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Biochemical Composition and Protein Quality of Three Soybean [*Glycine max* (L.) Merr.] Varieties Widely Grown in Burundi

Diomede Nzeyimana[1], Natalia A. Bugaets[1], Artem D. Bazyk[2], Natalya A. Pavlova[2], Ivan N. Kobzar[1]

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ABSTRACT

Background: Soybean is an important protein crop for food and feed systems, but data on the biochemical composition and safety-related elemental profile of locally cultivated varieties in Burundi remain limited. The aim of the study was to evaluate protein content, amino acid composition and elemental profile of three soybean varieties widely grown in Burundi.

Methods: Crude protein content was determined according to GOST 13496.4-2019. Amino acid composition and cationic and anionic composition were quantified by capillary electrophoresis. Selected trace and toxic elements were measured by inversion voltammetry using validated procedures. Amino acid score and biological value were calculated relative to the FAO/WHO reference protein.

Result: Crude protein content ranged from 40.5 to 42.2%, with the highest value recorded in SOPROSOY. Essential amino acid profiles were similar among the studied varieties: lysine was 2.8%, valine 1.9-2.0%, phenylalanine 2.2-2.3%, leucine + isoleucine 5.1-5.3%, methionine 0.42-0.49%, threonine 1.8% and tryptophan 0.031-0.056%. Tryptophan was the first limiting amino acid, while methionine + cysteine also had reduced scores. Lead, cadmium, cobalt, selenium and iodine were below the method detection limits. Zinc reached 120±50 mg/kg in SOPROSOY and exceeded the stated safety threshold. The studied varieties may be considered high-protein soybean raw materials; however, zinc accumulation requires monitoring when they are intended for food-oriented applications.

Key words: Amino acid composition, Burundi, Capillary electrophoresis, *Glycine max*, Inversion voltammetry, Protein quality, Soybean, Zinc.

INTRODUCTION

Soybean [*Glycine max* (L.) Merr.] is a leguminous crop widely grown in many agricultural regions owing to its high nutritional value, balanced amino acid composition and broad food and feed applications (Boukid, 2021; Wu, 2023). Global soybean production remains high and continues to increase. According to recent USDA FAS estimates, world soybean production was estimated at 427.60 million tonnes in 2025/2026 and is forecast to reach 441.54 million tonnes in 2026/2027, with a harvested area of 146.50 million ha and an average productivity of approximately 3.01 t/ha. Brazil and the United States remain the leading producers, with projected soybean production of 186.00 and 120.70 million tonnes, respectively, in 2026/2027 (USDA FAS, 2026). At the same time, long-term yield trends remain an important issue for global crop production, which increases the relevance of evaluating the quality of soybean raw materials from different agroecological regions (Ray *et al.*, 2021). Production has also increased in the European Union and Russia (Sinegovsky, 2024; Volkova and Smolyaninova, 2023).

In Africa, soybean production remains unevenly distributed. South Africa, Nigeria, Zambia and Uganda are among the important soybean-producing countries, whereas yields in many regions remain limited by agronomic and genetic constraints (Mabhaudhi *et al.*, 2021; Ninkuu *et al.*, 2025). Soybean has also become an increasingly important component of African food systems as an accessible source of dietary protein for humans and livestock (Adeyeye *et al.*, 2021; Messina, 2020). Recent studies on African soybean germplasm confirm the

[1]Department of Public Catering and Service, Kuban State Technological University, 2 Moskovskaya St., Krasnodar 350007, Russian Federation.

[2]Department of Biotechnology, Biochemistry and Biophysics, Kuban State Agrarian University named after I.T. Trubilin, 13 Kalinina St., Krasnodar 350044, Russian Federation.

Corresponding Author: Natalia A. Bugaets, Department of Public Catering and Service, Kuban State Technological University, 2 Moskovskaya St., Krasnodar 350007, Russian Federation.
Email: kubanochka23@yandex.ru

ORCIDs: 0009-0008-2770-6309, 0000-0003-4012-8837, 0009-0000-0224-2386, 0009-0004-4049-8533

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relevance of evaluating locally cultivated varieties according to their nutritional and biochemical characteristics. For example, Tondé *et al.* (2026) reported considerable variability in total protein, soluble sugars, phytic acid and antioxidant-related parameters among soybean varieties cultivated in Burkina Faso. Therefore, the assessment of locally adapted varieties is relevant for both nutritional use and raw material selection.

Soybean seeds usually contain 27-50% protein and 15-28% oil (Adeyeye *et al.*, 2022; Day *et al.*, 2022). Genotypic variability in soybean storage protein composition has been reported, indicating that varietal differences may affect not only total protein content but also protein quality and technological suitability of soybean raw materials (Goyal and Sharma, 2015). Soybean proteins contain essential amino acids and are characterized by comparatively high digestibility, which supports their use in plant-based diets (Friedman and Brandon, 2020; Wu, 2023). The biological value of soybean protein depends primarily on amino acid composition; lysine is especially important in diets based mainly on plant raw materials (Ma *et al.*, 2021; Nizkii *et al.*, 2022). In addition to protein, soybean seeds accumulate macro- and microelements, including potassium, phosphorus, magnesium, calcium, sulfur, iron and zinc (Nyaga *et al.*, 2022; Pant *et al.*, 2024). Mineral composition is influenced by genotype, soil properties and growing conditions and may include elevated concentrations of trace or potentially toxic elements (Li *et al.*, 2021; Wang *et al.*, 2022). Consequently, elemental analysis is required not only for nutritional characterization but also for assessment of compliance with food safety standards (Technical Regulation of the Customs Union TR CU 015/2011, 2017).

The expansion of soybean-based foods increases the need for raw materials with stable biochemical quality (Bilyeu *et al.*, 2021; Pomorova *et al.*, 2023). However, published data on the protein composition, amino acid balance and safety-related elemental profile of soybean varieties locally cultivated in Burundi remain scarce. The aim of the present study was to evaluate crude protein content, amino acid composition and elemental profile of three soybean varieties widely grown in Burundi, with particular attention to their biological value and selected safety-related indicators.

MATERIALS AND METHODS

Plant material

Soybean grain samples of three varieties widely cultivated in Burundi, 449/6/16, AGS 433 and SOPROSOY, were supplied by the Burundi Institute of Agricultural Sciences (ISABU) upon official request. The varieties were selected according to their agronomic relevance and use in local cultivation.

Determination of crude protein content and protein quality

Crude protein content was determined according to GOST 13496.4-2019. Protein quality was evaluated by comparing the content of essential amino acids in the studied soybean protein with the FAO/WHO reference protein pattern.

The amino acid score (AS, %) for each essential amino acid was calculated according to Equation (1):

$$ASj = \frac{Aj}{Aref.j} \times 100 \quad (1)$$

Where,

Aj = Content of the j-th essential amino acid in 100 g of the studied soybean protein, g.

Aref.j = Content of the corresponding amino acid in 100 g of the FAO/WHO reference protein, g.

The amino acid with the lowest score was considered the first limiting amino acid. The difference between the score of each essential amino acid and the score of the first limiting amino acid was calculated according to Equation (2):

$$\Delta ASj = ASj - ASmin \quad (2)$$

Where,

ΔASj = Score difference for the j^{th} essential amino acid, %.

ASmin = Lowest amino acid score among the essential amino acids, %.

The coefficient of amino acid score difference, also referred to as the comparable redundancy coefficient (RED, %), was calculated according to Equation (3):

$$RED = \frac{(\Sigma \Delta ASj)}{n} \quad (3)$$

Where,

n = Number of essential amino acids or amino acid groups included in the calculation.

The biological value (BV, %) of soybean protein was calculated according to Equation (4):

$$BV = 100 - RED \quad (4)$$

This calculation was used to compare the balance of essential amino acids among the studied soybean varieties relative to the FAO/WHO reference protein. The calculated BV characterizes amino acid balance and does not include in vivo protein digestibility.

Determination of amino acid composition

Sample preparation and amino acid analysis were performed by capillary electrophoresis using the Kapel-105M system according to validated procedures M 04-38-2009, GOST R 55569-2013 and GOST 31480-2012.

For determination of arginine, lysine, tyrosine, phenylalanine, histidine, leucine + isoleucine, methionine, valine, proline, threonine, serine, alanine, taurine and glycine, 100 mg (±0.1 mg) of homogenized soybean grain was hydrolyzed with 10 mL hydrochloric acid (1:1, v/v) at 110°C for 16 h. Hydrolysates were filtered, derivatized with phenyl isothiocyanate and analyzed by capillary electrophoresis using the Kapel-105M system (No. 2701). Separation was carried out at 25 kV and 30.0°C for 1199 s with UV detection at 254 nm using 30 mmol/L phosphate buffer containing 4 mmol/L beta-cyclodextrin as the

background electrolyte. Aspartic acid + asparagine, glutamic acid + glutamine and cystine were determined under the same hydrolysis and separation conditions, with a shorter run time of 779 s.

Tryptophan was determined after alkaline hydrolysis with saturated barium hydroxide solution at 110°C for 16 h. Barium ions were precipitated and the derivatized sample was analyzed at 25 kV and 30.0°C for 539 s with UV detection at 254 nm using 20 mmol/L sodium tetraborate as background electrolyte.

Determination of cationic and anionic composition

Ammonium, potassium, sodium, magnesium, calcium, chloride, sulfate, nitrate and phosphate ions were determined by capillary electrophoresis using the Kapel system according to validated procedures M 04-65-2010, M 04-73-2011, GOST R 56374-2015 and GOST R 56375-2015. Cations were analyzed after acid hydrolysis at 25 kV and 20.0°C for 419 s with UV detection at 267 nm using 20 mmol/L benzimidazole, 8 mmol/L tartaric acid and 2 mmol/L 18-crown-6 as the background electrolyte. Anions were determined using chromium (VI) oxide, diethanolamine and cetyltrimethylammonium hydroxide electrolyte at -25 kV and 20.0°C with detection at 374 nm. Chloride and nitrate were analyzed after aqueous extraction.

Determination of microelement content

Zinc, cadmium, lead, copper, cobalt, selenium and iodine were determined by inversion voltammetry using TA-type analyzers according to validated procedures MU 31-04/03, MU 31-04/04, MU 31-05/04, MU 31-14/06, MU 31-21/07 and Guidelines 4.1.1672-03.

Statistical analysis

All analyses were performed in triplicate and results are expressed as mean ± standard deviation. Differences among varieties were evaluated by one-way analysis of variance followed by Tukey's post hoc test at $p<0.05$.

Research period and laboratory conditions

The study was carried out in 2023-2024 at the Department of Public Catering and Service, the Engineering Center "High Technologies and Food Safety" and the Shared Research Center "Research Center of Food and Chemical Technologies" of Kuban State Technological University, Krasnodar, Russian Federation. Additional analytical measurements were performed in the Laboratory of Physical and Chemical Analysis of Kuban State Agrarian University named after I.T. Trubilin and at the "Argus" Testing Center of the Krasnodar Research Center for Animal Husbandry and Veterinary Medicine.

RESULTS AND DISCUSSION

Crude protein content

Crude protein content is a primary indicator of the value of soybean as food and feed raw material. In the studied samples, it ranged from 40.5% in 449/6/16 to 42.2% in SOPROSOY, while AGS 433 had an intermediate value of 41.2%. These values are within the typical range reported for soybean seeds and are close to the 38.1-43.6% interval described for soybean varieties cultivated in different regions of Russia (Litvinenko *et al*., 2023; Pomorova *et al*., 2023). Comparable inter-varietal variation has been

Table 1: Amino acid composition of soybean proteins grown in Burundi (% of dry matter).

Amino acid	449/6/16	AGS 433	SOPROSOY
Essential amino acids			
Valine	1.90±0.80	1.90±0.80	2.00±0.80
Lysine	2.80±1.10	2.80±1.10	2.80±1.10
Phenylalanine	2.20±0.90	2.20±0.90	2.30±0.90
Leucine + isoleucine	5.10±2.00	5.10±2.10	5.30±2.10
Methionine	0.49±0.20	0.43±0.17	0.42±0.17
Threonine	1.80±0.70	1.80±0.70	1.80±0.70
Tryptophan	0.056±0.023	0.031±0.012	0.032±0.013
Non-essential amino acids			
Arginine	3.40±1.30	2.90±1.20	2.90±1.20
Tyrosine	1.30±0.50	1.40±0.60	1.40±0.50
Histidine	1.00±0.40	1.00±0.40	1.00±0.40
Proline	2.30±0.90	2.20±0.90	2.30±0.90
Serine	2.40±1.00	2.40±1.00	2.40±0.90
Alanine	2.00±0.80	2.00±0.80	2.00±0.80
Taurine	<0.1	<0.1	<0.1
Glycine	1.90±0.80	2.00±0.80	2.00±0.80
Glutamic acid + glutamine	6.80±2.70	7.30±2.90	8.00±3.00
Aspartic acid + asparagine	7.50±3.00	8.00±3.00	9.00±4.00
Cysteine	0.71±0.29	0.70±0.30	0.70±0.30

Values are mean ± SD (n = 3).

reported for Indonesian soybean varieties, where crude protein content ranged from 28.03 to 44.72% and several varieties contained more than 40% crude protein (Arifin *et al.*, 2023). In the tropical soybean core collection studied by Obua *et al.* (2020), individual genotypes also differed markedly in protein content: Sline 5.18, BSPS 48A-8 and BSPS 48A-27-1 had the highest values, whereas NIIXGC 17.3 and Nam II had the lowest protein content. Against this background, the Burundian varieties studied here fall within the upper range reported for soybean germplasm and may be considered high-protein raw materials, although varietal differences were moderate.

Amino acid composition

Amino acid composition determines the nutritional completeness of soybean protein and affects the suitability of raw material for food formulations. All analyzed varieties contained the full set of essential amino acids (Table 1). Inter-varietal variation was limited: lysine remained stable at 2.8%, valine ranged from 1.9 to 2.0%, phenylalanine from 2.2 to 2.3%, leucine + isoleucine from 5.1 to 5.3%, methionine from 0.42 to 0.49%, threonine was 1.8% and tryptophan ranged from 0.031 to 0.056%. Stable lysine content is nutritionally important for plant-based diets, especially when soybean is used together with cereal-based raw materials. In the present study, lysine content was identical in all three Burundian varieties, indicating limited inter-varietal variation for this amino acid under the analyzed conditions. Differences in lysine concentration reported for soybean breeding materials in previous studies may be associated with genotype, growing region, soil and climatic conditions and the analytical basis used for expressing amino acid content (Nizkii *et al.*, 2022).

Protein quality

Comparison with the FAO/WHO reference protein showed that most essential amino acids had scores exceeding 100%, whereas methionine + cysteine and tryptophan were limiting (Table 2). Tryptophan had the lowest scores, 8.0-14.0% and was the first limiting amino acid. Methionine + cysteine also showed reduced scores, 67.7-70.6%. This pattern corresponds to the known limitation of soybean protein by sulfur-containing amino acids and, in some cases, tryptophan (Statsenko, 2003; Wu, 2023). Biological value varied from 12.3 to 15.8% according to the calculation used in the study. Therefore, the analyzed varieties combine high crude protein content with a generally favorable amino acid profile, but the formulation of foods or feeds may require compensation for limiting amino acids.

Cationic and anionic composition

Mineral composition characterizes the nutritional contribution of soybean grain and simultaneously indicates the possible accumulation of elements with safety relevance. Ammonium and potassium were the predominant cations in the studied samples, reaching 1.2-

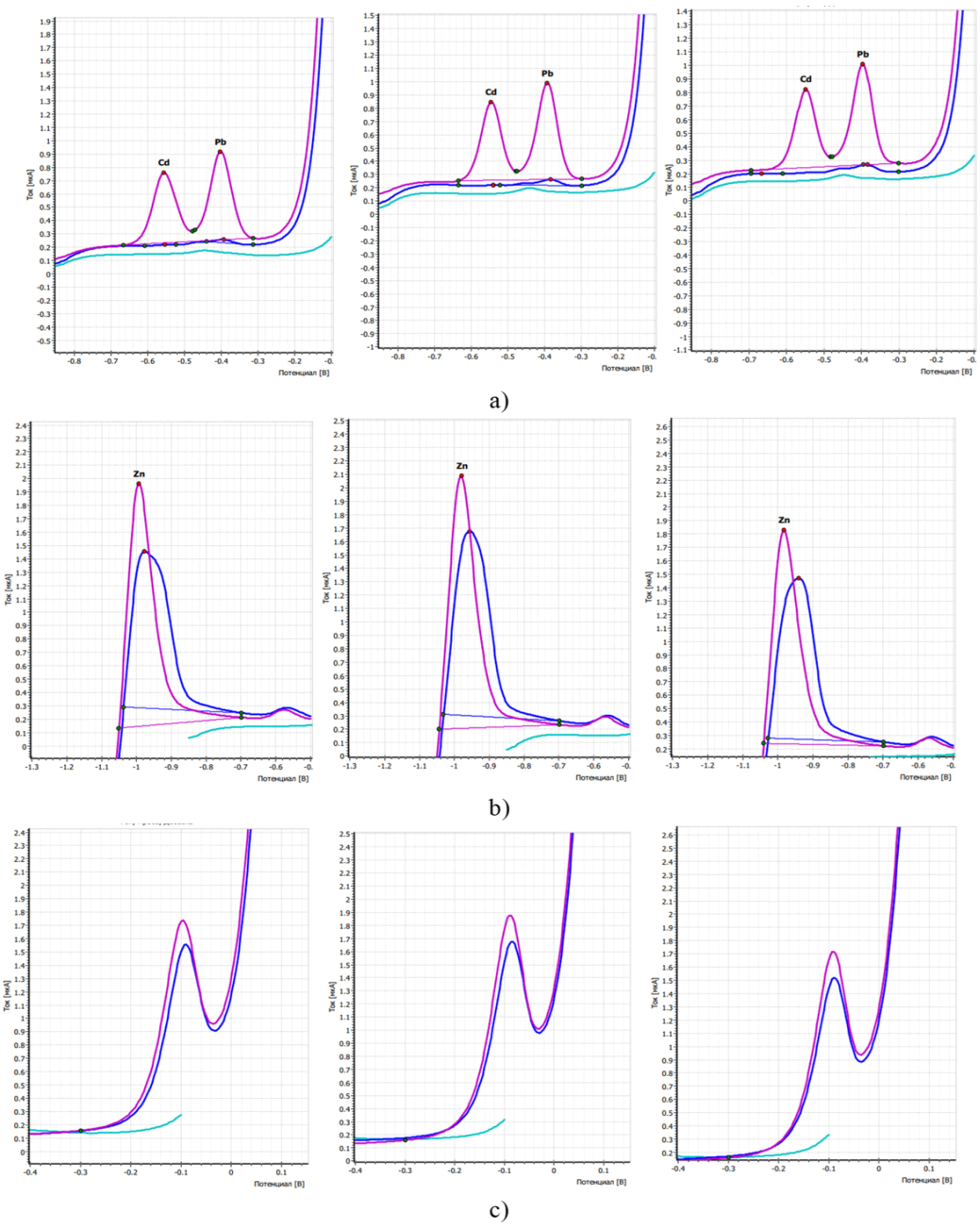
Table 2: Essential amino acid content and protein quality indices of soybean protein.

Essential amino acid	Reference protein (g/100 g)	449/6/16 (g/100 g)	Score (%)	ΔAS (%)	AGS 433 (g/100 g)	Score (%)	ΔAS (%)	SOPROSOY (g/100 g)	Score (%)	ΔAS (%)
Leucine + isoleucine	11.0	12.59	114.5	100.5	12.38	112.5	104.5	12.56	114.2	106.2
Lysine	5.5	6.91	125.6	111.6	6.80	123.6	115.6	6.64	120.7	112.7
Methionine + cysteine	3.5	2.96	84.6	70.6	2.74	78.3	70.3	2.65	75.7	67.7
Phenylalanine + tyrosine	6.0	8.64	144.0	130.0	8.74	145.7	137.7	8.77	146.2	138.2
Threonine	4.0	4.44	111.0	97.0	4.37	109.3	101.3	4.27	106.8	98.8
Tryptophan	1.0	0.14	14.0	0.0	0.08	8.0	0.0	0.08	8.0	0.0
Valine	5.0	4.69	93.8	79.8	4.61	92.2	84.2	4.74	94.8	86.8
Limiting amino acid	-	Tryptophan	-	-	Tryptophan	-	-	Tryptophan	-	-
RED, %	-	-	-	84.2	-	-	87.7	-	-	87.2
Biological value, %	-	-	-	15.8	-	-	12.3	-	-	12.8
Protein quality level	-	-	-	High	-	-	High	-	-	High

2.0% and 1.6-2.2%, respectively (Table 3). Sodium, magnesium and calcium were present at lower concentrations, while sulfur, phosphorus, chloride and nitrate generally did not exceed 0.40%. These data are consistent with published observations that potassium and phosphorus are among the dominant mineral components of soybean grain (Nyaga *et al*., 2022; Pant *et al*., 2024).

Trace and toxic elements

Among trace and toxic elements, lead, cadmium, cobalt, selenium and iodine were below the corresponding method detection limits (Table 4). This result is important for safety assessment because lead and cadmium are among the principal toxic contaminants controlled in grain raw materials. Copper ranged from 3.6±1.4 mg/kg in 449/6/16



(a) Determination of lead and cadmium content; (b) Determination of zinc content; (c) Determination of copper content. Measurements were performed under identical analytical conditions. Curves correspond to soybean varieties 449/6/16, AGS 433 and SOPROSOY.

Fig 1: Voltammograms obtained by inversion voltammetry for the determination of trace and toxic elements in soybean grains of different varieties.

Table 3: Cationic and anionic composition of soybean grains grown in Burundi (%).

Mineral	449/6/16	AGS 433	SOPROSOY
NH_4^+	1.60±0.60	2.00±0.80	1.20±0.50
K^+	2.00±0.80	2.20±0.90	1.60±0.60
Na^+	0.029±0.011	0.023±0.009	0.019±0.008
Mg^{2+}	0.31±0.12	0.20±0.08	0.26±0.10
Ca^{2+}	0.33±0.13	0.29±0.11	0.28±0.11
S (as SO_4^{2-})	0.09±0.04	0.033±0.013	0.030±0.013
P (as PO_4^{3-})	0.39±0.16	0.23±0.09	0.29±0.10
Cl^-	0.10±0.04	0.09±0.03	0.044±0.017
NO_3^-	0.044±0.018	0.062±0.025	0.041±0.016

Values are mean ± SD (n = 3).

Table 4: Microelement content in soybean grains commonly grown in Burundi (mg/kg).

Microelement	449/6/16	AGS 433	SOPROSOY
Pb	<0.01	<0.01	<0.01
Cd	<0.0015	<0.0015	<0.0015
Cu	3.6±1.4	4.2±1.6	6.8±2.7
Zn	73±28	110±40	120±50
Co	<0.5	<0.5	<0.5
Se	<0.02	<0.02	<0.02
I	<10	<10	<10

Values are mean ± SD (n = 3).

to 6.8±2.7 mg/kg in SOPROSOY. Zinc was the highest among the measured trace elements and varied from 73±28 to 120±50 mg/kg. The need for targeted zinc control is also supported by studies showing that zinc content and uptake in soybean are affected by soil conditions and zinc sources, which confirms the importance of considering both genotype and agroecological background when interpreting zinc accumulation in soybean grain (Sentimenla *et al.*, 2022). The maximum value in SOPROSOY exceeded the stated hygienic threshold of 50 mg/kg by up to 2.4 times (Technical Regulation of the Customs Union TR CU 015/ 2011, 2017). Soybean is capable of accumulating zinc and elevated concentrations have been reported for some genotypes and regions (Pant *et al.*, 2024; Wang *et al.*, 2022; Zhang *et al.*, 2019). Because zinc is essential but may become excessive under high dietary exposure, the observed levels should be considered when these varieties are selected for food products, especially for populations with sufficient zinc intake.

Representative voltammograms obtained by inversion voltammetry are presented in Fig 1. The graphical data support the analytical differentiation of lead and cadmium, zinc and copper signals under identical measurement conditions. Overall, the elemental profile indicates low contamination by lead and cadmium and the need for targeted control of zinc accumulation.

CONCLUSION

The studied soybean varieties 449/6/16, AGS 433 and SOPROSOY, widely cultivated in Burundi, were characterized by high crude protein content ranging from 40.5 to 42.2%, with the highest value recorded in SOPROSOY. All varieties contained the main essential amino acids; however, tryptophan was identified as the first limiting amino acid, while methionine + cysteine also showed reduced amino acid scores. Lead, cadmium, cobalt, selenium and iodine were below the method detection limits, whereas zinc was the only element requiring additional control, especially in SOPROSOY, where its concentration reached 120±50 mg/kg.

The obtained results indicate that the studied soybean varieties can be considered promising high-protein raw materials for food and feed applications in Burundi, provided that zinc accumulation is monitored during raw material selection. Further research should focus on the technological properties, digestibility and processing suitability of these varieties for the development of soybean-based foods and protein-enriched products.

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Disclaimers

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information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Informed consent

Not applicable. The study did not involve human participants or animals; the work was based on plant material and laboratory analyses.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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