Essential Amino Acids Profile of Tuber, Parts and Products of Selected Cassava (Manihot Esculenta Crantz) Varieties

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Abstract

Cassava remains a major staple in the diets of humans and livestock. The increased consumption of this produce has led to the development of β-carotene bio-fortified cassava varieties. However, there is little information on the nutrient composition of these cassava varieties and their products. Therefore, this study aimed to determine the essential amino acid (EAA) contents of cassava and its products. In a completely randomized design, tubers and leaves from different varieties of cassava plants (aged one year) were harvested and used for the study. Products (fresh peeled tuber, garri, garri flour, grit, grit flour, peelings, peels and leaves) were analyzed for the main EAA. The results showed that all the EAA analyzed were present in the cassava tubers and products analyzed. The AA concentration ranged from 0.05 g/kg of histidine found in freshly peeled tubers, and garri flours of TMS 07/0593 and TMS 01/1368, respectively to a maximum leucine content of 24.35 g/kg in the leaves of TMS 01/1412. Amino acid concentrations ranged from 0.05 to 24.35 g/kg. Except for isoleucine, which was high in cassava peels and peelings, cassava leaves had the highest concentration of amino acids among the cassava varieties and products analyzed. However, TMS 01/1412 showed consistently high essential amino acid content compared to the other cassava varieties. Thus, cassava and its by-products offer a significant amino acid profile, which could be valuable for livestock nutrition.

Keywords: Cassava by-products, amino acids, nutrient composition, tuber crops, cassava leaves.

Introduction

Cassava and its products are among the most consumed and major sources of nutrients in humans and animals. It is widely consumed in Africa, with over one billion people consuming cassava in various forms worldwide (Ogunwole et al., 2015; Adebayo, 2023). Rice, wheat, and maize are the only staple foods considered to be more important than cassava worldwide, while cassava is rated as the second most important food crop in sub-Saharan Africa (Katz & Weaver, 2020).

Growing awareness of dietary choices has driven the development of β-carotene bio-fortified cassava varieties by International Institute of Tropical Agriculture (Njoku et al., 2011), as a sustainable solution to combat vitamin A deficiency, especially in sub-Saharan Africa. The bio-fortification of cassava roots is expected to influence their chemical composition, including the amino acid content of cassava roots and its products. However, previous research has focused on

the potential and bioavailability of inherent β-carotene and cyanide in cassava diets for humans and animals (Ogunwole et al., 2015; Odoemelam et al., 2020).

Amino acids are essential components of human and animal nutrition (Karau & Grayson, 2014) acids are used as dietary supplements for humans and livestock. However, the indiscriminate use of amino acids has been reported to have side effects (Holecek, 2022). Hence, it is imperative to understand the dietary concentrations of amino acids in food and feed ingredients. Unfortunately, the amino acid content of most locally produced food products, including bio-fortified cassava, remains unknown. The limited information on the amino acid content of most locally produced food products makes it challenging for nutritionists to evaluate and investigate dietary and metabolic demands and pathways (Yeoh, 1996; Ford et al., 2023). Although, Oladimeji et al. (2022) documented the amino acid profile of cassava peel products and reported that glutamic acid is the most abundant amino acid in cassava peel, information on the amino acid profiles of other cassava products is still limited. Therefore, it is necessary to assess the AA content of cassava β-carotene and its products. In addition, knowledge of AA and other nutrients is pivotal to precision feeding in animal feed. Thus, this research was aimed at further assessing the much-needed information on the EAA profile of cassava tubers, parts, and their products.

Materials and Methods
Experimental Site
This experiment was carried out at the Research and Demonstration Farm of the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, at latitude 7.501424 °E and longitude 3.90992 °N. Chemical analyses were carried out at the Department of Animal Science Laboratories, University of Ibadan, Ibadan, Nigeria, at latitude 7.4506 °E and longitude 3.8951 °N coordinates.

Test Materials
Four yellow cassava varieties (TMS 01/1412, TMS 01/1371, TMS 01/1368, and TMS 07/0593) and TME 419 (conventional white variety in Nigeria), aged 12 months, were obtained from the International Institute of Tropical Agriculture, Ibadan, Nigeria, at latitude 7.501424 °E and longitude 3.90992 °N coordinates. Cassava varieties were grown in different experimental plots. Tubers and leaves from the plots were randomly harvested and processed into cassava products (fresh peeled tuber, garri, garri flour, grit, grit flour, peelings, peels, and dried leaves), as described by Ogunwole et al. (2017).

Preparation of Test Materials
Freshly peeled tubers were obtained by mechanically removing the ring-like covering (peelings). Garri was obtained from processed cassava root and was peeled and washed. The washed tuber was then grated and bagged in non-laminated sacks, and compressed overnight with a hydraulic press to release excess moisture. The cake obtained from the process was pulverized and dried through frying to obtain garri. Garri flour was obtained using the same method used for garri. However, rather than frying as in the case of garri, the flour obtained after pulverization was oven-dried at 65 °C until a constant weight was achieved.

Cassava grits were obtained from whole cassava tubers, which were washed, grated, bagged, dewatered through a hydraulic press, and then fried in a frying pan. Grit flour was obtained from the whole cassava tuber by washing the unpeeled tuber, grinding, bagging, and compressing it to remove its water content, and then drying it in an oven at a regulated temperature of 65 °C. These products were presented in granular form, dried, and stored in an airtight bag after which they were assayed.

For cassava peels, the tubers were water-cleansed and then carefully sliced by sloughing the covering to reveal the cream or whitish inner root skin color. The sliced samples were collected and oven-dried until a constant weight was achieved. However, cassava peelings were obtained from fresh cassava roots by mechanically peeling the ring-like covering of cassava tubers. Cassava leaves with no evidence of structural, insect, or microbiological damage were randomly sampled from each plot. The leaves were collected and oven-dried at 65℃ until a constant weight was achieved. All the samples were prepared in quadruplicate.

Amino Acid Determination
The essential amino acids were determined using the EN ISO 13903:2005 method described by Dalibard et al. (2014). Essential amino acids such as methionine, lysine, threonine, arginine, histidine, isoleucine, leucine, phenylalanine, and valine were isolated from the cassava products. The protein in the cassava products were hydrolysed using 0.1mol/L hydrochloric acid from 200mg of milled cassava products (<1mm particle size) under nitrogen atmosphere releasing free amino acids into solution. The proteins and other nitrogenous macromolecules co-extracted in solution were precipitated using sulfosalicylic acid (50g/L concentration), and the mixture was clarified by filtration through 0.45 µm cellulose acetate membranes. The filtrate was adjusted to pH 2.2 with sodium citrate buffer and loaded onto an ion-exchange resin column. Amino acids were separated by stepwise elution with lithium citrate buffers of increasing ionic strength and temperature. Post-column, amino acids were reacted with ninhydrin and detected photometrically at 570nm. Quantification was achieved using calibration curves prepared from the amino acids standards, with norleucine added as an internal standard to correct for recovery losses and injection variability. Each batch samples included procedural blanks, duplicate analyses, and spiked samples to monitor precision and recovery.

Statistical Analysis
Data were subjected to descriptive statistics and analysis of variance using SAS (2002), and means were separated at α0.05 using Duncan's multiple range test option of the same software.

Results

Methionine Content of Tuber and Products from Five Cassava Varieties

The methionine contents (g/kg) of tubers and products from the five varieties of cassava are presented in Table 1. The methionine content of tubers and products from the five cassava varieties was significantly different (P<0.05). Methionine content of Freshly Peeled Tuber obtained from TMS 01/1371 (0.15 g/kg) and TMS 01/1368 (0.15 g/kg) were similar (P<0.05) and higher than those of other cassava varieties. For garri, methionine contents of TMS 01/1371 (0.1 g/kg), TMS 01/1368 (0.09 g/kg), TMS 07/0593 (0.09 g/kg) and TME 419 (0.90 g/kg) were significantly (P>0.05) similar but lower (P<0.05) than the methionine content in TMS 01/1412. TMS 01/1371 (0.1 g/kg) had the highest methionine content for garri flour and was significantly higher than 0.070 g/kg in TMS 07/0593. However, this value was similar to the methionine contents of TMS 01/1412 (0.08 g/kg), TMS 01/1371 (0.08 g/kg) and TME 07/0593 (0.08 g/kg). For grit, TMS 01/1412 (0.24 g/kg) had the highest methionine content compared to other cassava varieties while for grit flour methionine contents (0.23 g/kg) of TMS 01/1412 and TMS 01/1371 were similar but higher than 0.15 g/kg, 0.13 g/kg, 0.09 g/kg in TMS 01/1368, TMS 07/0593, and TME 419, respectively. TME 419 (0.58 g/kg) had the highest (P<0.05) methionine content for peelings, TMS 07/0593 (0.69 g/kg) for peels while TMS 01/1412 (5.20 g/kg) and TME 419 (5.13 g/kg) had the highest for cassava leaves.

Table 1: Methionine content (g/kg) of tuber and products from five cassava varieties

Product	TMS 01/1412	TMS 01/1371	TMS 01/1368	TMS 07/0593	TME 419	SEM
Freshly peeled tuber	0.14[b]	0.15[a]	0.15[a]	0.12[d]	0.13[c]	0.03
Garri	0.12[a]	0.10[b]	0.09[b]	0.090[b]	0.09[b]	0.0034
Garri flour	0.08[ab]	0.10[a]	0.08[ab]	0.07[b]	0.08[ab]	0.0037
Grit	0.24[a]	0.23[b]	0.150[e]	0.20[c]	0.17[d]	0.009
Grit flour	0.23[a]	0.23[a]	0.15[b]	0.13[c]	0.09[d]	0.02
Peelings	0.55[b]	0.32[e]	0.48[d]	0.51[c]	0.58[a]	0.02
Peels	0.58[c]	0.40[e]	0.51[d]	0.69[a]	0.59[b]	0.03
Leaves	5.20[a]	4.31[d]	4.50[c]	4.85[b]	5.13[a]	0.09

[abcde]Means in the same row with different superscripts differ significantly (P<0.05). **SEM:** Standard Error of Mean.

Lysine content of tuber and products from five cassava varieties

The Lysine contents (g/kg) of tubers and products from five varieties of cassava are presented in Table 2. There was significant variation (P<0.05) in the lysine content of tubers and products from different cassava varieties. Freshly peeled tuber, TMS 01/01371 (0.31 g/kg) had the highest (P<0.05) lysine content while the least (P<0.05) lysine content was recorded for TMS 01/1412 (0.18 g/kg). For garri, TMS 01/1412 (0.44 g/kg) had the highest (P<0.05) lysine content while TMS 01/1371 (0.33 g/kg) and TMS 01/1368 (0.33 g/kg) were significantly (P<0.05) similar. Furthermore, TMS 07/0593 (0.32 g/kg) and TME 419 (0.32 g/kg) had significantly similar lysine content. Interestingly, TMS 01/1371 had significantly higher (P<0.05) lysine contents for garri flour (0.54 g/kg), grit (0.89 g/kg) and grit flour (0.93 g/kg). Peelings from TMS 01/1368 (2.00 g/kg) and TMS 01/1371 (1.12 g/kg) had the highest lysine content compared to other varieties while leaves from TME 419 (14.86 g/kg) had significantly higher (P<0.05) lysine content.

Table 2: Lysine content (g/kg) of tuber and products from five cassava varieties

Product	TMS 01/1412	TMS 01/1371	TMS 01/1368	TMS 07/0593	TME 419	SEM
Freshly peeled tuber	0.18[e]	0.31[a]	0.29[c]	0.25[d]	0.30[b]	0.01
Garri	0.44[a]	0.330[b]	0.33[b]	0.32[c]	0.32[c]	0.01
Garri flour	0.32[d]	0.54[a]	0.38[b]	0.22[e]	0.35[c]	0.22
Grit	0.78[b]	0.89[a]	0.59[e]	0.70[c]	0.66[d]	0.03
Grit flour	0.80[b]	0.93[a]	0.38[a]	0.47[d]	0.54[c]	0.06
Peelings	1.82[d]	1.12[e]	2.00[a]	1.90[c]	1.97[b]	0.09
Peels	2.11[b]	1.52[e]	2.02[c]	2.27[a]	1.90[c]	0.07
Leaves	14.22[b]	11.5[d]	12.73[c]	14.09[b]	14.86[a]	0.30

[abcde]Means in the same row with different superscripts differ significantly (P<0.05). SEM: Standard Error of Mean.

Threonine content of tuber and products from five cassava varieties

The threonine contents (g/kg) of tubers and products from the five varieties of cassava are presented in Table 3. There was significant variation (P<0.05) in the threonine content of tubers and products from different cassava varieties. TMS 01/1371 had

the highest threonine content (0.41 g/kg) from freshly Peeled Tuber compared to other varieties. Threonine contents of garri (0.35 g/kg), grits (0.63 g/kg) and leaves (12.59 g/kg) were higher in TMS 01/1412 compared to other varieties while garri flour (0.33 g/kg) and grit flour (0.63 g/kg) from TMS 01/1371 had higher contents of threonine. Cassava peels of TMS 07/0593 (1.94 g/kg) had higher threonine content, while peelings (1.65 g/kg) and leaves (12.59) of TME 419 also had higher threonine contents than other varieties.

Table 3: Threonine content (g/kg) of tuber and products from five cassava varieties

Product	TMS 01/1412	TMS 01/1371	TMS 01/1368	TMS 07/0593	TME 419	SEM
Freshly peeled tuber	0.37^c	0.41^a	0.40^b	0.33^d	0.36^c	0.007
Garri	0.35^a	0.29^b	0.24^d	0.32^c	0.24^d	0.010
Garri flour	0.23^c	0.33^a	0.24^b	0.22^e	0.23^c	0.010
Grit	0.63^a	0.60^b	0.44^d	0.70^c	0.44^d	0.020
Grit flour	0.62^b	0.63^a	0.24^e	0.47^d	0.41^c	0.04
Peelings	1.63^{ab}	0.96^d	1.60^{bc}	1.90^c	1.65^a	0.070
Peels	1.83^b	1.18^d	1.57^c	2.27^a	1.56^c	0.070
Leaves	12.59^a	10.23^d	11.08^c	14.09^b	12.06^b	0.20

^{abcde}Means in the same row with different superscripts differ significantly (P<0.05). SEM: Standard Error of Mean.

Arginine content of tuber and products from five cassava varieties

The arginine contents (g/kg) of tubers and products from the five varieties of cassava are presented in Table 4. There was significant variation (P<0.05) in the arginine content of tubers, and the products were influenced by the cassava varieties. TMS 01/1368 had the highest (P<0.05) content of arginine in freshly peeled tuber (1.39 g/kg), garri (1.56 g/kg), garri flour (0.90 g/kg), and grit flour (0.90 g/kg) while arginine was higher (P<0.05) for grit (2.70 g/kg), peelings (9.45 g/kg), and peels (9.45 g/kg) in TMS 07/0593. The leaves of TMS 01/1412 (16.14 g/kg) were higher in arginine than in the other cassava varieties.

Table 4: Arginine content (g/kg) of tuber and products from five cassava varieties

Product	TMS 01/1412	TMS 01/1371	TMS 01/1368	TMS 07/0593	TME 419	SEM
Freshly peeled tuber	0.06^e	0.36^c	1.39^a	0.12^d	0.48^b	0.10
Garri	0.40^c	0.30^e	1.56^a	0.77^b	0.37^d	0.10
Garri flour	0.21^c	0.29^b	0.90^a	0.19^d	0.18^e	0.07
Grit	0.62^c	0.84^b	0.58^{cd}	2.70^a	0.56^d	0.20
Grit flour	0.82^c	0.61^e	0.90^a	0.64^d	0.88^b	0.30
Peelings	3.52^c	1.28^e	6.84^b	9.45^a	1.98^d	0.80
Peels	4.01^b	1.50^d	3.18^c	9.45^a	1.45^d	0.80
Leaves	16.14^a	12.83^e	14.04^d	15.19^c	15.75^b	0.30

^{abcde}Means in the same row with different superscripts differ significantly (P<0.05). SEM: Standard Error of Mean.

Histidine content of tuber and products from five cassava varieties

The Histidine contents (g/kg) of tubers and products from five varieties of cassava are presented in Table 5. There was significant variation (P<0.05) in the histidine content of tubers and products from different cassava varieties.

Histidine content of TMS 01/1371 (0.25 g/kg) and TMS 01/1368 (0.26 g/kg) in freshly peeled tubers were similar (P>0.05) and higher than those of other varieties while garri (0.21 g/kg) and garri flour (0.20 g/kg) from TMS 01/1371 was higher in histidine than other varieties. However, histidine contents of TMS 01/1412 (0.09 g/kg), TMS 01/1368 (0.05 g/kg), TMS 07/0593 (0.05 g/kg), and TME 419 (0.09 g/kg) were not significantly different from each other. Also, TMS 01/1371 recorded the highest (P<0.05) contents of histidine in grit (0.40 g/kg) and grit flour (0.42 g/kg) while peelings (1.16 g/kg) and peels (1.36 g/kg) from TMS 01/1368 and TMS 07/0593, respectively had higher histidine contents than the other varieties. The highest levels of histidine (6.36 g/kg) in cassava leaves were obtained from TMS 01/1412 and TME 419.

Table 5: Histidine content (g/kg) of tuber and products from five cassava varieties

Product	TMS 01/1412	TMS 01/1371	TMS 01/1368	TMS 07/0593	TME 419	SEM
Freshly peeled tuber	0.08^c	0.25^a	0.26^a	0.05^c	0.12^b	0.02
Garri	0.16^d	0.21^a	0.20^b	0.18^c	0.10^e	0.01
Garri flour	0.09^b	0.20^a	0.05^b	0.05^b	0.09^b	0.02
Grit	0.30^c	0.40^a	0.30^c	0.36^b	0.26^d	0.01
Grit flour	0.30^b	0.42^a	0.06^e	0.24^c	0.18^d	0.03
Peelings	1.10^b	0.67^d	1.16^a	1.11^b	0.94^c	0.05
Peels	1.25^b	0.74^d	0.99^c	1.36^a	0.69^e	0.07
Leaves	6.36^a	5.06^d	5.70^c	6.09^b	6.36^a	0.60

^{abcde}Means in the same row with different superscripts differ significantly (P<0.05). SEM: Standard Error of Mean.

Isoleucine content of tuber and products from five cassava varieties

Table 6 shows the isoleucine content (g/kg) of the tubers and products from the five cassava varieties. There was significant variation (P<0.05) in tubers and products from the five cassava varieties, except leaves. TMS 01/1371 had a higher (P<0.05) isoleucine content in freshly peeled tubers than in the other cassava varieties. Also, TMS 01/1371 had the highest (P<0.05) isoleucine content of 0.32 g/kg in garri flour while the lowest (P<0.05) content of 0.13 g/kg was recorded in TMS 07/0593. Grit (0.68 g/kg), peels (1.61 g/kg), grit flour (0.63 g/kg), peels (1.61 g/kg) and leaves (1.31 g/kg) from TMS 01/1412 had higher (P<0.05) isoleucine contents than the other varieties. The isoleucine content of the grit flour (0.63 g/kg) from TMS 01/1371 was similar (P>0.05) to that of TMS 01/1412. Nevertheless, peelings (1.58 g/kg) from TME 419 was richer (P<0.05) in isoleucine than those from other cassava varieties.

Table 6: Isoleucine content (g/kg) of tuber and products from five cassava varieties

Product	TMS 01/1412	TMS 01/1371	TMS 01/1368	TMS 07/0593	TME 419	SEM
Freshly peeled tuber	0.41^b	0.42^a	0.40^c	0.34^e	0.36^d	0.01
Garri	0.36^a	0.28^b	0.19^e	0.22^c	0.20^d	0.02
Garri flour	0.24^b	0.32^a	0.21^c	0.13^e	0.18^d	0.02
Grit	0.68^a	0.60^b	0.42^d	0.41^d	0.43^c	0.03
Grit flour	0.63^a	0.63^a	0.21^d	0.33^c	0.37^b	0.05
Peelings	1.51^b	0.90^e	1.34^c	1.10^d	1.58^a	0.07
Peels	1.61^b	1.12^e	1.36^d	1.50^c	1.52^b	0.05
Leaves	1.31^a	1.09^e	1.15^d	1.24^c	1.28^b	0.02

^{abcde}Means in the same row with different superscripts differ significantly (P<0.05). SEM: Standard Error of Mean.

Leucine content of tuber and products from five cassava varieties

The Leucine contents (g/kg) of tubers and products from five varieties of cassava are presented in Table 7. There was significant variation (P<0.05) in the leucine content of tubers and products from different cassava varieties. Leucine contents of freshly peeled tubers from TMS 01/1412 (0.67 g/kg) and TMS 01/1371(0.68 g/kg) were similar but higher than leucine from other cassava varieties. Also, higher values of leucine (0.57, 1.08, 2.63, 24.35 g/kg) were obtained for garri, grit, peels and leaves, respectively, from TMS 01/1412. However, peelings from TME 419 had the highest leucine content among the different cassava varieties, whereas the lowest values of leucine were recorded in peelings, peels, and leaves from TMS 01/1371.

Table 7: Leucine content (g/kg) of tuber and products from five cassava varieties

Product	TMS 01/1412	TMS 01/1371	TMS 01/1368	TMS 07/0593	TME 419	SEM
Freshly peeled tuber	0.67[a]	0.68[a]	0.64[b]	0.57[d]	0.57[c]	0.010
Garri	0.57[a]	0.47[b]	0.31[e]	0.37[c]	0.34[d]	0.025
Garri flour	0.38[b]	0.48[a]	0.32[e]	0.21[e]	0.29[d]	0.024
Grit	1.08[a]	1.00[b]	0.69[d]	0.69[d]	0.72[c]	0.050
Grit flour	1.02[b]	1.05[a]	0.32[e]	0.54[d]	0.60[c]	0.08
Peelings	2.36[b]	1.46[e]	2.17[c]	1.85[d]	2.65[a]	0.10
Peels	2.63[a]	1.84[e]	2.27[d]	2.52[c]	2.57[b]	0.080
Leaves	24.35[a]	20.25[e]	21.40[d]	22.94[c]	23.85[b]	0.40

[abcde]Means in the same row with different superscripts differ significantly (P<0.05). SEM: Standard Error of Mean.

Phenylalanine content of tuber and products from five cassava varieties

The Phenylalanine contents (g/kg) of tubers and products from five cassava varieties are presented in Table 8. There was significant variation (P<0.05) in the phenylalanine content of tubers and products from different cassava varieties. Freshly peeled tuber from cassava variety TMS 01/1371 recorded significantly higher phenylalanine (0.57 g/kg) compared to other cassava varieties. While TMS 07/0593 (0.47 g/kg) and TME 419 (0.46 g/kg) had similar phenylalanine in freshly peeled tubers. Garri from TMS 01/1412 had higher level of phenylalanine compared to other varieties while garri flour from TME 419 had the highest phenylalanine content. Also, TMS 01/1412 had higher phenylalanine contents for grit (0.76 g/kg), grit flour (0.75 g/kg), peelings (1.56 g/kg), peels (1.61 g/kg) and leaves (15.36 g/kg) followed by TME 419 with values 0.49, 0.43, 1.48, 1.50, and 14.81 g/kg for these products, respectively.

Table 8: Phenylalanine content (g/kg) of tuber and products from five cassava varieties

Product	TMS 01/1412	TMS 01/1371	TMS 01/1368	TMS 07/0593	TME 419	SEM
Freshly peeled tuber	0.49[c]	0.57[a]	0.56[b]	0.47[d]	0.46[d]	0.01
Garri	0.50[a]	0.17[b]	0.12[e]	0.14[c]	0.13[d]	0.04
Garri flour	0.36[b]	0.21[c]	0.13[d]	0.08[e]	0.38[a]	0.03
Grit	0.76[a]	0.47[c]	0.31[e]	0.35[d]	0.49[b]	0.04
Grit flour	0.75[a]	0.39[c]	0.13[e]	0.22[d]	0.43[b]	0.06
Peelings	1.56[a]	0.88[e]	1.18[c]	1.13[d]	1.48[b]	0.08
Peels	1.61[a]	1.05[e]	1.17[d]	1.14[c]	1.50[b]	0.06
Leaves	15.36[a]	12.50[e]	13.59[d]	14.12[c]	14.81[b]	0.30

[abcde]Means in the same row with different superscripts differ significantly (P<0.05). SEM: Standard Error of Mean.

Valine content of tuber and products from five cassava varieties

The valine content (g/kg) of the tubers and products from the five varieties of cassava are presented in Table 9. There was significant variation (P<0.05) in the valine content of tubers and products from different cassava varieties. TMS 01/1371 had the highest valine content of 0.54 g/kg for freshly peeled tuber, while the least value of 0.44 g/kg was recorded in TMS 07/0593. Higher levels of valine were recorded for Garri (0.44 g/kg), grit (0.83 g/kg), peels (2.09 g/kg) and leaves (15.81 g/kg) from TMS 01/1412. However, peels from TME 419 (2.09 g/kg) was similar to that obtained from TMS 01/1412. Also, valine values recorded for garri flour obtained from TMS 01/1371 (0.40 g/kg) and peelings from TME 419 (2.05 g/kg) were higher than those obtained from other cassava varieties.

Table 9: Valine content (g/kg) of tuber and products from five cassava varieties

Product	TMS 01/1412	TMS 01/1371	TMS 01/1368	TMS 07/0593	TME 419	SEM
Freshly peeled tuber	0.45[c]	0.54[a]	0.52[b]	0.44[e]	0.45[d]	0.01
Garri	0.44[a]	0.36[b]	0.27[d]	0.29[c]	0.27[d]	0.02
Garri flour	0.29[b]	0.40[a]	0.27[c]	0.19[e]	0.24[d]	0.20
Grit	0.83[a]	0.76[b]	0.54[d]	0.56[c]	0.55[d]	0.03
Grit flour	0.78[b]	0.80[a]	0.27[e]	0.43[d]	0.48[c]	0.06
Peelings	1.92[b]	1.16[e]	1.79[c]	1.58[d]	2.05[a]	0.08
Peels	2.09[a]	1.44[e]	1.74[d]	2.04[b]	2.09[a]	0.06
Leaves	15.81[a]	12.86[d]	13.84[c]	15.10[b]	15.36[b]	0.30

[abcde]Means in the same row with different superscripts differ significantly (P<0.05). SEM: Standard Error of Mean.

Discussion

There are over 300 known amino acids; however, only 20 are required for metabolic functions (Rodwell, 2003; Chikezie et al., 2016). Of these, ten are considered essential amino acids because they cannot be synthesized by animals and must be obtained through diet (Dalibard et al., 2014). This makes it crucial for humans and livestock to consume these essential amino acids in their diet, as they cannot be produced by the body and are necessary for the synthesis of non-essential amino acids.

Despite growing advocacy for higher protein consumption driven by a rising population and its vital role in body physiology (Ogutu et al., 2024), essential amino acid composition remains the key indicator for assessing protein quality in any product. Methionine is an essential sulfur-amino acid required for detoxification of cyanide to thiocyanate (Oloruntola, 2020). It is also considered the first limiting amino acid in a typical ration of ruminants and poultry. The high methionine contents of garri, garri flour, grit, grit flour and leaves from cassava varieties TMS 01/1412 is a potential advantage for performance in livestock as it contains higher level of methionine. In addition, aside from the leaves, the cassava peels had higher methionine content than other products from the cassava tuber. The higher methionine content favors increased inclusion of this variety in livestock diets owing to its role in the detoxification of cyanide.

With the exception of TMS 01/1412, leaves from all the biofortified varieties monitored had lower methionine content than TME 419. This suggests that biofortifying cassava with β-carotene may reduce the methionine content in the leaves. The methionine content of cassava leaves (0.36%) reported by Zekarias et al. (2019) was lower than that reported in this study. All cassava varieties, except TMS 01/1371, had higher methionine contents in their peels than the 0.04% reported for cassava peels by Oloruntola (2020). The methionine content of freshly peeled cassava tubers obtained in this study (0.012–0.014%) was comparable to the 0.014% value reported by Nassar et al. (2009) for cassava cultivar UnB01.

Lysine is the first limiting amino acid in swine nutrition and the second limiting amino acid in poultry and ruminants (Dalibard et al., 2014). The lysine contents of grit and grit flour followed the same pattern across the different varieties, except for TMS

07/0593 and TME 419. The similarity in lysine content may be due to the similar processing methods involved prior to their exposure to heat treatment. Grit is obtained by air-frying to obtain the final products; however, the study showed that heat treatment influenced the lysine content of the grits differently. The lysine content of grits made from the cassava varieties TMS 01/1368, TMS 07/0593, and TME 419 increased. However, TMS 01/1412 and TMS 01/1371 varieties had grit with a lower lysine content than the grit flour. The lower values in grits from TMS 01/1412 and TMS 01/1371 agree with the findings of Dalibard et al. (2014), who reported that heat treatment such as toasting lowers lysine content due to biochemical reactions such as Maillard reactions.

Lysine is an amino acid deficient in most cereals consumed worldwide (Sanchez & Demain, 2014). The lysine content of products such as cassava peel is reportedly low (Aro & Aletor, 2012). However, Oladimeji et al. (2022) in their study reported that lysine (1.64 g/kg) was the second most prominent essential amino acid in sundried cassava peel meal. Nassar and Sousa (2007) suggested that the development of cassava varieties with improved lysine content enhances their value in food and feed. Increased dietary lysine levels have been linked to improved FCR and performance (Weurding et al., 2003). The lysine content of the cassava products studied (0.018-1.486%) was higher than the 0.01% reported for cassava (Morgan & Choct, 2016). The value of the cassava peel products was lower than the value (2.31%) reported by Aro and Aletor (2012). The reported lysine content of 0.356% in cassava grits (Abioye et al., 2022), was lower than the lysine content recorded in this study; the cassava grit value ranges from (TMS 01/1368) 0.59% to 0.89% (TMS 01/1371). The lysine content of cassava grits was improved by varietal differences, indicating that improvements in cassava have also improved the lysine levels of cassava and its products. All the cassava products studied showed a lot of promise to replace maize as they contain higher lysine content than maize, which was reported to range between 0.15 and 0.25% (Chand et al., 2022).

Threonine, methionine, and lysine are considered the limiting amino acids in poultry diets of poultry (Ravindran, 2013). Threonine also plays an important role in mucus secretion, immune responses, and intestinal enterocytes (Kleyn & Chrystal, 2020). Cassava products with higher threonine

levels are expected to boost gut development in birds fed a higher dietary inclusion. Fermentation has also been employed to improve amino acids such as threonine (Boonnop et al., 2009; Aro & Aletor, 2012). Aro and Aletor (2012) observed a significant threonine increase in microbial and natural fermentation of cassava products. The threonine value (2.7%) reported by Abioye et al. (2022) for cassava grit from UMUCASS 37 (TMS 01/1412) was higher than the values reported for cassava grits in this study. However, the observed difference could be due to age at harvest. The varieties used in this study were aged one year at harvest, whereas the cassava variety evaluated by Abioye et al. (2022) was purchased from the open market. The leaves of the cassava varieties had the highest threonine and could be used to enrich the tuber and peel owing to the higher level of threonine.

Arginine is an essential amino acid in children and young animals because of its role in maintaining muscle mass and connecting tissues (Dalibard et al. 2014; Lopez-Cervantes, 2021). The arginine content in cassava leaves was the highest, as expected, largely due to the higher crude protein content. Leaves from cassava from TMS 01/1412 had the highest arginine content, which positively correlated with the level of β-carotene content in cassava tubers when similar varieties were studied by Ogunwole et al. (2015). They reported that TMS 01/1412 had the highest β-carotene content (30 µg/100g). The leaves had a higher arginine content than the 0.3% reported by Gil and Buitrago (2002). Aro and Aletor (2012) reported that cassava tubers are rich sources of arginine. This study suggests that the arginine content of cassava tubers is significantly influenced by the tuber variety. The tuber from TMS 01/1368 provided the highest arginine content.

Histidine is an amino acid that plays a critical role in the immune system, and muscle contractions and gastric acid stimulation have been reported (Peters & Kovacic, 2009). The histidine content of the freshly peeled tubers shows that TMS 01/1371 and TMS 01/1368 are the most promising cassava tubers when a histidine-rich diet is considered. Decreased histidine content was observed in garri compared to freshly peeled tuber except for TMS 01/1412 (0.16 g/kg) and TMS 07/0593 (0.18 g/Kg) which had higher histidine compared to freshly peeled tubers which had 0.08 g/kg and 0.05 g/Kg respectively. This decrease could be due to the application of heat in the processing of garri. The garri flour further showed reduction with TMS 01/1371 recording the highest histidine content among the varieties considered. This decrease further emphasizes the importance of processing methods for determining amino acid concentrations in protein materials. The reduction in histidine attests to the documented role of heat in the denaturation of amino acids in proteins (Zhang et al., 2023).

The highest histidine content recorded in grit (0.40 g/kg) and grit flour (0.42 g/kg) from TMS 01/1371 could influence its preference by nutritionists due to its critical roles. Cassava grit flour from TMS 01/1368 (0.06 g/kg), TMS 07/0593 (0.24 g/kg), and TME 419 (0.18 g/kg) had reduced histidine content compared to grit. The reduction in histidine could be due to the

grinding and longer heat treatment applied to the grit powder. The peels and peelings had higher histidine contents than the other cassava products considered, except the leaves. This finding aligns with that of Ravindran (1991), who reported a higher concentration of nutrients in cassava peels by-products. The leaves had the highest histidine content among all the products determined, with TMS 01/1412 and TME 419 recording 6.36 g/kg of histidine. Higher histidine levels favor its use as a valuable plant protein source in human and livestock nutrition.

Isoleucine is considered to be a neutral polar amino acid and is slightly soluble (Read & Brenner, 2001). They can be synthesized from intermediate products. However, production via this route is limited and has been reported to be between 2-5% (Kleyn & Chrystal, 2020). Montagnac et al. (2009) reported that cassava roots had a low concentration of isoleucine. The results obtained from this study showed that peels have a higher concentration of isoleucine than tubers. The poor solubility of isoleucine may be responsible for its higher retention in products such as garri and grits observed in this study. The processing of garri and grits involves pressing the tubers to extract and reduce the moisture content.

The isoleucine content (0.93g/100 g) reported by Gomes and Nassar (2013) for 530 cassava cultivar roots was higher than that reported in this study. This corroborated their findings that varietal differences influence the isoleucine content of cassava products and leaves. The cassava varieties showed the highest isoleucine content for most of the products studied, except for fresh tuber and garri flour, indicating higher promise in diets where isoleucine needs to be considered. Reports have suggested that isoleucine should be included in the diet because of its documented role in detoxifying cyanide, which is commonly found in cassava products (Dalibard et al., 2014; Omode et al., 2018).

Leucine is known for its role in the regulation of branched amino acid catabolism (Dalibard et al., 2014). It is also known to improve protein synthesis and protein catabolism and anabolism balance (Wolters et al., 2021). Freshly peeled tuber, garri, Garri flour had relatively low leucine content, indicating a low contribution to dietary intake of leucine compared with grit, grit flour, peelings, peels, and leaves.

The implication of heat sensitivity reported by Ito et al. (2019) could be responsible for lower leucine content observed for garri which ranged between (0.31-0.57g/Kg). The lower leucine content observed in garri flour from TMS 01/1412, TMS 07/0593 and TME 419 corroborated the findings of Kim et al. (2017) that heat treatment could influence amino acid degradation and nutritional quality.

The grit and grit flour had higher leucine contents compared to garri and garri flour. This suggests that the presence of peel in grit flour and grit helps increase the source of leucine in cassava-based diets. The leucine contents in cassava peels and peelings were over 3 times higher than values obtained

from garri and garri flour. The higher values obtained from the peels buttress the submission by Amaza (2021). The results showed that if peels were properly processed, they could serve as a valuable source of leucine. Fermentation has also been suggested as a tool for improving the protein quality in cassava peel (Andriani et al., 2015). Oladimeji et al. (2022) found that leucine, at a concentration of 2.22 g/kg, is the most abundant essential amino acid in sundried cassava peels. The authors also noted that leucine was the predominant essential amino acid in other cassava peel products, including coarse cassava peel mash (1.77 g/kg), fine cassava peel mash (1.56 g/kg), and whole cassava peel mash (1.67 g/kg). This supports the reason that cassava tubers have drawn attention in animal feed, especially when peels are often discarded.

Leaves had the highest leucine content among all cassava products considered. The high leucine content agrees with the report of Latif and Muller (2015), who reported that cassava leaves are nutrient-dense and could provide valuable protein and amino acid sources for low-protein diets.

Phenylalanine is an aromatic amino acid that plays a significant role in thermogenesis, thyroid hormone synthesis, growth, and nutrient metabolism (Gropper & Smith, 2013; Chrystal et al., 2020). The phenylalanine content of the freshly peeled tubers studied was influenced by the variety of cassava. The garri from the freshly peeled tuber decreased significantly with TMS 01/1412, only recording higher phenylalanine (0.50 g/kg) compared to the fresh tuber (0.49 g/kg). Similar reduction pattern was observed for garri flour, which had TME 419 (0.38 g/kg) and TMS 01/1412 (0.36 g/kg). Heat and fermentation could be implicated in the observed decrease in phenylalanine content.

Cassava grit has higher phenylalanine levels than grit flour, suggesting phenylalanine loss during grit flour production. Cassava variety TMS 01/1412 had the highest phenylalanine content in both grit (0.76 g/kg) and grit flour (0.75 g/kg). These higher values indicate that TMS 01/1412 will support livestock in adapting to environmental temperature changes. The peelings of TMS 01/1412 had the highest values for peels (1.56 g/kg) and peelings (1.61 g/kg). The high values recorded for the peels could be responsible for the higher values obtained for the grit and grit flours. Grits and grit flour were obtained from unpeeled cassava tubers.

Cassava leaves had the highest phenylalanine content among all products considered, with TMS 01/1412 (15.36 g/kg) being the highest among the varieties. This shows that the leaves could be a valuable and inexpensive source of nutrients for improved performance and nutrient metabolism.

Valine is a glucogenic amino acid involved in protein synthesis, tissue and muscle metabolism (Amaya-Farfan & Percheco, 2003; Dalibard, 2014). Linamarin, a precursor of hydrogen cyanide, is synthesized from valine (Andersen et al., 2000). The valine content of the freshly peeled tubers was different from that of TMS 01/1371 (0.54 g/kg), which had the

highest valine content, and TMS 07/0593 exhibited the lowest (0.44 g/kg). The results showed that varietal differences and genetics influence nutrient levels, despite the similarities in their freshness. This agrees with the findings of Montagnac et al. (2009) that the genotype influences the nutrient profile of cassava.

The processing of the fresh tubers to garri resulted in decreased valine content of garri, though most of the valine were retained, in garri from cassava variety TMS 01/1412 (0.44 g/kg) when compared to 0.45 g/kg in the freshly peeled tuber. In addition, the oven-drying method used in the processing of the garri flour further decreased the valine level with TMS 01/1371, maintaining the highest content. This result attests to the submission of Zhang et al. (2023) that heat treatment could result in the modification of amino acids in proteinaceous materials. These differences also attest to the fact that various cassava products react differently to heat treatment.

The grit had higher valine compared to grit flour, though TMS 01/1412 had a higher value in both cases (0.83 g/kg for grit and 0.78 g/kg for grit). The lower valine content in the flour could be due to the processing method employed in the processing of the grit flour, which involves the reduction in surface area for easy penetration of heat in the product.

Significantly higher valine was observed in the peelings and peels of the varieties studied, however, TME 419 had the highest level (2.05 g/kg in peelings and 2.09 g/kg in peels). This result attests to the fact that cassava peels/peelings which are often discarded, as a rich source of valine. This study demonstrated that cassava leaves had the highest amino acid concentrations among all the cassava products studied, with TMS01/1412 having the highest values of all varieties, followed by TME 419. The high amino acid content observed in the leaves underscores the reason that cassava leaves are relished and often used in traditional dishes (Latif & Muller, 2015). In addition, peelings, peels, and leaves had consistently higher levels of amino acids than other cassava products considered in this study. Therefore, it seems that an increase in the level of cassava fiber, as evidenced by the more fibrous nature of these products compared to other cassava products studied, may be synonymous with an increase in the amino acid composition of cassava.

Conclusion
The processing of cassava and its byproducts, such as leaves and peels, offers a significant amino acid profile value and can reduce waste when purposefully used in animal feed. The leaves of cassava had a richer composition of amino acids, whereas the cassava variety TMS 01/1412 showed consistently high essential amino acids compared to other varieties across the products considered.

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Data Availability
It will be available on request.

Declarations
Consent to publish does not apply to this study, as it does not involve any individual data, images, or information requiring such consent.

Consent to Participate
It is not applicable. This study did not involve human participants, surveys, or interviews, which would require consent to participate.

Consent for Publication
The consent of all the authors was obtained.

Competing Interests
The authors declare no competing interests.

Ethics Declarations
It is not applicable. This study did not involve human or animal subjects; therefore, ethical approval was not required.

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