), who reported enhanced β-carotene accumulation following nitrogen application, attributable to nitrogen's role in chloroplast development and carotenoid synthesis, and phosphorus's contribution to ATP production and metabolic energy flow. Vitamin C content also rose substantially under the same fertilization regime, particularly in NASPOT-12, supporting Abdel-Rahman's (2012) assertion that nutrient availability enhances vitamin C levels under favorable conditions. Although absolute values remained below those of certain high-performing genotypes, the relative gains were nutritionally meaningful, improving antioxidant

potential and postharvest stability. Vitamin E content similarly increased in Alamura with moderate nitrogen application, likely reflecting nitrogen-sensitive lipid and isoprenoid metabolism, which contributes to antioxidant defense and tuber quality, despite limited comparative data for sweet potato.

While these nutrient gains are substantial, they were accompanied by increases in anti-nutritional factors such as phytates and tannins, highlighting a trade-off between improved nutrient density and reduced bioavailability. Overall, the combination of moderate nitrogen and high phosphorus emerges as the most balanced fertilization strategy, maximizing nutrient enhancement while minimizing anti-nutrient buildup and environmental risks. These results reinforce the importance of genotype-specific and sustainable nutrient management practices to optimize both the nutritional quality and health impact of OFSP.

The functional properties of orange-fleshed sweet potato (OFSP)—crucial for processing performance, storage stability, and nutritional quality—were significantly influenced by nitrogen (N) and phosphorus (P) fertilization, with clear genotype-specific responses. Near-neutral pH values, consistent with those reported by Rodrigues et al. (2016), were observed across varieties, contributing to mild flavor and high consumer acceptability. Kulfo and Kabode exhibited higher pH values, suggesting lower organic acid content and improved palatability, whereas NASPOT-12 displayed lower pH under high fertilization, potentially due to increased organic acid accumulation, which may influence both flavor and shelf life.

Bulk density, a key determinant of packaging efficiency and storage requirements, was highest in Dilla under phosphorus-only application, indicating phosphorus's role in promoting starch granule compaction. This finding is consistent with Grabowski et al. (2006) and highlights the potential benefits for storage stability and reduced packaging costs—an important advantage for smallholder producers. Water absorption capacity (WAC) was greatest in NASPOT-12 under moderate nitrogen and high phosphorus application, likely due to increased water-binding sites from starch granule modification. These values exceeded those reported by Obomeghei et al. (2020), underscoring the variety's suitability for baking and infant food formulations, where high WAC improves product texture and rehydration properties.

Gelatinization temperature was highest in NASPOT-12 under high N and P inputs, indicating increased thermal resistance of starch granules. While this may raise cooking energy requirements, it also enhances textural stability in thermally processed products. Oil absorption capacity (OAC) improved significantly in Dilla with high nitrogen application, reflecting nitrogen's influence on starch–protein interactions. Enhanced OAC improves flavor retention and mouthfeel in fried and baked products, consistent with observations by Onuh et al. (2004).

Conclusion

This study demonstrated that nitrogen and phosphorus fertilization significantly enhanced both the nutritional quality and functional properties of sweet potato roots, with varieties such as NASPOT-12 and Alamura showing marked increases in key nutrients—including β-carotene, vitamin E, calcium, and zinc—under optimal application rates of 23 kg ha^{-1} N and 46 kg ha^{-1} P_2O_5. NASPOT-12, in particular, exhibited consistently superior vitamin and mineral profiles, along with improved functional traits such as water absorption capacity and gelatinization temperature, which were advantageous for processing and consumption. However, fertilization also increased levels of anti-nutritional factors such as tannins and phytates, highlighting a trade-off that required careful management. These findings underscored the need for fertilization strategies tailored to specific genotypes and local ecological conditions to maximize nutrient uptake while maintaining overall food quality. To facilitate adoption and sustainability, improving farmers' access to affordable fertilizers and providing targeted training on effective nutrient management were identified as essential. Furthermore, long-term research was recommended to evaluate the agricultural, nutritional, and environmental impacts of these fertilization practices, thereby supporting food security and contributing to the alleviation of micronutrient deficiencies in vulnerable regions.

Acknowledgements

The Ethiopian Ministry of Education is acknowledged for supporting the work.

Author contributions

MHL designed and conducted the experiment, collected and analyzed data, and prepared and edited the manuscript. AMI provided supervision, contributed to conceptualization, designed the laboratory work, and assisted with manuscript editing. FG supervised the study, provided material support, and contributed to manuscript editing. AH oversaw data analysis and management, contributed to manuscript writing, and assisted with manuscript editing. HMB provided supervision, contributed to the conceptualization and design of fieldwork, participated in data analysis, and assisted with manuscript editing. All authors have read and approved the final version of the manuscript.

Funding

This research received no external funding.

Conflict of Interest
The authors indicate no conflict of interest in this work.

References

Abdel-Rahman NA. 2012. Characterization of three genotypes of sweet potato and their suitability for jam making. American Journal of Plant Nutrition and Fertilization Technology 2, 1-9. https://doi.org/10.3923/ajpnft.2012.1.9.

Abushita AA, Hebshi EA, Daood HG, Biacs PA. 1997. Determination of antioxidant vitamins in tomatoes. Food Chemistry 60(2), 207-212. https://doi.org/10.1016/S0308-8146(96)00321-4.

Agbede TM. 2010. Tillage and fertilizer effects on some soil properties, leaf nutrient concentrations, growth and sweet potato yield on an Alfisol in southwestern Nigeria. Soil and Tillage Research 110(1), 25-32. https://doi.org/10.1016/j.still.2010.06.003.

Alexopoulos AA, Varzakas T, Karras S, Koriki A, Kotsiras A, Xynias I. 2016. Effect of nitrogen and phosphorus fertilization on growth components, yield and tuber quality characteristics of two potato cultivars grown under organic production system. In III International Symposium on Horticulture in Europe-SHE2016 1242, 191-198. https://doi.org/10.17660/ActaHortic.2019.1242.27.

AOAC. 1984. Official Method of Analysis, 14th ed. Association of Official Analytical Chemists, Washington, DC.

AOAC. 2000. Official Methods of Analysis, 17th ed. Association of Official Analytical Chemists, Washington, DC.

AOAC. 2005. Official Methods of Analysis of AOAC International, 17th ed., Vol. II. AOAC International, Washington, DC, USA.

Bouis HE, Saltzman A. 2017. Improving nutrition through biofortification: a review of evidence from HarvestPlus, 2003 through 2016. Global Food Security 12, 49-58. https://doi.org/10.1016/j.gfs.2017.01.009.

Chandrasekara A, Josheph Kumar T. 2016. Roots and tuber crops as functional foods: a review on phytochemical constituents and their potential health benefits. International Journal of Food Science 2016(1), 3631647. https://doi.org/10.1155/2016/3631647.

Dako E, Retta N, Desse G. 2016. Comparison of three sweet potato (*Ipomoea batatas* (L.) Lam) varieties on nutritional and anti-nutritional factors. Global Journal of Science Frontier Research: D Agriculture and Veterinary 16(4), 1-11.

EFDD Hawassa. 2019. Socio-Economic and Geo-Spacial Data Analysis and Dissemination Core Work Process: Socio-Economic Profile. Finance and Economic Development Department of Hawassa City (EFDD Hawassa), Hawassa, Ethiopia. http://www.hawassafinance.com.

Eluagu E, Onimawo I. 2010. Effect of processing on the mineral composition and antinutritional factors of orange fleshed sweet potato (*Ipomoea batatas* L. Lam) flours. Electronic Journal of Environmental, Agricultural and Food Chemistry 9(6), 1000-1005.

Esan VI, Omilani OO, Okedigba I. 2021. Effects of organic and inorganic fertilizers on sweet potato production in Iwo, Nigeria. African Journal of Plant Science 15(5), 131-137. https://doi.org/10.5897/AJPS2021.2130.

Essilfie EM. 2015. Yield and storability of sweetpotato (*Ipomoea batatas* (L.) Lam) as influenced by chicken manure and inorganic fertilizer. Doctoral dissertation, University of Ghana.

Etana G, Belew D, Beyene TM. 2022. Proximate composition of orange fleshed sweet potato (*Ipomoea batatas* (L.) Lam) varieties as influenced by blended fertilizer level. 38, 252-259.

Gemechu GE, Belew D, Beyene TM. 2020. Blended fertilizer effect on quality of orange fleshed sweet potato (*Ipomoea batatas* (L.) Lam) varieties. Biol. Chem. Res. 37(2), 72-86.

Grabowski JA, Truong VD, Daubert CR. 2006. Spray-drying of amylase hydrolyzed sweetpotato puree and physicochemical properties of powder. Journal of Food Science 71(5), E209-E217. https://doi.org/10.1111/j.1750-3841.2006.00036.x.

Huang AS, Tanudjaja L, Lum D. 1999. Content of alpha-, beta-carotene, and dietary fiber in 18 sweetpotato varieties grown in Hawaii. Journal of Food Composition and Analysis 12(2), 147-151. https://doi.org/10.1006/jfca.1999.0819.

Ihekoronye AI, Ngoddy PO. 1985. Integrated food science and technology for the tropics, ix–386.

Ishfaq M, Wang Y, Xu J, Hassan MU, Yuan H, Liu L, He B, Ejaz I, White PJ, Cakmak I, Chen WS. 2023. Improvement of nutritional quality of food crops with fertilizer: a global meta-analysis. Agronomy for Sustainable Development 43(6), 74. https://doi.org/10.1007/s13593-023-00923-7.

Islam I, Shaikh AU, Shahidul IM. 2009. Antioxidative and antimutagenic potentials of phytochemicals from *Ipomoea batatas* (L.) Lam. International Journal of Cancer Research 5(3), 83-94. https://doi.org/10.3923/ijcr.2009.83.94.

Jennings D. 2009. Tropical root and tuber crops. Cassava, sweet potato, yams and aroids. By V.

Lebot. Wallingford, UK: Experimental Agriculture 45(3), 382-382. https://doi.org/10.1017/S0014479709007832.

Konak M, Çarman K, Aydin C. 2002. PH—Postharvest technology: Physical properties of chick pea seeds. Biosystems Engineering 82(1), 73-78. https://doi.org/10.1006/bioe.2002.0053.

Kumar JS, Niwas N, Jose S, Sunitha S. 2023. Study on effect of various levels of nitrogen on growth, yield and quality of sweet potato varieties [*Ipomoea batatas* (L) Lam.]. Journal of Crop and Weed 19(1), 16-21. https://doi.org/10.22271/09746315.2023.v19.i1.1653.

Mehansho H. 2006. Symposium: food fortification in developing countries. Journal of Nutrition 136, 1059-1063. https://doi.org/10.1093/jn/136.4.1059.

Mitiku DH, Teka TA. 2017. Nutrient and antinutrient composition of improved sweet potato (Ipomea batatas (L) Lam) varieties grown in eastern Ethiopia. Nutrition & Food Science 47(3), 369-380. https://doi.org/10.1108/NFS-07-2016-0098.

Obomeghei AA, Olapade AA, Akinoso R. 2020. Evaluation of the chemical composition, functional and pasting properties of four varieties of Nigerian sweet potato [*Ipomoea batatas* L. (Lam.)] flour. African Journal of Food, Agriculture, Nutrition and Development 20(3), 15764-15778. https://doi.org/10.18697/AJFAND.91.18405.

Onuh JO, Akpapunam MA, Iwe MO. 2004. Comparative studies of the physicochemical properties of two local varieties of sweet potato flours. Nigerian Food Journal 22(1), 141-146. https://doi.org/10.4314/nifoj.v22i1.33579.

Ooko Abong' G, Muzhingi T, Wandayi Okoth M, Ng'ang'a F, Ochieng' PE, Mahuga Mbogo D, Malavi D, Akhwale M, Ghimire S. 2020. Phytochemicals in leaves and roots of selected Kenyan orange fleshed sweet potato (OFSP) varieties. International Journal of Food Science 2020(1), 3567972. https://doi.org/10.1155/2020/3567972.

Oomen HAPC, Grubben GJH. 1977. Tropical leaf vegetables in human nutrition. Communication 69, Department of Agricultural Research, Royal Tropical Institute, Amsterdam, Netherlands. Orphan Publishing Co., Willemstad, Curacao.

Pagard A, Zare-Bavani MR, Eftekhari SA. 2024. Effects of fertigation and foliar application of boron on fruit yield and several physiological traits of bell pepper. International Journal of Horticultural Science and Technology 11(4), 423-436. https://doi.org/10.22059/IJHST.2023.362449.668.

Pakrah S, Rahemi M, Nabipour A, Zahedzadeh F, Kakavand F, Vahdati K. 2021. Sensory and nutritional attributes of Persian walnut kernel influenced by maturity stage, drying method, and cultivar. Journal of Food Processing and Preservation 45(6), e15513. https://doi.org/10.1111/jfpp.15513.

Pardales JR, Roa JR. 2002. Rootcrop agriculture in the Philippines: The quest for food security and livelihood. In Secondary Farmers of Secondary Crops? Women and Rootcrop Livelihood in the Philippines, 3-11. UPWARD.

Price ML, Van Scoyoc S, Butler LG. 1978. A critical evaluation of the vanillin reaction as an assay for tannin in sorghum grain. Journal of Agricultural and Food Chemistry 26(5), 1214-1218. https://doi.org/10.1021/jf60219a031.

Rodrigues NDR, Barbosa Junior JL, Barbosa MIMJ. 2016. Determination of physico-chemical composition, nutritional facts and technological quality of organic orange and purple-fleshed sweet potatoes and its flours. International Food Research Journal 23(5).

Sanoussi AF, Adjatin A, Dansi A, Adebowale A, Sanni LO, Sanni A. 2016. Mineral composition of ten elite sweet potato (Ipomoea batatas [L] Lam) landraces of Benin. International Journal of Current Microbiology and Applied Sciences 5(1), 103-115. http://dx.doi.org/10.20546/ijcmas.2016.501.009.

SAS Institute. 2008. JMP user's guide. SAS Institute, Cary, NC.

Siwela M, Taylor JR, De Milliano WA, Duodu KG. 2007. Occurrence and location of tannins in finger millet grain and antioxidant activity of different grain types. Cereal Chemistry 84(2), 169-174. https://doi.org/10.1094/CCHEM-84-2-0169.

Souri MK, Hatamian M. 2019. Aminochelates in plant nutrition: a review. Journal of Plant Nutrition 42(1), 67-78. https://doi.org/10.1080/01904167.2018.1549671.

Tee ES, Kuladevan R, Young SI, Khor SC, Zakiyah H. 1996. Laboratory procedures in nutrient analysis of foods. Division of Human Nutrition, Institute of Medical Research, Kuala Lumpur, Malaysia.

Tewodros M, Neim S, Mesfin S, Getachew W, Ashenafi A. 2017. Effect of mineral N and P fertilizers on storage tuber yield and yield components of taro [*Colocasia esculenta* (L.) Schott] in Southwest Ethiopia. Journal of Biological and Chemical Research 34, 688-695.

Ukom AN, Ojimelukwe PC, Okpara DA. 2009. Nutrient composition of selected sweet potato [*Ipomea batatas* (L) Lam] varieties as influenced by

different levels of nitrogen fertilizer application. Pakistan Journal of Nutrition 8(11), 1791-1795. https://doi.org/10.3923/pjn.2009.1791.1795.

Uwah DF, Undie UL, John NM, Ukoha GO. 2013. Growth and yield response of improved sweet potato (*Ipomoea batatas* (L.) Lam) varieties to different rates of potassium fertilizer in Calabar, Nigeria. Journal of Agricultural Science 5(7), 61-69. http://dx.doi.org/10.5539/jas.v5n7p61.

Vaintraub IA, Lapteva NA. 1988. Colorimetric determination of phytate in unpurified extracts of seeds and the products of their processing. Analytical Biochemistry 175(1), 227-230. https://doi.org/10.1016/0003-2697(88)90382-X.

Vosawai P, Halim RA, Shukor AR. 2015. Yield and nutritive quality of five sweet potato varieties in response to nitrogen levels. Advances in Plants and Agriculture Research 2(5), 231-237. https://doi.org/10.15406/apar.2015.02.00067