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Comparative assessment for nutritional and antinutritional qualities revealed better performance of traditional white-fleshed sweet potatoes than orange-fleshed sweet potatoes

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Abstract: Recent introduction of beta-carotene rich orange-fleshed sweet potatoes (OFSP) has resulted to consumers' low demands for traditional white-fleshed sweet potatoes (TWFSP), without due consideration of their nutritional qualities. This study appraised the nutritional compositions of OFSP and TWFSP. They were analyzed for mineral content, antinutrients, and phytochemicals at National Root Crops Research Institute, Umudike. The field experiment was conducted using randomized complete block design with three replicates. TWFSP showed higher concentrations of minerals, anti-nutrients and phytochemicals than OFSP. In TWFSP, potassium ranged from 1879.20 ± 0.01 mg kg^{-1} ('B_3V_3') to 1960.30 ± 0.01 mg kg^{-1} ('B_2V_2') while in OFSP it varied from 1162.60 ± 0.02 mg kg^{-1} ('$B_{26}T_{26}$') to 1800.20 ± 0.01 mg kg^{-1} ('$B_{10}T_{10}$'). The antinutrients and phytochemicals results showed that flavonoids in TWFSP ranged from 0.30 ± 0.01 mg TAE kg^{-1} ('B_1V_1') to 970.50 ± 0.02 mg TAE kg^{-1} (B_3V_3) while it varied from 0.20 ± 0.01 mg TAE kg^{-1} ('B_4T_4') to 670.30 ± 0.01 mg TAE kg^{-1} ('B_8T_8') in OFSP. Heritability estimates were high for all antinutrients and minerals while genetic advance was high only for potassium (42.206) and phosphorus (10.288) traits. Variation between phenotypic coefficient of variation and genotypic coefficient of variation was negligible, with the former higher for most minerals and antinutrients. TWFSP were found richer than OFSP, and suggests improvement by selection.

Key words: antinutrient, cultivars, phytochemicals, minerals, nutrition, sweet potatoes

Primerjalna ocena hranilne in nehranilne kakovosti je odkrila, da ima sladki krompir z belim založnim parenhimom boljše lastnosti kot tisti z oranžnim

Izvleček: Nedavna uvedba sladkega krompirja z oranžnim mesom (OFSP) bogatega z beta-karotenom, je povzročila slabše povpraševanje potrošnikov po tradicionalnem sladkem krompirju z belim mesom (TWFSP), ne da bi ustrezno upoštevali njegove prehranske lastnosti. Ta študija preučuje prehransko sestavo sladkega krompirja z belim in oranžnim mesom (založnim parenhimom). Vzorci so bili analizirani na vsebnost elementov, bioaktivnih sestavin in antinutrientov na National Root Crops Research Institute, Umudike. Nigerija. Terenski poskus je bil izveden z uporabo naključne blokovne zasnove s tremi ponovitvami. Krompir z belim mesom je pokazal večje vsebnosti mineralov, antihranil in bioaktivnih sestavin v primerjavi z oranžnim sladkim krompirjem. V krompirju z belim mesom se je kalij gibal od 1879,20 ± 0,01 mg kg^{-1} ('B_3V_3') do 1960,30 ± 0,01 mg kg^{-1} ('B_2V_2'), medtem, ko se je v krompirju z oranžnim mesom gibal od 1162,60 ± 0,02 mg kg^{-1} ('$B_{26}T_{26}$') do 1800,20 ± 0,01 mg kg^{-1} ('$B_{10}T_{10}$'). Rezultati antinutrientov in bioaktivnih sestavin so pokazali, da je bila vsebnost flavonoidov v krompirju z belim mesom od 0,30 ± 0,01 mg TAE kg^{-1} ('B_1V_1') do 970,50 ± 0,02 mg TAE kg^{-1} (B_3V_3), v krompirju z oranžnim mesom pa od 0,20 ± 0,01 mg TAE kg^{-1} ('B_4T_4') do 670,30 ± 0,01 mg TAE kg^{-1} ('B_8T_8'). Določitve dednih znakov so bile velike za vse antinutriente in vsebnosti elementov, genetska prednost je bila večja samo za kalij (42,206) in fosfor (10,288). Razlike med fenotipičnim in genotipičnim koeficientom spremenljivosti so bile zanemarljive, pri čemer so bile razlike v genotipičnem koeficientu večje za vsebnosti večine elementov in antinutrientov. Sorte z belim založnim parenhimom so se izkazale po večji vsebnosti koristnih snovi, kar nakazuje, da jih je potrebno uporabiti v žlahtniteljskih programih.

Ključne besede: antihranilo, sorte, fitokemikalije, minerali, prehrana, sladki krompir

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1 INTRODUCTION

Most traditional white-fleshed sweet potato (TWFSP) especially cultivars from Abakaliki, Nigeria, seem to have gone into extinction as a result of introduction of the orange-fleshed sweet potatoes (OFSP) (Mazuze, 2004). Beta-carotene, a known vitamin A precursor and carotenoids are plentiful in OFSP and their regular consumption can prevent blindness especially night blindness (Ndirigue, 2004; Park et al., 2016). TWFSP cultivars have been grown among local farmers for several years due to their high yielding capability, and consumer's acceptability despite its low beta-carotene contents. However, the high adoption rate of the recently introduced OFSP cultivars seemed to have caused a total replacement of TWFSP cultivars among farmers and consumers (Mazuze, 2004).

Although OFSP cultivars have been recognized for better beta-carotene contents than TWFSP cultivars, there is no elaborate record that compared other nutritional and antinutritional properties between them. Generally, sweet potatoes have been a vital food supply for the poorest farmers and food-insecure people around the world (Sugri et al., 2017). Studies reported that after maize, rice, and wheat, sweet potato is the fifth most important food crop in the developing world, with over 110 million metric tonnes produced per annum (Kanu et al., 2018). Sweet potatoes are abundant in protein, dietary fiber, polyphenols, vitamins and minerals but low in fat, which perhaps made it an ideal food for a greater percentage of the world's populace (Kanu et al., 2018; Tunio et al., 2019).

In many countries, including countries of sub-Saharan Africa, sweet potatoes especially white flesh sweet potatoes are the most utilized traditional root crops when compared to other root crops. In most Nigerian localities, TWFSP cultivars appear to be the most prevalent choice among local farmers probably among other benefits, because of their enormous volatile organic compounds (flavor) content (Mazuze, 2004; Kanu et al., 2018).

Previous studies have examined the nutritional properties of sweet potato cultivars grown in different countries of the world and have found considerable variation in nutrients among different sweet potato cultivars (Sanoussi et al., 2016; Kanu et al., 2018). The differences observed could be attributed to soil, climate, growing conditions, varying genetic make-up of cultivars and other factors (Mwanri et al., 2011; Sanoussi et al., 2016). However, none of these studies investigated the nutritional potentials of a given white fleshed sweet potato cultivar(s) in comparison with the OFSP cultivars, which recently have seemingly dominated greater parts of sub-Saharan African countries since development and introduction.

We hypothesize that the nutritional potentials of different OFSP and TWFSP cultivars will vary but to what extent and which would be better we cannot ascertain. Hence, the present study was undertaken to make a comparative assessment or appraisal of the nutritional, antinutritional and phytochemical properties of the available traditional white-fleshed sweet potatoes and the orange-fleshed sweet potato cultivars in the region and check for variability and trait association for better future sweet potato breeding.

2 MATERIALS AND METHODS

2.1 MATERIALS, EXPERIMENTAL SITE, DESIGN AND AGRONOMIC PRACTICE

Twenty-two cultivars of orange-fleshed sweet potato genotypes were collected from the National Root Crops Research Institute (NRCRI) Umudike, Abia State, Nigeria and three traditional white fleshed cultivars of sweet potato were collected from farmers in Abakaliki, Ebonyi State, Nigeria. The summary and description of each sweet potato cultivar are presented in Table 1.

The stems cuttings were collected and planted at the research and teaching farm of the Department of Crop Production and Landscape Management, Ebonyi State University, Abakaliki, Nigeria during raining season precisely June, 2019 which lasted till September the same year. The experimental design utilized was a randomized complete block design with three replicates. Standard agronomic management practices included; weeding, fertilizer (NPK 20:10:10), fungicide (mancozeb/chlorothalonil) and insecticide (malathion1/cypermethrin) applications at the rates provided on the labels, respectively. Tuber weighing 10 kg was harvested from each cultivar for nutritional analysis. All tubers were harvested, washed, and sliced before freeze-drying.

The dried potato slices were then pulverized, sieved through a 100-mesh sieve, and stored at –20 °C for all analysis. The laboratory analysis was carried out at the NRCRI central molecular biology laboratory, Umudike.

2.2 MINERAL ANALYSIS

The method of the Association of Official Agricultural Chemists (AOAC) in 2010 was used for the determination of mineral content; 1 g of the pulverized samples was placed in a crucible and ignited in a muffle furnace at 550 °C for 6 hours. The resulting ash was dissolved in

Table 1: Description of 25 sweet potato cultivars

S/N	Genotypes	Sources	Sowing/Harvesting date	Skin and flesh color
1	'B_6T_6'	NRCRI	June. 28, 2019/September. 28, 2019	purple/yellow
2	'B_1T_1'	NRCRI	June. 28, 2019/September. 28, 2019	purple/yellow
3	'B_3V_3'	ABAKALIKI	June. 28, 2019/September. 28, 2019	White/white
4	'$B_{17}T_{17}$'	NRCRI	June. 28, 2019/September. 28, 2019	purple/yellow
5	'B_8T_8'	NRCRI	June. 28, 2019/September. 28, 2019	purple/yellow
6	'$B_{28}T_{28}$'	NRCRI	June. 28, 2019/September. 28, 2019	purple/yellow
7	'$B_{13}T_{13}$'	NRCRI	June. 28, 2019/September. 28, 2019	purple/yellow
8	'$B_{26}T_{26}$'	NRCRI	June. 28, 2019/September. 28, 2019	purple/yellow
9	'$B_{10}T_{10}$'	NRCRI	June. 28, 2019/September. 28, 2019	purple/yellow
10	'$B_{16}T_{16}$'	NRCRI	June. 28, 2019/September. 28, 2019	purple/yellow
11	'$B_{29}T_{29}$'	NRCRI	June. 28, 2019/September. 28, 2019	Brown/Yellow
12	'$B_{19}T_{19}$'	NRCRI	June. 28, 2019/September. 28, 2019	Brown/yellow
13	'B_2V_2'	ABAKALIKI	June. 28, 2019/September. 28, 2019	Light purple/white
14	'$B_{11}T_{11}$'	NRCRI	June. 28, 2019/September. 28, 2019	Brown/yellow
15	'B_5T_5'	NRCRI	June. 28, 2019/September. 28, 2019	Brown/yellow
16	'$B_{18}T_{18}$'	NRCRI	June. 28, 2019/September. 28, 2019	Brown/yellow
17	'B_7T_7'	NRCRI	June. 28, 2019/September. 28, 2019	Brown/yellow
18	'$B_{15}T_{15}$'	NRCRI	June. 28, 2019/September. 28, 2019	Brown/yellow
19	'$B_{14}T_{14}$'	NRCRI	June. 28, 2019/September. 28, 2019	Brown/yellow
20	'$B_{20}T_{20}$'	NRCRI	June. 28, 2019/September. 28, 2019	Brown/yellow
21	'B_3T_3'	NRCRI	June. 28, 2019/September. 28, 2019	Red/yellow
22	'B_1V_1'	ABAKALIKI	June. 28, 2019/September. 28, 2019	Red/White
23	'B_2T_2'	NRCRI	June. 28, 2019/September. 28, 2019	Red/yellow
24	'B_4T_4'	NRCRI	June. 28, 2019/September. 28, 2019	Red/yellow
25	'B_9T_9'	NRCRI	June. 28, 2019/September. 28, 2019	Red/yellow

NRCRI: National Root Crops Research Institute, Umudike, Abia State, Nigeria

10 ml of 10 % HNO_3 and heated slowly for 20 minutes. After heating, it was filtered and the filtrate was used for the determination of mineral content. Atomic Absorption Spectrophotometer (AAS) was used in all analyses.

2.3 EXTRACTION OF PHENOLICS AND FLAVONOIDS

Total phenolics and flavonoids in freeze-dried OFSP and TWFSP roots were determined through colorimetric assay using the method of Abidemi (2013). Briefly, 1 g of the freeze-dried root powdered sample was weighed into clean propylene tubes before the addition of 10 ml of 80 % methanol, vortexed, shaken on a mechanical shaker, and incubated at a temperature of 25 °C for 12 hours. The mixture was then centrifuged at 3226 × g for 10 min, and the supernatant aliquot was collected to determine the total phenolics and total flavonoid contents.

2.4 DETERMINATION OF THE TOTAL POLYPHENOL CONTENT

The method of Baba and Malik (2015) was used to quantify the total phenolic content using the Folin-Ciocalteu technique. Exactly 20 ml of the sample blank solution (80 % methanol), gallic acid standards (0.001–0.1 kg ml^{-1}), and 5 ml of samples were pipetted into their corresponding test tubes, followed by the addition of 100 ml of 10 % Folin–Ciocalteu reagent and the mixtures are then shaken thoroughly. After 5 minutes, 80 ml of 7 % sodium carbonate was added and gently mixed before the plate was covered with aluminum foil and the reaction was allowed to incubate for 90 minutes at room temperature.

The absorbance value was then taken at 725 nm in a spectrophotometer. The concentration of total phenolic compounds in mg kg^{-1} of the dry sample as gallic acid equivalent was determined using an external standard calibration procedure (mg GAE).

2.5 ANALYSIS OF FLAVONOIDS

Exactly 250 ml titration flask, 0.005 kg of each plant sample was weighed, and 100 ml of 80 percent aqueous methanol was added at room temperature and agitated in an electric shaker for 4 hours. This process was repeated with the entire solution filtered through Whatman filter paper no. 42. The filtrate was then placed in a crucible and evaporated to dryness over a water bath before being weighed (Abidemi, 2013).

2.6 ANALYSIS OF TANNIN

Tannin was analyzed using the method of Ejikeme et al. (2014). Exactly 0.001 kg of the samples was weighed into a plastic bottle followed by the addition of 1000 ml of water and shaken for 1 hour in a shaker. It was then filtered, and 10 ml of the extract was measured into a test tube, along with 3 ml of 0.1 N HCl and three drops of ferrocyanide. It was let to stand for 10 minutes before being measured in a UV-Spectrophotometer at a wavelength of 605 nm.

$$\text{Tannic acid (mg kg}^{-1}) = C \times \text{extract volume} \times 0.1$$

$$\text{Aliquot volume} \times \text{mass of the sample}$$

Where, C is the concentration of tannic acid read.

2.7 EXTRACTION AND DETERMINATION OF OXALATE

Extraction of total oxalate was done as reported by Liu et al. (2009) and Nguyễn and Savage (2013). 1 g of each powdered sample was added to 0.5 mol l^{-1} of HCl before being diluted in 1 ml distilled water. The homogenate was put in 10 ml graduated tubes and cooked for 20 minutes in a boiling water bath. After the homogenate had cooled, distilled water was added to each tube to bring the total volume to 10 ml. About 1 ml of the homogenate was clarified the next day at 4 8C by centrifugation (12,000 g, 10 min). After that, 0.016 ml NaOH (2 mol l^{-1}) was carefully added to 0.5 ml supernatant.

Initially, a 2 ml test tube was added 20 mg of oxalate oxidase and then filled with other ingredients, including 0.06 ml of distilled water, 0.08 ml of colorant (10 mg of 4-aminoantipyrine), 25 ml of N, N-dimethylaniline, 0.04 ml of horseradish peroxide and 0.05 ml oxalate extract. The reaction mixture's absorbance at 555 nm was measured in a spectrophotometer after 90 minutes of incubation at room temperature. The oxalate content was calculated using a standard curve made by mixing 0, 2, 4, 6, 8, and 10 mg oxalic acid into a 1 ml reaction system, respectively. The results are given as mean mg oxalate kg^{-1} (Liu et al., 2009).

2.8 SAPONINS ANALYSIS

Saponin was analyzed according to the methods of Akpe et al. (2021). In a beaker, 0.005 kg of sample was added in 50 ml of 20 % ethanol. The suspension was heated for four hours in a hot water bath with constant stirring at a temperature of 60 °C. The mixture was filtered after 4 hours, and the residue was extracted again with another 25 ml of 20 % ethanol. The combined extract was concentrated and reduced to 40 ml in a water bath at 90 °C. The sample was placed in a separator-funnel and 20 ml diethyl ether was added and thoroughly shaken. The extracts' aqueous layer was recovered, while the other layers were discarded. Exactly 60 ml of n-butanol was then added and the extract was washed twice with 10 ml of 5 % aqueous sodium chloride. The remaining extracts were evaporated in a water bath and dried in an oven to a constant mass and weighed.

2.9 ALKALOIDS ANALYSIS

5 g of sample was weighed into a beaker; 100 ml of 100 % acetic acid in ethanol (1:1) was measured into the sample container and covered for 4 hours. After four hours, the extracted sample was filtered. It was then concentrated to a fraction of its original volume using a water bath. Drop-by-drop, ammonia solution was added to the concentrated extract, allowing the precipitate to settle before being filtered and washed with dilute ammonium hydroxide. The crude alkaloid was extracted from the residue and dried in an oven before being weighed.

2.10 ANTHOCYANINS ANALYSIS

The total anthocyanin content was calculated using Giusti and Wrolstad's method (2001) and Wegdan et al. (2020). In summary, two dilutions of the sample extract were made as follows 1 ml of the extracted sample so-

lution was added to a 10 ml volumetric flask each. One dilution volume was adjusted using potassium chloride buffer (pH 1.0), while the other was adjusted with sodium acetate buffer (pH 4.5). For equilibration, the dilution was allowed to sit for 15 minutes. Each dilution's absorbance was measured against water at 510 and 700 nm. The diluted sample's absorbance (A) was determined as follows:

$$A = (A_{510} - A_{700})\ \text{pH 1.0} - (A_{510} - A_{700})\ \text{pH 4.5}$$

The concentration of monomeric anthocyanin pigment was determined using the following formula: Monomeric anthocyanin pigment

$$(\text{mg } 100\ \text{g}^{-1}) = (A \times MW \times \text{DF} \times 1000) / (\varepsilon \times 1)$$

Where *MW* is the molecular weight, DF is the dilution factor, and ε is the molar absorptivity, calculate pigment content as cyanidin-3-glucoside.

Where *MW* = 449.2 and ε = 26,900

2.11 STATISTICAL ANALYSIS

All analyses such as ANOVA, genetic variability including phenotypic coefficient of variation percentage (% PCV) and genotypic coefficient of variation percentage (% GCV), Pearson correlation, Clusters and PCA were performed using the R statistical package (R-4.2.1) version (R Core Team, 2022).

3 RESULTS AND DISCUSSION

The results of the mineral contents of orange-fleshed sweet potatoes and indigenous or traditional white-fleshed sweet potatoes are presented in Table 2, Table 3, and Figure 1 while those of the antinutrients and phytochemicals are presented in Table 4, Table 5, and Figure 2.

3.1 COMPARATIVE ANALYSIS OF VARIATION AMONG OFSP AND TWFSP

3.1.1 Minerals

The results showed significant variation for the variables, and that both OFSP and TWFSP cultivars contained all the eight minerals including calcium, iron, potassium, phosphorus, sodium, magnesium, manganese, and zinc (Table 2). The studies of Mwanri et al. (2011) and Sanoussi et al. (2016) reported the presence of these minerals in orange-flesh sweet potatoes. Their concentrations as observed in the present study showed evidence that sweet potatoes possess high nutritional value. Minerals are needed in the body to keep the heart beating, blood clotting, nerve responses and reactions, and most importantly keep the body fluid balance in check (Mwanri et al., 2011; Sanoussi et al., 2016). The proper consumption of minerals is essential for human health. For instance, potassium is highly needed for proper neuronal transmission, and protein synthesis (Sebeo et al., 2009). Of the eight minerals studied, the concentrations of six minerals including zinc, calcium, iron, potassium, phosphorus, and sodium were found to be higher in TWFSP compared to the OFSP. The higher concentrations of these minerals in traditional white-fleshed cultivars suggested the presence of variation in their genetic make-up, and showed that this group may possess more nutrient and health benefits than orange-fleshed sweet potatoes (Table 3). Zinc and iron contents were higher in TWFSP cultivar 'B_3V_3' with values of 8.30 ± 0.01 mg kg^{-1} and 12.60 ± 0.01 mg kg^{-1}, respectively. Comparatively, OFSP cultivars, B_8T_8 and '$B_{26}T_{26}$' expressed the values 7.60 ± 0.02 mg kg^{-1} and 12.40 ± 0.02 mg kg^{-1} for zinc and iron, respectively. Although there is no literature on the TWFSP cultivars used in this study, the values we had for OFSP cultivars were close to those of Sanoussi et al. (2016). Zinc has been reported as a catalyst in a variety of activities in our bodies including involvement in macromolecules metabolism and required for cell division, tissue repair and normal reproductive development (Sebeo et al., 2009). Furthermore, iron has been implicated in the formation of hemoglobin in red blood cells, hence TWFSP cultivars, especially 'B_3V_3' will be of health importance for people with a metabolism health related problems and those suffering from iron deficiency compared to OFSP cultivars with lower mean concentrations. Phosphorus and sodium were also higher in TWFSP cultivar 'B_1V_1' with mean concentrations of 486.40 ± 0.03 mg kg^{-1} and 374.20 ± 0.02 mg kg^{-1}, respectively compared to the values of phosphorus (295.80 ± 0.01 mg kg^{-1}) and sodium (216.60 ± 0.01 mg kg^{-1}) in OFSP cultivars '$B_{17}T_{17}$' and 'B_6T_6', respectively. Magnesium and manganese with values 301.20 ± 0.03 mg kg^{-1} and 3.30 ± 0.03 mg kg^{-1} were the only minerals that had higher mean concentrations found in OFSP cultivars '$B_{18}T_{18}$' and '$B_{26}T_{26}$', respectively. These values were against the lowest mean concentrations of 260.50 ± 0.02 mg kg^{-1} and 1.70 ± 0.01 mg kg^{-1} for magnesium and manganese observed in TWFSP cultivars 'B_1V_1' and 'B_3V_3', respectively. These mean concentrations varied compared to 235.00 mg kg^{-1} reported for magnesium in an OFSP cultivar (Sanoussi et al., 2016). The reason for this variation may be attributed to differences in edaphic factors of the locations they were

Table 2: Mineral content (mg kg^{-1}) of orange-fleshed sweet potatoes and Abakaliki indigenous white-fleshed sweet potatoes

Genotypes	Ca	Na	Mg	P	K	Fe	Zn	Mn
'B_6T_6'	271.20 ± 0.02^{i}	218.80 ± 0.01^{a}	243.40 ± 0.02^{j}	301.30 ± 0.01^{c}	1274.30 ± 0.02^{b}	6.80 ± 0.01^{c}	5.20 ± 0.02^{e}	1.20 ± 0.00^{de}
'B_1T_1'	248.60 ± 0.01^{d}	226.20 ± 0.02^{c}	228.60 ± 0.01^{f}	393.10 ± 0.01^{h}	1451.70 ± 0.01^{h}	10.50 ± 0.01^{hi}	6.80 ± 0.01^{i}	1.20 ± 0.02^{cde}
'B_3V_3'	363.20 ± 0.01^{v}	372.50 ± 0.01^{r}	260.50 ± 0.02^{o}	442.30 ± 0.02^{t}	1879.20 ± 0.01^{w}	12.60 ± 0.01^{l}	8.30 ± 0.01^{l}	2.20 ± 0.01^{h}
'$B_{17}T_{17}$'	220.50 ± 0.01^{c}	301.70 ± 0.01^{i}	221.60 ± 0.02^{d}	295.80 ± 0.01^{a}	1332.60 ± 0.02^{d}	5.40 ± 0.02^{b}	6.10 ± 0.01^{g}	1.80 ± 0.01^{g}
'B_8T_8'	293.70 ± 0.02^{l}	358.70 ± 0.02^{o}	270.40 ± 0.01^{s}	437.10 ± 0.01^{s}	1492.70 ± 0.02^{k}	11.50 ± 0.02^{k}	7.60 ± 0.02^{k}	1.50 ± 0.01^{def}g
'$B_{28}T_{28}$'	300.40 ± 0.01^{n}	339.10 ± 0.01^{l}	256.80 ± 0.01^{n}	403.30 ± 0.01^{k}	1631.60 ± 0.02^{q}	12.40 ± 0.02^{l}	7.20 ± 0.01^{j}	2.30 ± 0.01^{h}
'$B_{13}T_{13}$'	294.40 ± 0.04^{m}	346.30 ± 0.03^{n}	213.60 ± 0.02^{b}	401.40 ± 0.03^{j}	1425.40 ± 0.01^{g}	5.60 ± 0.02^{b}	6.40 ± 0.02^{gh}	1.50 ± 0.02^{defg}
'$B_{26}T_{26}$'	216.60 ± 0.02^{b}	251.50 ± 0.01^{d}	200.50 ± 0.02^{a}	385.50 ± 0.01^{f}	1162.60 ± 0.02^{a}	2.50 ± 0.02^{a}	7.10 ± 0.01^{j}	3.30 ± 0.03^{i}
'$B_{10}T_{10}$'	314.30 ± 0.02^{r}	382.50 ± 0.02^{s}	256.10 ± 0.01^{m}	433.70 ± 0.02 ^{r}	1800.20 ± 0.01^{v}	11.50 ± 0.01^{k}	6.20 ± 0.02^{g}	2.20 ± 0.01^{h}
'$B_{16}T_{16}$'	286.80 ± 0.01^{j}	316.30 ± 0.01^{k}	261.90 ± 0.01^{p}	405.30 ± 0.01^{m}	1508.30 ± 0.02^{l}	10.50 ± 0.02^{hi}	4.80 ± 0.01^{d}	0.80 ± 0.01^{bc}
'$B_{29}T_{29}$'	253.20 ± 0.02^{e}	301.40 ± 0.01^{i}	225.80 ± 0.01^{e}	300.20 ± 0.01^{b}	1401.30 ± 0.02^{e}	12.40 ± 0.02^{l}	4.40 ± 0.03^{c}	1.50 ± 0.02^{defg}
'$B_{19}T_{19}$'	270.50 ± 0.01^{h}	223.70 ± 0.03^{b}	251.40 ± 0.02^{k}	331.60 ± 0.02^{d}	1285.30 ± 0.01^{c}	7.40 ± 0.02^{d}	4.60 ± 0.02^{cd}	1.40 ± 0.03^{defg}
'B_2V_2'	386.30 ± 0.03^{x}	391.40 ± 0.01^{t}	281.50 ± 0.02^{u}	473.40 ± 0.01^{x}	1960.30 ± 0.02^{y}	11.60 ± 0.02^{k}	7.50 ± 0.02^{k}	1.70 ± 0.03^{fg}
'$B_{11}T_{11}$'	303.60 ± 0.01^{p}	345.30 ± 0.02^{m}	263.50 ± 0.03^{q}	447.40 ± 0.02^{u}	1612.80 ± 0.01^{o}	11.70 ± 0.02^{k}	5.20 ± 0.01^{e}	1.70 ± 0.08^{g}
'B_5T_5'	321.90 ± 0.01^{s}	360.50 ± 0.03^{p}	301.20 ± 0.01^{v}	401.60 ± 0.02 ^{j}	1402.50 ± 0.01^{f}	8.40 ± 0.02^{e}	3.80 ± 0.01^{b}	1.70 ± 0.01^{g}
'$B_{18}T_{18}$'	325.30 ± 0.02^{t}	296.50 ± 0.03^{h}	264.50 ± 0.03^{r}	391.30 ± 0.03^{g}	1452.60 ± 0.02^{i}	10.40 ± 0.02^{h}	5.50 ± 0.03^{f}	1.10 ± 0.01^{cd}
'B_7T_7'	301.20 ± 0.02^{o}	263.90 ± 0.01^{f}	270.50 ± 0.03^{s}	452.50 ± 0.02^{w}	1771.30 ± 0.01^{u}	11.10 ± 0.01^{j}	4.70 ± 0.02^{d}	1.80 ± 0.00^{g}
'$B_{15}T_{15}$'	254.20 ± 0.01^{f}	312.50 ± 0.03^{j}	233.60 ± 0.02^{g}	428.30 ± 0.02^{q}	1620.40 ± 0.02^{p}	9.30 ± 0.02^{g}	6.30 ± 0.01^{gh}	2.30 ± 0.01^{h}
'$B_{14}T_{14}$'	206.40 ± 0.03^{a}	301.60 ± 0.03^{i}	254.40 ± 0.02^{l}	398.40 ± 0.02^{i}	1487.20 ± 0.02^{j}	8.80 ± 0.01^{f}	7.60 ± 0.01^{k}	1.60 ± 0.02^{efg}
'$B_{20}T_{20}$'	267.70 ± 0.02^{g}	254.50 ± 0.02^{e}	228.80 ± 0.01^{f}	404.20 ± 0.01^{l}	1692.10 ± 0.01^{s}	7.40 ± 0.02^{d}	6.50 ± 0.01^{h}	1.80 ± 0.01^{g}
'B_3T_3'	314.50 ± 0.03^{r}	365.60 ± 0.03^{q}	241.50 ± 0.03^{i}	375.50 ± 0.04^{e}	1550.30 ± 0.02^{m}	6.80 ± 0.02^{c}	6.40 ± 0.01^{gh}	0.30 ± 0.00^{a}
'B_1V_1'	374.20 ± 0.02^{w}	410.40 ± 0.02^{u}	274.70 ± 0.03^{t}	486.40 ± 0.03^{y}	1901.50 ± 0.02^{x}	10.80 ± 0.01^{i}	6.50 ± 0.03^{h}	1.70 ± 0.01^{fg}
'B_2T_2'	340.70 ± 0.03^{u}	338.80 ± 0.01^{l}	264.20 ± 0.03^{r}	422.50 ± 0.03^{p}	1596.60 ± 0.04^{n}	8.70 ± 0.02^{ef}	3.50 ± 0.02^{a}	1.40 ± 0.02^{def}g
'B_4T_4'	305.40 ± 0.03^{q}	312.50 ± 0.04^{j}	238.90 ± 0.01^{h}	413.10 ± 0.01^{o}	1632.70 ± 0.03^{r}	7.50 ± 0.04^{d}	4.70 ± 0.02^{d}	1.30 ± 0.02^{def}
'B_9T_9'	288.70 ± 0.02^{k}	294.30 ± 0.02^{g}	216.50 ± 0.02^{c}	407.50 ± 0.01^{n}	1701.80 ± 0.02^{t}	7.50 ± 0.03^{d}	4.50 ± 0.03^{cd}	0.60 ± 0.02^{ab}

The results are the standard deviations of three duplicate samples; values in the same column with similar letters are not significantly different at 0.05, Keys: Ca = calcium, Na = sodium, P = phosphorus, K = potassium, Zn = zinc, Fe = iron, Mg = magnesium, Mn = manganese

planted and fertilizer application as has been suggested in potato (*Solanum tuberosum* L.) (Liang et al., 2019). Manganese is very important component of glucose tolerance factor (GTF), which regulates blood glucose levels while magnesium is an essential component in many enzyme reactions and has an important role in the immune system regulation (Siddiqui et al., 2014; Konieczynski et al., 2022).

3.1.2 ANTINUTRIENTS AND PHYTOCHEMICALS

The antinutrients (oxalate, tannins, saponins and alkaloids) and phytochemicals (total polyphenols, anthocyanins and flavonoids) quantified in this study were all present in all the 25 cultivars at varying concentrations (Table 4). TWFSP cultivars had higher concentrations of all the antinutrients when also compared with OFSP (Table 5). The alkaloids and anthocyanin were the two compounds higher in OFSP than TWFSP. The highest mean value of alkaloids concentrations in OFSP was 1.30 ± 0.01 mg kg^{-1} for cultivar 'B_6T_6' contrary to 1.20 ± 0.01 mg kg^{-1} for TWFSP cultivar 'B_1V_1'. The values we obtained for alkaloids in this study deferred from the 6.20 ± 0.01 mg kg^{-1} reported in different cultivars of OFSP (Ogah et al., 2014; Akpe et al., 2021). This may be due to differences in plant maturity date, post-harvest storage and processing, location, growth season, soil type and nutrients (Li et al., 2012). Alkaloids have been implicated in a wide range of pharmacological effects, including anti-malarial, anti-cancer (Kittakoop et al., 2014), anti-bacterial (Cushnie et al., 2014) and anti-hyperglycemic (Qiu et al., 2014). Other compounds quantify in this study including oxalate, flavonoids, tannin, polyphenols and saponin were higher in TWFSP than OFSP. The concentrations of total polyphenols, flavonoids, tannins and oxalate in TWFSP were 123.80 ± 0.01 mg kg^{-1}, 970.50 ± 0.02 mg kg^{-1}, 4.70 ± 0.01 mg kg^{-1}, and 382.20 ± 0.02 mg kg^{-1}, respectively for cultivars 'B_3V_3' compared to the maximum mean concentration values of 89.20 ± 0.02 mg kg^{-1}, 673.80 ± 0.0102 mg kg^{-1}, 3.90 ± 0.01 mg kg^{-1} and 330.30 ± 0.0 mg kg^{-1} respectively in OFSP cultivars 'B_1T_1', 'B_8T_8', 'B_4T_4' and '$B_{13}T_{13}$' respectively. The concentrations obtained for tannin, flavonoids, and total polyphenols varied compared to the studies by Akpe et al. (2021) that reported 2.80 ± 0.01 mg kg^{-1}, 9.70 ± 0.01 mg kg^{-1}, and 7.20 ± 0.01 mg kg^{-1} for tannins, flavonoids, and total polyphenols, respectively. Flavonoids have antioxidant effects and have been shown to inhibit the initiation, promotion, and progression of tumors and can equally reduce coronary heart disease (Ezeonu & Ejikeme, 2016). Tannins have also been implicated in antiviral, antibacterial, and antitumor activity (Ezeonu & Ejikeme, 2016) while saponins are helpful in treating yeast and fungal infections. TWFSP also has higher content of oxalate with mean concentrations of 7.20 ± 0.01 mg kg^{-1} compare to 6.20 mg kg^{-1} in OFSP. Oxalate can prevent calcium absorption and utilization in the body. This eventually could lead to disorders like osteomalacia and rickets in the human body (Reddy & Pierson, 1994).

Table 3: The basic statistics description of mineral content of TWFSP and OFSP

TWFSP (Traditional white-fleshed sweet potatoes)								
Parameter	Ca	Na	Mg	P	K	Fe	Zn	Mn
Mean	374.60	391.40	272.20	467.30	1913.70	11.70	7.40	1.90
Median	374.20	391.40	274.70	473.40	1901.50	11.60	7.50	1.90
Minimum	363.10	372.40	260.30	442.10	1879.10	10.70	6.20	1.40
Maximum	386.60	410.60	281.60	486.60	1960.40	12.70	8.40	2.30
Range	235.00	38.20	21.30	44.50	81.30	2.00	2.20	0.90
OFSP (Orange-fleshed sweet potatoes)								
Parameter	Ca	Na	Mg	P	K	Fe	Zn	Mn
Mean	281.80	305.10	248.10	392.30	1513.00	8.80	5.70	1.50
Median	291.20	307.10	251.40	402.50	1500.50	8.80	5.90	1.60
Minimum	206.20	218.70	200.30	295.70	1162.40	2.50	3.30	0.30
Maximum	340.90	382.60	333.40	452.70	1800.20	12.50	7.80	3.50
Range	134.70	163.90	133.10	157.00	637.80	10.00	4.50	3.20

Ca = calcium, Na = sodium, P = phosphorus, K = potassium, Zn = zinc, Fe = iron, Mg = magnesium, Mn = manganese

Table 4: Anti-nutrient and phytochemical compositions (mg kg^{-1}) of orange-fleshed sweet potatoes and Abakaliki indigenous white-fleshed sweet potatoes

Genotypes	Oxalate	Tannin	Saponin	Alkaloids	Polyphenol	Flavonoids	Anthocyanin
'B$_6$T$_6$'	4.50 ± 0.01^{fa}	3080 ± 0.01^{de}	0.70 ± 0.01^{ghi}	1.30 ± 0.00^{a}	81.80 ± 0.01^{b}	592.10 ± 0.01^{bc}	478.10 ± 0.01^{b}
'B$_1$T$_1$'	2.80 ± 0.01^{m}	2.20 ± 0.01^{o}	1.10 ± 0.01^{de}	0.70 ± 0.00^{bc}	89.20 ± 0.02^{b}	601.50 ± 0.01^{bc}	403.20 ± 0.02^{bc}
'B$_3$V$_3$'	7.20 ± 0.01^{a}	4.70 ± 0.01^{a}	1.50 ± 0.01^{b}	0.40 ± 0.00^{a}	123.80 ± 0.01^{a}	970.50 ± 0.02^{a}	0.40 ± 0.04^{a}
'B$_{17}$T$_{17}$'	4.10 ± 0.01^{hi}	3.20 ± 0.01^{ghi}	0.80 ± 0.01^{fg}	0.10 ± 0.00^{bcd}	76.20 ± 0.02^{b}	534.10 ± 0.01^{bc}	313.70 ± 0.01^{c}
'B$_8$T$_8$'	3.80 ± 0.02^{j}	3.10 ± 0.01^{hij}	0.50 ± 0.01^{jk}	0.50 ± 0.00^{dcf}	92.60 ± 0.01^{b}	673.80 ± 0.02^{b}	445.70 ± 0.02^{c}
'B$_{28}$T$_{28}$'	4.30 ± 0.01^{gh}	3.70 ± 0.01^{de}	0.70 ± 0.00^{fgh}	0.80 ± 0.01^{b}	80.40 ± 0.01^{b}	645.20 ± 0.02^{b}	319.30 ± 0.02^{c}
'B$_{13}$T$_{13}$'	6.20 ± 0.01^{b}	4.10 ± 0.01^{bc}	1.40 ± 0.01^{bc}	0.70 ± 0.01^{bc}	82.10 ± 0.01^{bcd}	572.20 ± 0.01^{bc}	382.80 ± 0.02^{bc}
'B$_{26}$T$_{26}$'	4.10 ± 0.01^{l}	3.20 ± 0.01^{ghi}	1.10 ± 0.01^{e}	0.30 ± 0.01^{gh}	49.50 ± 0.03^{c}	403.60 ± 0.01^{c}	283.00 ± 00.03^{c}
'B$_{10}$T$_{10}$'	5.20 ± 0.02^{d}	3.30 ± 0.03^{fgh}	1.20 ± 0.01^{de}	0.70 ± 0.01^{bcd}	0.70 ± 0.00^{d}	0.80 ± 0.00^{d}	70.50 ± 0.01^{d}
'B$_{16}$T$_{16}$'	2.40 ± 0.01^{n}	3.20 ± 0.02^{ghi}	0.40 ± 0.01^{k}	0.60 ± 0.00^{bcd}	1.40 ± 0.01^{d}	0.70 ± 0.01^{d}	58.10 ± 0.01^{d}
'B$_{29}$T$_{29}$'	1.50 ± 0.01^{o}	2.80 ± 0.01^{jk}	0.60 ± 0.01^{hij}	0.80 ± 0.01^{b}	1.20 ± 0.03^{d}	0.50 ± 0.04^{d}	49.90 ± 1.17^{d}
'B$_{19}$T$_{19}$'	3.40 ± 0.01^{kl}	2.40 ± 0.04^{mn}	1.10 ± 0.01^{de}	0.40 ± 0.01^{fgh}	1.10 ± 0.00^{d}	0.30 ± 0.00^{d}	41.70 ± 0.00^{d}
'B$_2$V$_2$'	5.10 ± 0.01^{d}	3.40 ± 0.01^{fg}	1.20 ± 0.01^{de}	0.20 ± 0.01^{h}	1.20 ± 0.01^{d}	0.70 ± 0.01^{d}	0.20 ± 0.01^{d}
'B$_{11}$T$_{11}$'	5.60 ± 0.02^{c}	3.90 ± 0.01^{cd}	0.90 ± 0.01^{f}	0.70 ± 0.01^{bcd}	0.80 ± 0.06^{d}	0.70 ± 0.01^{d}	38.70 ± 0.21^{d}
'B$_5$T$_5$'	4.90 ± 0.01^{e}	3.20 ± 0.01^{ghi}	1.20 ± 0.01^{de}	0.30 ± 0.01^{gh}	0.40 ± 0.01^{d}	0.60 ± 0.00^{d}	40.10 ± 0.01^{d}
'B$_{18}$T$_{18}$'	4.20 ± 0.02^{hi}	3.00 ± 0.00^{ij}	0.70 ± 0.01^{ghi}	0.20 ± 0.00^{h}	0.60 ± 0.01^{d}	0.80 ± 0.01^{d}	39.30 ± 0.01^{d}
'B$_7$T$_7$'	4.60 ± 0.01^{f}	2.70 ± 0.01^{ghi}	0.50 ± 0.01^{fg}	0.40 ± 0.01^{bcd}	0.80 ± 0.03^{b}	0.60 ± 0.03^{bc}	45.20 ± 0.83^{c}
'B$_{15}$T$_{15}$'	3.60 ± 0.01^{jk}	3.00 ± 0.01^{ij}	0.60 ± 0.01^{hij}	0.60 ± 0.01^{bcd}	1.20 ± 0.01^{d}	0.40 ± 0.01^{d}	51.40 ± 0.01^{d}
'B$_{14}$T$_{14}$'	3.20 ± 0.01^{l}	3.50 ± 0.01^{ef}	0.70 ± 0.01^{ghi}	0.80 ± 0.01^{b}	1.20 ± 0.01^{d}	0.20 ± 0.01^{d}	62.30 ± 0.01^{d}
'B$_{20}$T$_{20}$'	3.80 ± 0.01^{j}	3.20 ± 0.01^{ghi}	1.10 ± 0.01^{de}	1.20 ± 0.02^{a}	1.10 ± 0.02^{d}	0.40 ± 0.03^{d}	61.30 ± 0.14^{d}
'B$_3$T$_3$'	4.20 ± 0.01^{hi}	4.10 ± 0.01^{bc}	0.80 ± 0.01^{fg}	0.70 ± 0.01^{bc}	0.90 ± 0.01^{d}	0.70 ± 0.00^{d}	60.20 ± 0.01^{d}
'B$_1$V$_1$'	6.10 ± 0.01^{b}	4.30 ± 0.01^{b}	1.70 ± 0.01^{a}	1.20 ± 0.02^{a}	1.20 ± 0.01^{d}	0.30 ± 0.01^{d}	0.50 ± 0.01^{d}
'B$_2$T$_2$'	4.10 ± 0.01^{l}	2.60 ± 0.01^{klm}	1.10 ± 0.01^{e}	0.40 ± 0.00^{efg}	0.10 ± 0.00^{d}	0.30 ± 0.01^{d}	48.90 ± 0.04^{d}
'B$_4$T$_4$'	4.30 ± 01^{gh}	2.50 ± 0.00l^{mn}	1.30 ± 0.00^{cd}	0.60 ± 0.00^{bcd}	0.70 ± 0.01^{d}	0.20 ± 0.00^{d}	46.30 ± 0.01^{d}
'B$_9$T$_9$'	5.30 ± 0.01^{d}	2.30 ± 0.02^{no}	0.80 ± 0.01^{fg}	0.60 ± 0.01^{cde}	0.50 ± 0.01^{d}	0.40 ± 0.01^{d}	51.10 ± 0.01^{d}

The results are the standard deviations of three duplicate samples; values in the same column with similar letters are not significantly different at 0.05

Table 5: The basic statistics description of antinutrient and phytochemical contents of TWFSP and OFSP

TWFSP (Traditional white-fleshed sweet potatoes)							
Parameters	OXA	TAN	SAP	ALK	POL	FLA	ANT
Mean	6.10	4.10	1.40	0.60	42.00	323.80	259.70
Maximum	7.20	4.70	1.80	1.30	123.90	970.60	690.60
Range	2.20	1.40	0.70	1.20	122.80	970.40	653.60
Minimum	5.00	3.30	1.10	0.10	1.10	0.20	37.00
Median	6.10	4.30	1.50	0.40	1.20	0.70	51.70
OFSP (Orange-fleshed sweet potatoes)							
Parameters	OXA	TAN	SAP	ALK	POL	FLA	ANT
Mean	4.10	3.10	0.80	0.60	25.70	183.20	154.10
Median	4.10	3.10	0.80	0.60	1.10	0.70	59.10
Minimum	1.40	2.10	0.30	0.20	0.30	0.10	37.20
Maximum	6.20	4.20	1.50	1.30	98.30	806.50	495.30
Range	4.80	2.10	1.20	1.10	98.00	806.40	458.10

OXA = Oxalate, TAN = Tannins, SAP = Saponins, ALK = Alkaloids, POL = Polyphenol, FLA = Flavonoids, ANT = Anthocyanins

3.2 TRAIT ASSOCIATION, GENETIC VARIABILITY AND PRINCIPAL COMPONENT ANALYSIS

The comprehensive correlations between the levels of all the minerals, antinutrients and phytochemicals in OFSP and TWFSP were investigated using Pearson's correlation analysis.

Among the minerals, positive significant correlations across the minerals were observed except for zinc and manganese, which had either negative or positive insignificant correlation with other minerals. Potassium showed substantial positive correlation with phosphorus (r = 0.776) and calcium (r = 0.707) (Figure 1). The result of this study is in congruence with that of Sanoussi et al. (2016) who reported high significant correlation between calcium and magnesium in sweet potatoes. Among the phytochemicals, total polyphenols showed the highest significant positive correlation with anthocyanins and flavonoids with correlation values of 0.980 and 0.980 respectively. Oxalate, which is an antinutrient, showed significant association with tannins and saponins with values of 0.477 and 0.593, respectively (Figure 2). The strong positive correlation observed among traits suggested high relatedness among them and that any trait can influence the other in the same direction.

Considering minerals, antinutrients and phytochemicals, the percentage value of PCV were higher than the percentage values of GCV showing how little the environment affected each trait. PCV values for minerals ranged from 39.981 to 10.581, while GCV values ranged from 37.875 % to 8.9714 %. PCV values for antinutrients and phytochemicals ranged from 159.890 % to 20.302 % while GCV values ranged from 149.450 % to 19.824 % (Table 6). The difference between GCV and PCV was very small and ranged from 2.1058 to 0.000 for minerals, while the difference between PCV and GCV for antinutrients and phytochemicals ranged from 10.4906 % to 0.0942 %. The PCV and GCV reported in our study are higher than the values of 14.41 % and 15.98 % reported for Iron by Amoros et al. (2020) and lower than the 254.75 % and 253.96 % respectively, reported for anthocyanin by Dutta et al. (2022). The higher percentage values of PCV than GCV showed that environment influences the expression of minerals and antinutrients in sweet potatoes, while the extremely small (less than 10 %) difference between PCV and GCV confirmed that environment indeed interacts in the expression of all traits studied (Uyeda et al., 2015). This equally implies that selection and hybridization may not be suitable for improving the content of sweet potatoes (Uyeda et al., 2015).

Heritability (H2b) in the broader sense was generally high for antinutrients, phytochemicals and minerals, ranging from 0.7189 to 1.0 for minerals and from 0.8731 to 0.9934 for antinutrients and phytochemicals (Table 6). This result varied slightly higher than the 0.81 reported for iron and zinc by Uyeda et al. (2015) and the same with the studies of Dutta et al. (2022) who reported 0.99 for anthocyanin. The genetic advance (GA) was relatively low for all traits except potassium (42.206) and phosphorus (10.288) among the other traits for minerals. The genetic advance for phytochemicals was higher for flavonoids and anthocyanin with values of 35.699 and 57.526, respectively. The low genetic advance with high heritability observed in all minerals, antinutrients and

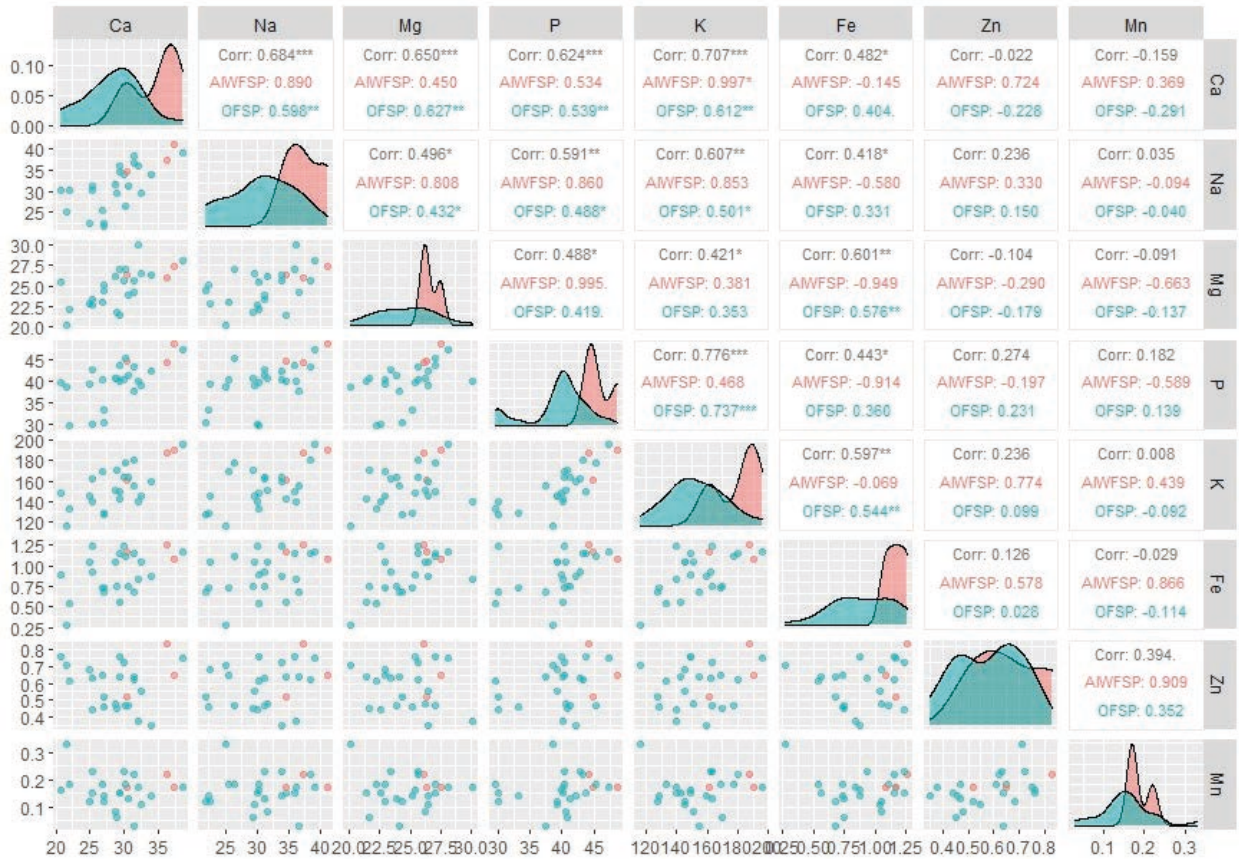

Figure 1: Pearson correlation plot for minerals. Ca = calcium, Na= sodium, P= phosphorus, K= potassium, Zn = zinc, Fe = iron, Mg = magnesium, Mn= manganese, Red color = Orange-fleshed sweet potatoes, Green = Traditional white-fleshed sweet potatoes

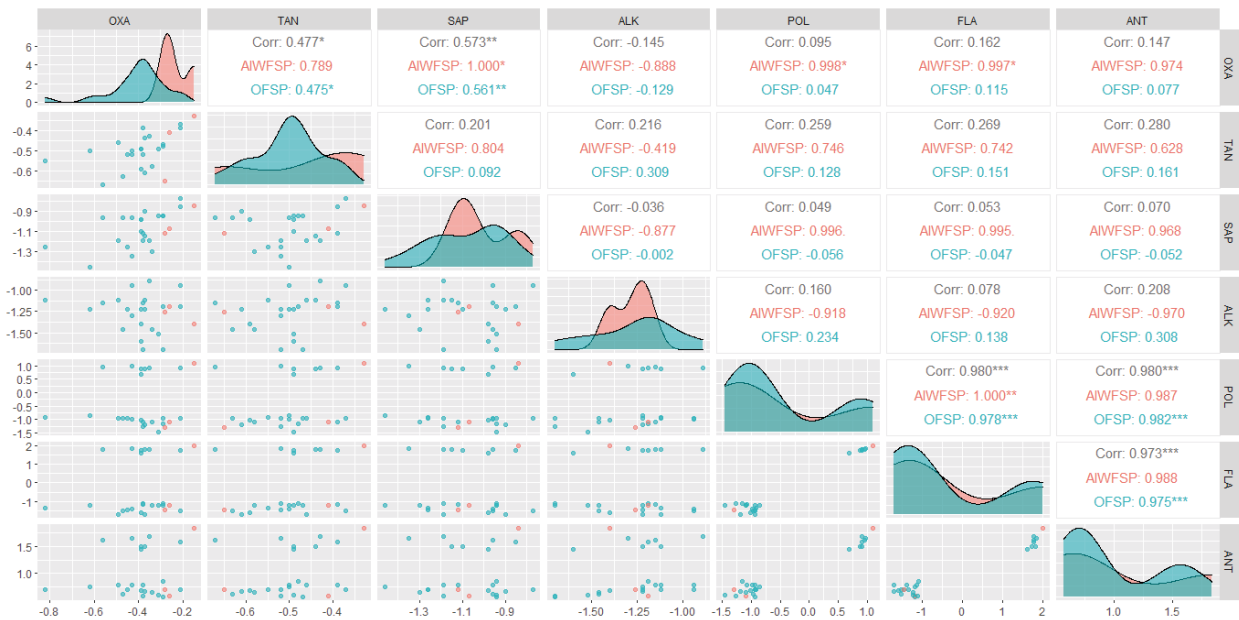

Figure 2: Pearson correlation plot for antinutrients. OXA = Oxalate, TAN = Tannins, SAP = Saponins, ALK = Alkaloids, POL =Total polyphenols, FLA = Flavonoids, ANT = Anthocyanins, Red color = Orange-fleshed sweet potatoes, Green = Traditional white-fleshed sweet potatoes

Table 6: Estimates of genetic parameters of antinutrients and phytochemicals from different cultivars of orange-fleshed and sweet potatoes

Traits	Gra. M	Min	Max	VE	VG	PV	ECV %	GCV %	PCV %	PCV-GCV	H_2b	GA	GAM
Ca	29.29	20.62	38.66	0.001	21.249	21.25	0.09	15.737	15.737	0.0003	1	9.4959	32.418
Na	31.544	21.87	41.06	0.0008	28.958	28.959	0.0871	17.059	17.06	0.0002	1	11.085	35.142
Mg	25.096	20.03	33.34	1.9817	5.0691	7.0508	7.0508	8.9714	10.581	1.6093	0.7189	3.9326	15.67
P	40.13	29.57	48.66	0.0006	24.942	24.942	0.061	12.445	12.445	0.0002	1	10.288	25.636
K	156.11	116.24	196.04	0.0005	419.78	419.78	0.0139	13.125	13.125	0	1	42.206	27.037
Fe	0.915	0.25	1.27	0.0006	0.0663	0.0669	2.6294	28.141	28.268	0.127	0.991	0.528	57.705
Zn	0.5886	0.33	0.84	0.0004	0.0168	0.0172	3.5196	22.021	22.282	0.2606	0.9767	0.2639	44.835
Mn	0.1562	0.03	0.35	0.0004	0.0035	0.0039	12.265	37.875	39.981	2.1058	0.8974	0.1155	73.944
Traits	Gra. M	Min	Max	VE	VG	PV	ECV %	GCV %	PCV %	PCV-GCV	H_2b	GA	GAM
OXA	0.4312	0.14	0.72	0.0001	0.0151	0.0152	2.7326	28.498	28.592	0.0942	0.9934	0.2523	58.511
TAN	0.323	0.21	0.47	0.0002	0.0041	0.0043	4.3784	19.824	20.302	0.4778	0.9535	0.1288	39.876
SAP	0.0914	0.03	0.18	0.0001	0.0011	0.0012	10.551	36.287	37.901	1.6136	0.9167	0.0654	71.554
ALK	0.0604	0.01	0.13	0.0001	0.0008	0.0009	14.992	46.828	49.669	2.8406	0.8889	0.0549	90.894
POL	2.7634	0.03	12.39	1.9024	16.088	17.99	49.912	145.15	153.49	8.3421	0.8943	7.8135	282.75
FLA	20.004	0.01	97.06	129.84	893.19	1023	56.962	149.4	159.89	10.4906	0.8731	57.526	287.57
ANT	16.677	3.7	69.06	36.09	332.87	368.96	36.024	109.4	115.18	5.7783	0.9022	35.699	214.06

Ca = calcium, Na = sodium, P = phosphorus, K = potassium, Zn = zinc, Fe = iron, Mg = magnesium, Mn = manganese, OXA = Oxalate, TAN = Tannins, SAP = Saponins, ALK = Alkaloids, POL = Polyphenols, FLA = Flavonoids, ANT = Anthocyanins, VE = Environmental variance, VG = Genotypic variance, PV = Phenotypic variance, ECV = Environmental coefficient of variation, GCV = Genotypic coefficient of variation, PCV = Phenotypiccoefficient of variation, H2b = Broad sense heritability, GA = Genetic advance, GAM = Genetic advance as a percentage of mean, Min = Minimum, Max = Maximum, Gra. M = Grand mean

phytochemicals studied indicates that these traits are significantly influenced by environmental factors and phenotypic selection may not be possible for enhancement (Uyeda et al., 2015).

The PCA biplot loading for the minerals revealed an overall variance of 68.3 % for dimensions 1 and 2. Dimension (PC1) explained the highest variation at 48.9 % (Figure 3). The plot of different dimensions for the minerals showed that dimension 2 had the highest concentrations or magnitude of zinc and manganese while iron and sodium were higher in dimensions 4 and 5, respectively (Figure 4). Magnesium had higher concentration

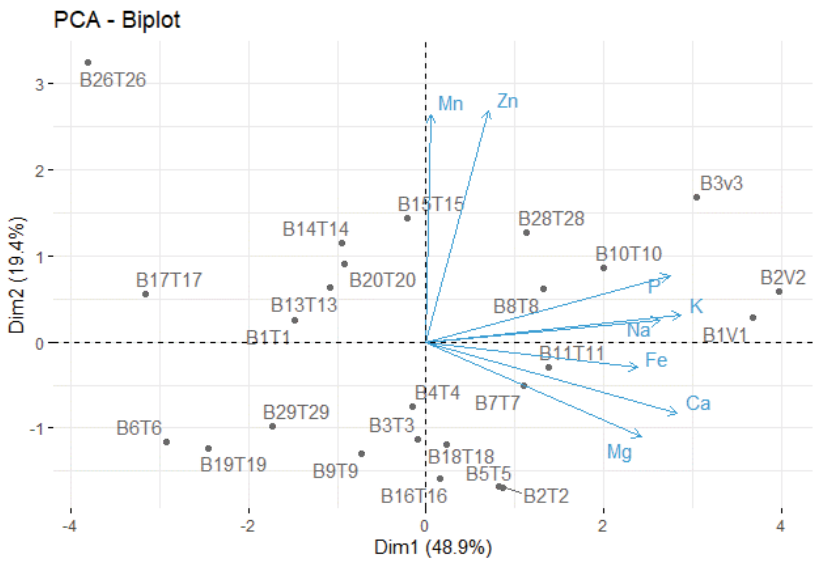

Figure 3: Principal component analysis for minerials. Ca = calcium, Na= sodium, P = phosphorus, K = potassium, Zn = zinc, Fe = iron, Mg = magnesium, Mn = manganese

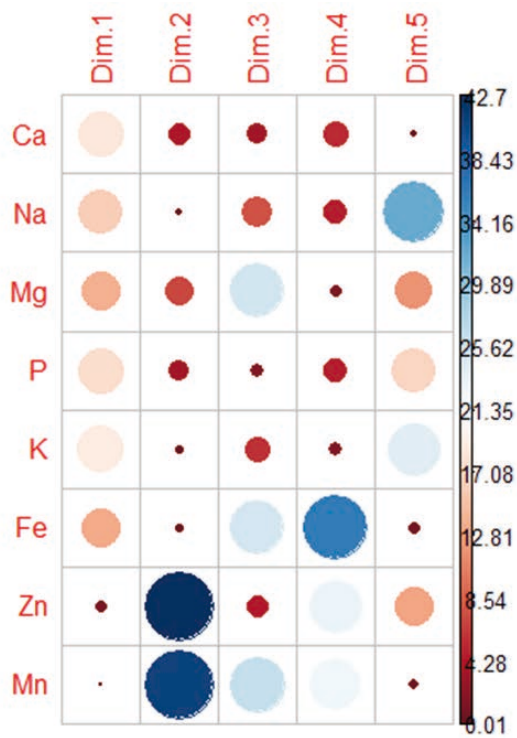

Figure 4: Dimension plots analysis for minerals. Ca = calcium, Na = sodium, P = phosphorus, K = potassium, Zn = zinc, Fe = iron, Mg = magnesium, Mn = manganese

in dimension 3 compared to other dimensions whereas potassium was higher in dimension 5, comparatively. A PCA biplot demonstrates how each trait affects a principal component and how they are related to one another. Based on the factor loading, manganese, phosphorus, potassium, zinc, and sodium contributed most to the variation observed in PC1 suggesting a positive and high correlation with some of the cultivars such as '$B_{28}T_{28}$', '$B_{10}T_{10}$', 'B_2V_2', 'B_8T_8', 'B_3V_3', and 'B_1V_1' since the smaller angle (less than 90 degree) between the two vectors indicates positive and greater correlation (Olanrewaju et al., 2021). It is clear from the PCA biplot that accessions loading in PC1 had a larger content of minerals (Mn, P, K, Zn, and Na) than accessions loading in PC2. The present result is similar to the studies of Laurie et al. (2022) which found sweet potatoes major nutrient in PC1.

The biplot of the principal component analysis for antinutrients revealed an overall variance of 78.7 % for dimension 1 and 2. Dimension (PC1) explained the highest variation at 48.8 % (Figure 5). The plot of different dimensions for antinutrients showed that dimensions 3 and 5 had the highest concentrations of alkaloid and oxalate, respectively (Figure 6). Among the 5 dimensions considered, saponin was higher in dimension 4. Based on the factor loading, saponin, oxalate, tannin, and alkaloids contributed most to the variation observed in PC1 indicating a positive and high correlation with some of the cultivars such as 'B_1V_1', '$B_{13}T_{13}$', and 'B_3V_3'. The PCA biplot clearly showed that the accessions loading in PC1 had a higher content of antinutrients than the accessions loading in PC2. The analysis also revealed that out of the three cultivars that showed strong and positive association with these antinutrients (saponin, oxalate, alkaloid, and tannin), two ('B_1V_1' and 'B_3V_3') were of traditional white flesh sweet potato cultivars. Although, studies are limited based on the samples used in the present study, however, our findings are similar to those of Ellong et al. (2014) which also reported strong relationship between polyphenols or phenoics and sweet potatoes.

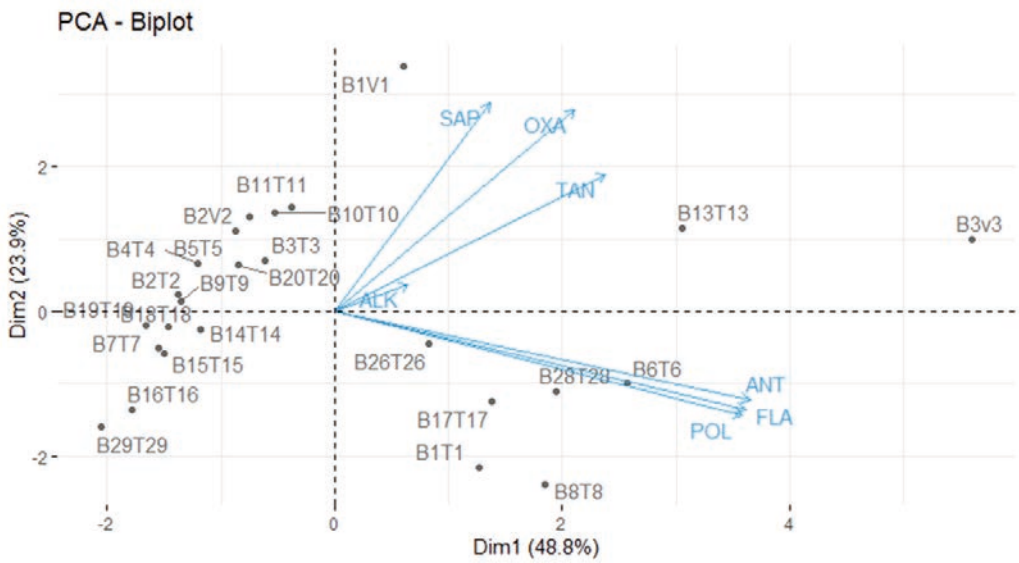

Figure 5: Principal component analysis for anti-nutrient. OXA = Oxalate, TAN = Tannins, SAP = Saponins, ALK = Alkaloids, POL = Total Polyphenols, FLA = Flavonoids, ANT = Anthocyanins

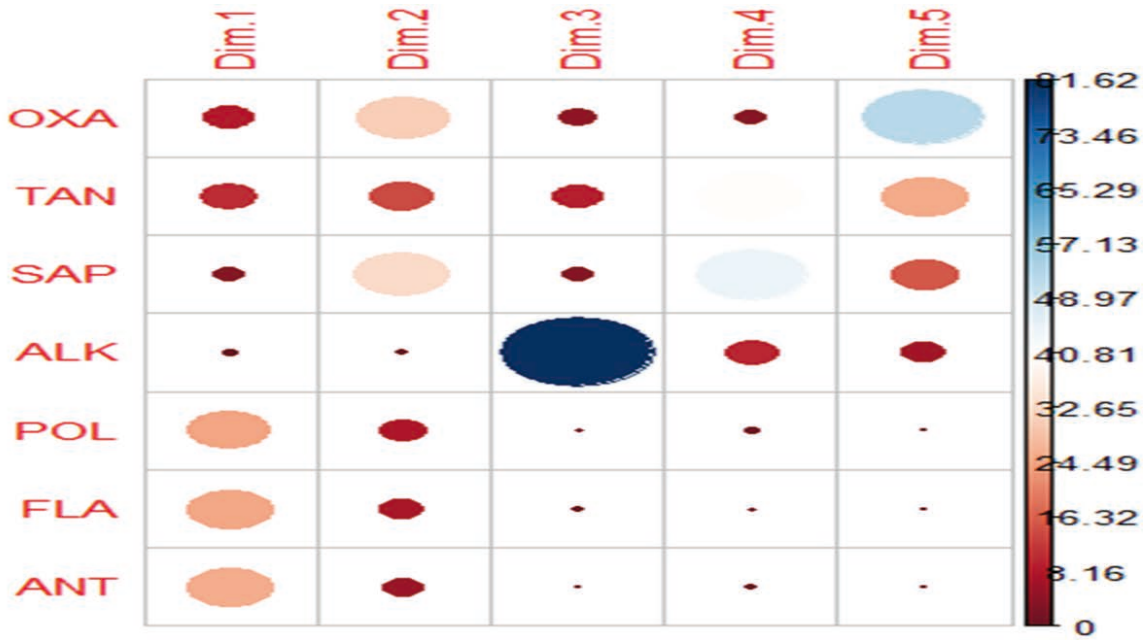

Figure 6: Dimension plot analysis for antinutrient. OXA = Oxalate, TAN = Tannins, SAP = Saponins, ALK = Alkaloids, POL = Total Polyphenols, FLA = Flavonoids, ANT = Anthocyanins

3.3 CLUSTER ANALYSIS

The hierarchical clustering analysis constructed using pvclust cluster method with AU/BP Pvalues in percentages and the bootstrapping of 10,000 are shown below in figures 7 and 8 for mineral and antinutrients,

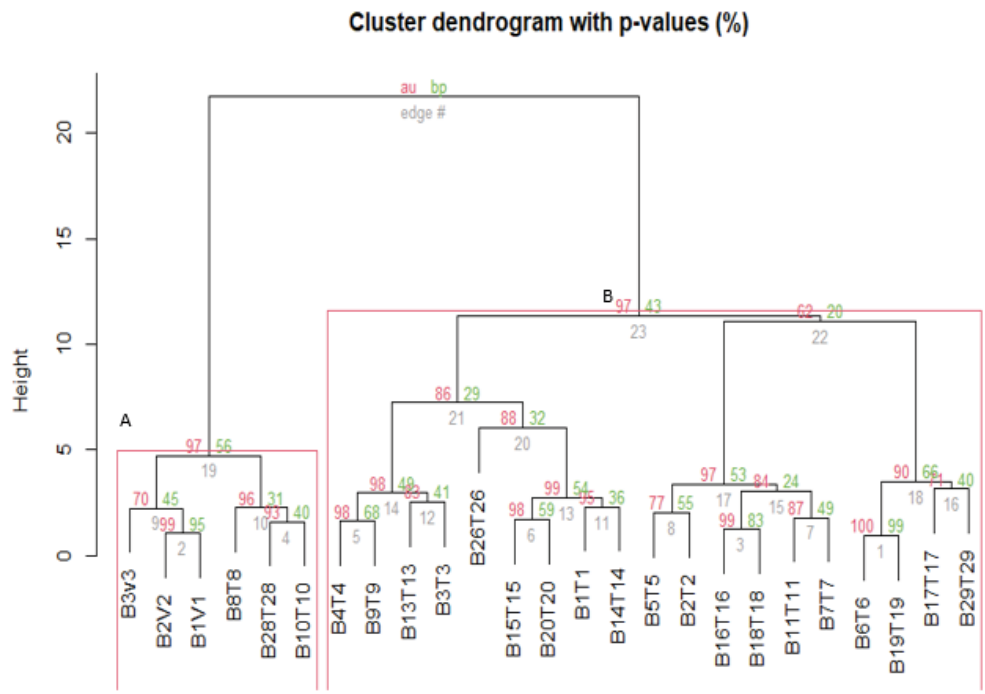

Figure 7: Cluster dendrogram with au/bp values (%) based mineral. The values at the edges of the cluster are P-values (%) calculated over a multiscale bootstrap with 1000 resamples. Values on the left in red = au (approximate unbiased) P-values, and values on the right in green = bp (bootstrap probability) values. Clusters with au above 95 % are highlighted in blocks suggest high relatedness.

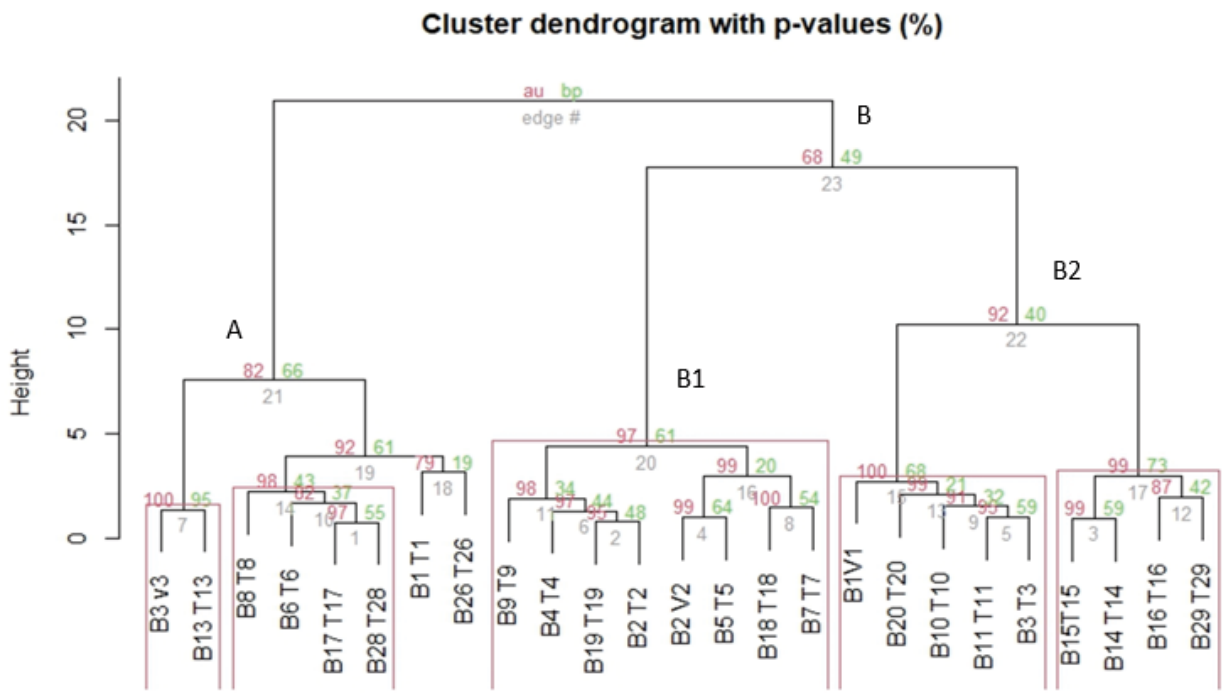

Figure 8: Cluster dendrogram with au/bp values (%) for antinutrient analysis. The values at the edges of the cluster are P-values (%) calculated over a multiscale bootstrap with 1000 resamples. Values on the left in red = au (approximate unbiased) P-values, and values on the right in green = bp (bootstrap probability) values. Clusters with au above 95 % are highlighted in block suggest high relatedness

respectively. This method offers two types of p-values: AU (Approximately Unbiased) p-value and BP (Bootstrap Probability) value. The AU p-value calculated by multiscale bootstrap resampling is a better approximation of the unbiased p-value than the BP value calculated by normal bootstrap resampling. Therefore, AU p-values above 95 % indicate significant clusters (Suzuki & Shimodaira, 2009; de Croos & Pálsson, 2012). The cluster dendrogram for the minerals grouped the genotypes into two groups (A and B) according to the relatedness of their mineral composition. Cluster A contains only six cultivars, including all traditional white-fleshed sweet potatoes ('B_1V_1', 'B_2V_2' and 'B_3V_3') and a few OFSP ('$B_{10}T_{10}$,' 'B_8T_8' and '$B_{28}T_{28}$'). Cluster B consists of 19 genotypes and included all OFSPs.

The cluster dendrogram for antinutritional analysis (Figure 8) was also divided into two clusters A and B. Cluster B was further divided into B1 and B2. Cluster A had eight genotypes, including '$B_{13}T_{13}$,' 'B_6T_6,' '$B_{17}T_{17}$,' '$B_{26}T_{26}$,' 'B_1T_1,' 'B_8T_8,' '$B_{28}T_{28}$' and 'B_3V_3.' 'B_3V_3' was the only TWFSP in cluster A. However, cluster B had two TWFSPs, B_2V_2 in cluster B1 and 'B_1V_1' in cluster B2. Cluster B had a total of 17 genotypes. The appearance of 'B_3V_3' of TWFSP among the cultivars of OFSP in cluster A showed that the grouping pattern of the genotypes did not completely follow their source or geographical distribution. This suggests that 'B_3V_3' which fell into cluster A despite its origin or geographical distribution showed a sign of broad genetic base of the genotype. Lee et al. (2019) reported that breeding has enhanced the diversity of cultivated potatoes, especially with its related wild relatives at both phenotypic and genotypic levels. This type of clustering was also reported by Lee et al. (2015) where OFSP cultivars fell into the same cluster compared to TWFSP.

4 CONCLUSIONS

The study revealed significant variation for the traits in both TWFSP and OFSP cultivars. Of the eight minerals studied, the concentrations of six minerals including zinc, calcium, iron, potassium, phosphorus, and sodium were found to be higher in TWFSP compared to the OFSP which suggest that the former may possess more nutrient and health benefits than the latter.

Except for alkaloids and anthocyanin, TWFSP cultivars had higher concentrations for all the antinutrients compared to OFSP cultivars.

The positive significant correlations across the minerals and phytochemicals suggested high relatedness among traits and this can encourage the selection of fewer traits in future trials, which would reduce cost in traits measurement and management without undermining experiment precision.

The high genetic advance with high heritability observed for potassium and phosphorus (minerals), flavonoids and anthocyanin (phytochemicals) indicates that these traits would respond to selection as the best improvement approach.

Despite the lack of carotene, the traditional white-fleshed sweet potatoes proved to possess higher concentrations of these minerals and phytochemicals than orange-fleshed sweet potatoes of which the three varieties of TWFSP involved in the study stood out the best, comparatively.

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4.2 DATA AVAILABILITY STATEMENT

All data set generated during and/or analyzed to support the findings of this study are phenotypic data and can be made available from the corresponding author on request.

4.3 COMPETING INTERESTS

The authors declare that there are no conflicts of interest, financial or nonfinancial, directly or indirectly.

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