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Food value of four ginger clones (*Zingiber officinale*) consumed in Burkina Faso

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Abstract

Introduction: Ginger is a rhizome widely consumed fresh, dried, or in processed form. Known for its nutritional qualities and its macronutrient and micronutrient content, it is one of the most widely used spices in the world. However, these qualities can vary depending on several factors, including genetic and edaphic factors. The objective of this study was to evaluate the physicochemical parameters of four ginger clones from Burkina Faso and Côte d'Ivoire.

Method: The analysis of physicochemical parameters focused on determining fat, moisture, ash, starch content, fiber content, swelling power, protein content, amino acid content, total sugars, and polyphenols.

Results: Physicochemical analyses showed that water content ranged from 54.23 to 81.15%, 3.56 to 4.25% for fiber, 1.11 to 4.82% for fat, ash varied from 2.04 to 1.09%, protein varied from 2.35 to 1.38%, and amino acids varied from 4.76 to 8.61%. The total sugar content varied from 32.29% to 10.42%, and polyphenols ranged from 69.82% to 49.92%.

Conclusion: Analysis of the physicochemical parameters revealed that the ginger clones analyzed had variable levels, which could guide their production and use.

Keywords: Ginger; Clone; Physicochemical; Burkina Faso; Ivory Coast.

1. Introduction

Zingiber officinale, commonly known as "ginger" in English and "gnamakou" in Dioula, is a well-known herbaceous plant belonging to the Zingiberaceae family. It is grown for its underground stems, which have been widely used as a spice, flavoring agent, and herbal medicine for centuries [1]. In addition, consuming ginger rhizome is a typical traditional remedy for relieving common health problems, including pain, nausea, vomiting, and even diabetes [2, 3]. Ginger extracts are believed to have good antioxidant potential, which is beneficial for people suffering from cardiovascular disease [4]. Ginger is also known to improve sperm parameters as well as the functions of reproduction [5, 6].

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It can be used fresh, dried, powdered, or in the form of juice or oil [7]. There are many local varieties grown around the world. Among African varieties, Jamaican ginger is very popular mainly because of its delicate aroma and fine-textured powder, while dried ginger from Nigeria and Sierra Leone has a camphor-like, coarser smell and is rich in aroma and pungency factors. The chemical composition of ginger varies depending on the variety, geography, and climatic conditions [8]. Some varieties of African ginger are very rich in protein and fat [9].

Introduced to Burkina Faso around ten years ago, ginger is considered a cash crop that plays an important economic role for producers. However, ginger cultivation is not widespread and production is limited to small areas despite its many virtues. It is mainly grown in the southwestern and western parts of the country's Hauts-Bassins region [10]. Given its virtues, ginger could occupy a much more important place in Burkina Faso. Better knowledge of local production would encourage increased consumption. This would allow the population to better benefit from its many advantages related to its physicochemical composition, which is strongly influenced by conditions such as edaphic, meteorological, and genotypic factors. Ginger is used safely in the medical, pharmaceutical, and food industries. The underground stem or rhizome is the most sought-after commercial product. In Burkina Faso, ginger is used as a spice in meals, for the production of a popular juice called "gnamakou-dji," for the production of syrup, in pharmacopoeia, in cosmetics, and for other purposes. The objective of this study was to collect and perform a physicochemical characterization of four ginger clones available and marketed in Burkina Faso.

2. Material And Methods

2.1. Plant material, and sampling

The ginger clones were collected by the INERA team mainly in western Burkina Faso, namely Bérégadougou and Kénédougou. Clones from Côte d'Ivoire were also included as they supply the local market. **Table 1** summarizes the collection and coding of ginger clones. The samples were cleaned, then crushed, packaged in plastic pots and bags, and stored in the freezer for analysis.

Table 1 Collection and coding of ginger samples

Origin	Province	Place of Collection	Sample	Code
Burkina Faso	Comoé	Bérégadougou	Bérégadougou	BCB
	Kénédougou	Kologho	Long arm	KCBL
			Short arm	KCBC
Ivory Coast	Public procurement	Public procurement	Ivory Coast	CCI

2.1.1. Analysis of physicochemical parameters

Determination of water content

The water content was determined by differential weighing after drying at 105±2°C in accordance with standard [11].

Determination of lipid content

The lipid content of the samples is determined using the Soxhlet method, in accordance with standard [12]. Extraction is carried out using heat (boiling) by soaking, followed by rinsing the sample with hexane. The lipid content is determined by weighing after evaporation of the hexane by distillation.

Determination of protein content

The nitrogen content was determined and the crude protein content calculated using the Kjeldahl method in accordance with standard [13].

2.1.2. Amino acid analysis

The profile and quantity of amino acids were determined by reverse-phase high-performance liquid chromatography (HPLC) using the Pico Tag method [14]. The amino acid derivatives were then separated by HPLC and detected by UV detector at 254 nm [15]. The analysis (identification and quantification) of amino acids was then performed using Empower 2 software (Waters, USA).

Determination of fiber content

Crude fiber was measured using the method described by AOAC [16]. A quantity of 5 g of each sample was weighed into a flask. A quantity of 100 ml of 0.25N sulfuric acid was added to the contents, homogenized, and brought to a boil for 30 min under reflux cooling. Next, 100 ml of 0.31 N sodium hydroxide is added to the contents and the mixture is boiled for 30 minutes under reflux. The extract obtained is filtered through ashless filter paper and the residue is washed several times with hot water until the alkali is completely removed. After removal, the residue is dried in an oven at 105°C for 8 hours, cooled in a desiccator, and then weighed. The residue obtained is incinerated in a furnace at 550°C for 3 hours. Finally, it is cooled in a desiccator and the ashes are weighed.

Determination of ash

The ash content was determined by differential weighing after passing the samples through an oven for 4 hours at 600°C in accordance with standard [17].

2.1.3. Mineral analysis

The calcium (Ca), magnesium (Mg), potassium (K), iron (Fe), and zinc (Zn) contents of the ginger clones were determined by flame atomic absorption spectrometry according to the method described by Jorhem [18].

Polyphenol assay

The total polyphenol content in ginger pulp extracts was determined by spectrophotometry using the Folin-Ciocalteu reagent method [19]. This assay is based on the quantification of the total concentration of hydroxyl groups present in the extract.

2.1.4. Total sugar measurements

Total sugars were determined using the orcinol method [20]. In the presence of concentrated hot sulfuric acid, carbohydrates undergo quantitative hydrolysis, releasing free oses and osidic units that are dehydrated into furfuryl derivatives, which condense with orcinol to form an orange-brown complex. This color develops maximum absorption at 510 nm. To do this, 0.05 g of the ground sample was placed in a beaker and 5 mL of distilled water was added. The mixture was stirred magnetically for 10 minutes, transferred to a 100 mL volumetric flask, and the volume was made up with distilled water and then homogenized. Then 1 mL of the homogenate was taken into a test tube and 2 mL of orcinol reagent and 7 mL of 60% H_2SO_4 were added (done three times). The test tubes were shaken and then placed in a boiling water bath for 20 minutes. They were then placed in the dark for 45 minutes and then at room temperature for 10 minutes. After homogenization, the absorbance was measured at 510 nm using a spectrophotometer. The total sugar content was determined using the D-glucose calibration curve.

2.1.5. Starch measurement

Starch extraction

Starch extraction was performed using the filtration method by Alves [21]. The samples were washed with tap water, sorted, peeled with a stainless-steel knife, and rinsed three times with distilled water. The samples thus prepared were split lengthwise and cut into cubes approximately 5 cm in size, but the ginger tubers were first cut into cylinders approximately 10 cm in length. They were then ground for 20 minutes using a blender. The resulting pulp was then mixed in equal proportions with distilled water, macerated using a spatula, and filtered through a white cotton cloth with a mesh size of approximately 200 µm. This operation was repeated several times until the liquid flowing from the filter was clear (approximately four times). All the filtrates together constitute the starch milk. This is left to settle for 4 hours at 4°C. The resulting sediment is washed four times with distilled water and left to dry on racks covered with aluminum foil at 45°C for 24 hours in a dryer. The dry starch is then ground using a porcelain mortar and sieved to obtain a particle size equivalent to that of commercial starch (less than 50µm). This preparation with a particle size of less than 50µm constitutes native starch.

Swelling power

The swelling power and solubility of starch in water is determined according to temperature. A 1% (W/V) starch solution is prepared and placed in a water bath at different temperatures ranging from 60°C to 90°C in 5°C intervals. The mixture is stirred at maximum speed for 30 minutes, then centrifuged at 5000 rpm for 15 minutes [21]**.** Swelling is estimated by the amount of water retained by the sample by determining the dry matter in the sediment (2 hours at 130°C). Solubility is determined by measuring the amount of sugar solubilized in the supernatant.

2.2. Statistical analyses

The means and standard errors of the means of the physicochemical and biochemical analysis results were calculated using EXCEL 2019.

Analysis of variance (ANOVA) at a significance level of p=0.05 of the results of the physicochemical and biochemical analyses, as well as principal component analysis (PCA), was performed using XLSAT 2016 version 7.5.2 software.

3. Results

3.1. Physicochemical results

Physicochemical analyses were performed on the different ginger clones. Table 2 shows the proximate composition of the four clones analyzed. The water content of the ginger clones ranged from 81.15±0.03 to 54.23±5.39%. The total fat content of the four ginger clones analyzed ranged from 4.82±0.21 % to 1.11±0.11 %. The samples representing these values are clones CCI and KCBC, respectively. These average fat contents are similar for the three clones from Burkina Faso. However, the fourth clone (CCI) showed a statistically significant variation compared to the other three, with the highest value of 4.82%. The total protein content ranged from 2.35±0.03% for the CCI clone from Côte d'Ivoire to 1.38±0.02% for the BCB clone. Analysis of variance revealed significant differences between most of the results.

Fiber content ranged from 4.25±0.15% to 3.56±0.02%. It remained stable in the samples according to the analysis of variance, despite varietal differences.

The ash content of the samples varied from 2.77±0.1 to 1.09±0.16%. Statistical analysis did not reveal any significant difference between the results α=0.502% (Pr>F).

The starch content analysis yielded results ranging from 3.56±0.44% to 2.34±0.48%. The samples representing these values are KCBL and KCBC, respectively.

Table 2 Proximal composition of ginger clones

Samples	Water content (%)	Fiber (%)	Starch (%)	Ash (%)	Fat (%)	Protein (%)
CCI	54.23±11.62^{b}	4.25±0.48^{a}	2.78±0.19^{ab}	2.04±0.50^{a}	4.82±1.61^{a}	2.35 ±0.38^{a}
BCB	80.19 ±11.62^{a}	4.14±0.48^{a}	2.67±0.13^{bc}	1.44 ±0.50^{a}	1.19 ±1.61^{b}	1.38±0.38^{c}
KCB L	74.56±0.69^{a}	3.56±0.48^{a}	3.03± 0.44^{a}	1.48±0.50^{a}	1.94 ±1.61^{b}	1.88±0.38^{b}
KCBC	81.15±11.62^{a}	4.21±0.48^{a}	2.34±0.48^{c}	1.09±0.50 ^{a}	1.1 ±1.61^{b}	1.99 ±0.38^{ab}
Pr > F	0.012	0.366	0.031	0.502	0.01	0.008
Significant	Yes	No	Yes	No	Yes	Yes

Legend: CCI: ginger from Côte d'Ivoire; BCB: ginger from Bérégadougou; KCBL: ginger from Kénédougou, long stem; KCBC: ginger from Kénédougou, short stem.

Table 3 shows the content of 17 amino acids, including 8 non-essential amino acids (NEAAs) and 9 essential amino acids (EAAs).

Table 3 Amino acid content of ginger clones

	Name	CCI	BCB	KCBC	KCBL
1	**Asp** (aspartic acid)	1.8577	0.6314	1.9794	1.5557
2	**Glu** (glutamic acid)	0.9760	0.5580	1.1111	0.8923
3	**Ser** (serine)	0.4864	0.2291	0.4230	0.3459
4	**Gly** (glycine)	0.4797	0.2650	0.5305	0.3760
5	**His** (histidine)	0.2280	0.1155	0.2054	0.1728

6	**Arg** (arginine)	0.7042	0.2674	0.5726	0.6067
7	**Thr** (threonine)	0.4163	0.2202	0.4221	0.3377
8	**Ala** (alanine)	0.3110	0.1901	0.2289	0.2646
9	**Pro** (proline)	0.3941	0.2990	0.3991	0.3375
10	**Tyr** (tyrosine)	0.3154	0.1773	0.3726	0.2338
11	**Val** (valine)	0.5817	0.5164	0.6169	0.5709
12	**Met** (methionine)	0.2542	0.2299	0.2438	0.1989
13	**Cys** (cysteine)	0.0469	0.0394	0.0124	0.0059
14	**Ile**(serine)	0.3552	0.2246	0.3624	0.2882
15	**Leu** (leucine)	0.4927	0.2727	0.5984	0.4006
16	**Phe** (phenylalanine)	0.3968	0.1957	0.4273	0.2856
17	**Lys** (lysine)	0.1336	0.3300	0.1114	0.3411
TOTAL amino acids %		**8.4299**	**4.7618**	**8.6171**	**7.2140**
AANE		**2.8585**	**2.1051**	**2.9877**	**2.5957**
AAE		**5.5713**	**2.6567**	**5.6294**	**4.6183**

Legend: **AANE**: His+Thr+Val+Met+Ile+Leu+Phe+Lys; **AAE**: Asp+Glu+Ser+Gly+Arg+Ala+Pro+Tyr+Cys; Table 4 shows the content of various minerals, namely calcium (Ca), magnesium (Mg), iron (Fe), zinc (Zn), sodium (Na), and potassium (K).

Table 4 Mineral content of ginger clones

Code Sample	Ca (mg/kg)	Mg (mg/kg)	Fe (mg/kg)	Zn (mg/kg)	Na (mg/kg)	K (mg/kg)
CCI	10125.125 [a]	4026.726 [a]	1449.103 [a]	119.622 [a]	215,789 [a]	14,447.368 [b]
BCB	6,671.892 [b]	2,616,123 [b]	754,712 [b]	46,547 [b]	143,103 [b]	10,055.172 [c]
KCBL	4,572,850 [c]	2,562,269 [c]	718,330 [c]	19,946 [c]	146,552 [b]	17,456.897 [a]
BCBC	4,268.298 [d]	2,338,519 [d]	618,237 [d]	46,100 [b]	130,769 [c]	9,564.182 [d]
Pr > F	0,000	0.000	0.000	0.000	0.000	0.000
Significant	Yes	Yes	Yes	Yes	Yes	Yes

Table 5 shows the biochemical composition of the four ginger clones, which indicates that the polyphenol content of the ginger samples ranged from 69.82 ± 9.54 to 49.92 ± 2.23 mg/100 g DAE. The total sugar content ranged from 32.29 ± 4.80 to 10.43 ± 0.02%, with the highest content found in the Ivorian clone.

Table 5 Polyphenol and total sugar content of ginger clones

Samples	POLYPHENOLS (mg/100g EAG)	Total sugars (%)
CCI	59.79 ± 10.52[a]	32.30 ± 9.38 [a]
BCB	69.82 ±10.52[a]	11.63 ±9.38[b]
KCB L	49.92 ±10.52[a]	16.57 ± 9.38[b]
KCBC	62.90 ±10.52 [a]	10.43 ± 9.38[b]
Pr > F	0.209	0.02
Significant	No	Yes

Table 6 shows the swelling rate (SR) of different varieties of ginger samples from Burkina Faso and Côte d'Ivoire. The starch swelling rate varied significantly depending on the temperature, from 60.11% to 91.40%, except for the BCB clone, where it remained stable.

Table 6 Swelling rate of ginger clones

Temperature in °C	TG CCI (%)	TG BCB (%)	TG KCBC (%)	TG KCBL (%)
60°C	89.47 ± 6.40^{b}	86.79 ± 6.40^{a}	76.57 ± 6.40 ^{b}	91.40 ± 6.40^{c}
65°C	72.59 ± 10.60^{a}	84.08 ± 10.60^{a}	60.11 ± 10.40^{a}	82.74 ± 10.60^{abc}
80°C	88.44 ±1.77^{b}	89.12 ± 4.33 ^{a}	86.89 ± 1.77^{cd}	91.20 ±1.77 ^{c}
85°C	90.43 ± 65.34^{b}	88.78 ± 1.77^{a}	90.98 ± 646.34^{d}	83.94 ± 646.34^{bc}
70°C	76.13 ± 3.93 ^{a}	80.50 ± 646.34 ^{a}	80.65 ± 3.93^{bc}	74.84 ± 3.93^{a}
75°C	76.98 ± 4.45 ^{a}	80.00 ± 3.83^{a}	76.07 ± 4.45^{b}	78.26 ± 4.45^{ab}
90°C	88.05 ± 145.30 ^{b}	86.73 ± 4.45^{a}	88.71 ± 145.22^{d}	87.49 ± 145.22^{c}
Pr > F	0.000	0.311	0.000	0.022
Significant	Yes	No	Yes	Yes

Analysis of the correlation matrix reveals a negative correlation between swelling capacity and temperature between 60°C and 75°C, but a positive correlation between 80°C and 90°C. Thus, between 60°C and 75°C, swelling power decreases as the temperature increases, while it increases with temperature between 80°C and 90°C (Table 7).

Table 7 Correlation between different starch swelling rates and temperature

T(°C) / Samples	60	65	70	75	80	85	90
CCI	0.360	-0.603	-0.401	-0.352	0.301	0.415	0.279
BCB	0.145	-0.094	-0.410	-0.454	0.351	0.322	0.140
KCBC	-0.139	-0.808	0.026	-0.160	0.280	0.446	0.354
KCBL	0.454	-0.097	-0.600	-0.382	0.441	-0.021	0.205

3.2. Principal component analysis

Figure 1 shows the principal component analysis of the four ginger clones. Principal component analysis shows that the parameters considered in this study can be represented on two axes. The two axes summarize 89.25% of the information.

Parameters such as fiber, fat, protein, starch, total sugars, and ash contribute significantly to the formation of axis F1, while polyphenol and water content values contribute to the formation of axis F2.

Axis F1 consists of the CCI and KCBL samples, which have high fiber, fat, protein, starch, total sugar, and ash content. These samples have low water and polyphenol content.

The F2 axis consists of the BCB and KCBC samples, which have very high water and polyphenol content. Unlike the samples on the F1 axis, these samples have low fiber , fat, protein, starch, total sugar, and ash content.

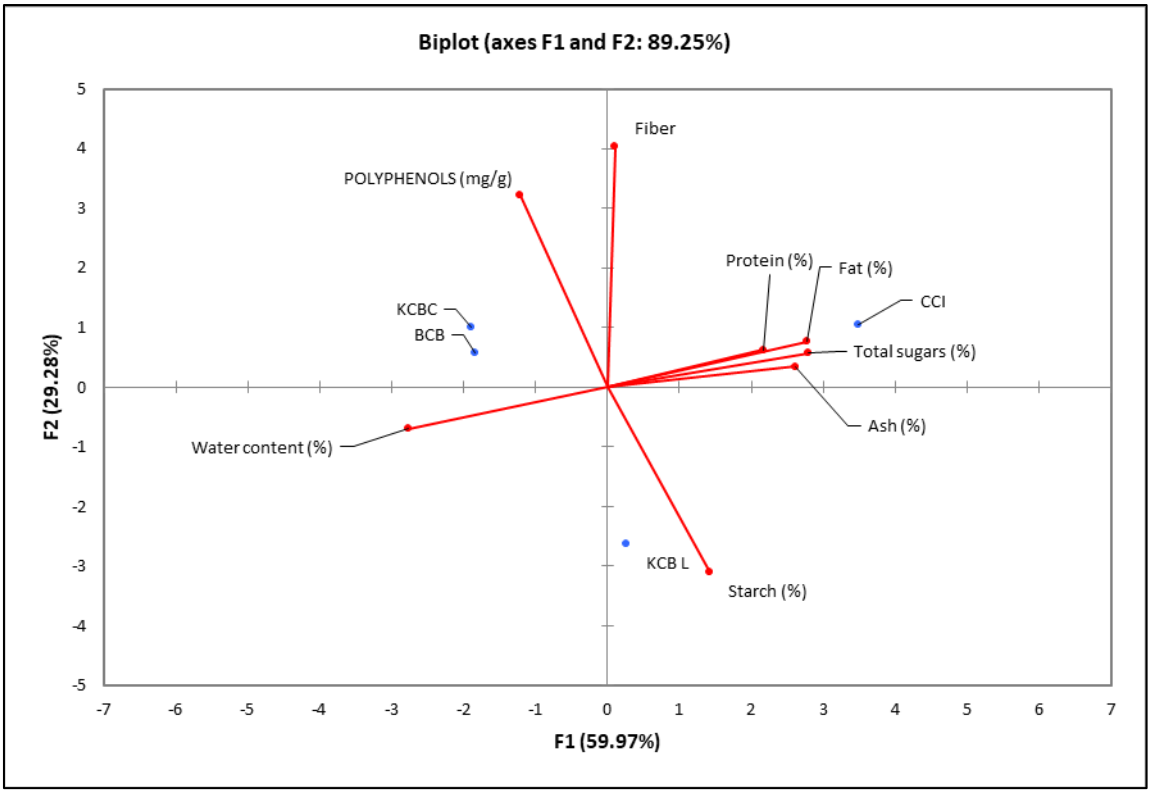

Figure 1 Principal component analysis of the physicochemical parameters of four ginger samples

4. Discussion

Analysis of water content showed similarity in most samples. These results are similar to those obtained in a study of two varieties of ginger [22]. However, the CCI sample showed a significantly different result from the other three clones. Its water content is lower, and this difference could be explained by the time interval between harvest and analysis, which could also indicate a longer shelf life. The water content of ginger is influenced by several factors, including genetics, geographical origin, storage conditions, and duration of storage [23] **.** In general, all samples have a relatively high-water content, which can promote the growth of microorganisms that can degrade the product. Therefore, ginger cannot be stored for long periods at room temperature [24]. Moisture plays a crucial role in food stability, as it directly influences shelf life.

The average fiber content of the different ginger samples shows no significant variation. These values are higher than those cited in the book on spice chemistry and USDA data [25, 26]. Our samples can therefore be considered rich in fiber. This is an advantage for these four ginger clones, as fiber is essential for maintaining good health and reducing the risk of various diseases, such as cardiovascular disease and diabetes [25].

The KCBL and KCBC clones had lower starch contents than those obtained from ginger in Côte d'Ivoire [27]. This difference in variation could be due to species diversity, climatic conditions, maturity and different extraction processes, temperature, and extraction time [28]. Thus, the high fiber content of our samples reveals that they are fibrous varieties that favor fiber synthesis over other substances such as starch. Nevertheless, considering the extraction process, the results obtained are not actually the starch content but rather the starch extraction yield. However, the starch extraction yield of our clones appears to be lower [29]. Ginger starch is highly sought after because its high gelatinization temperature makes it possible to incorporate it into sterilized products such as infant foods [30]. Despite this potential of ginger starch, its low yield in our samples indicates that it is preferable to direct them towards other uses such as the production of ginger-based beverages.

The fat content of the Ivorian clone is significantly higher than most data on the composition of ginger rhizomes [25, 31]. The uniqueness of this clone may be due to its low water content, which may have led to a concentration of fat. Recent studies show that oil extracted from ginger rhizomes contains bioactive molecules such as sesquiterpenes, flavonoids, and polyphenols, which have healing properties that can protect the body against oxidative damage and

many diseases [32]**.** In view of these virtues, the CCI sample with the highest fat content would be of particular interest for cosmetic and pharmacological use.

The highest protein content was found in the Côte d'Ivoire CCI clone, which is consistent with the results obtained in other studies on the composition of ginger rhizomes [25]. As for the KBCL and KCBC clones, their protein content is similar to the results obtained by [8]. These results are significantly lower than those found by Ajayi in Nigeria, who obtained 12.05% and 11.65% respectively for white ginger and yellow ginger [33]. Given the low values obtained, our ginger clones can be considered low in protein. Although protein is crucial for several functions such as muscle repair and growth, ginger, which is consumed in small quantities, cannot meet the body's protein requirements.

The nutritional value of a protein depends mainly on its ability to satisfy the body's nitrogen and essential amino acid requirements. Clones contain both essential and non-essential amino acids, which are important for the proper functioning of the body. In our four clones, aspartic acid is the most abundant non-essential amino acid. Valine, followed by leucine, are the most dominant essential amino acids. These amino acids are known for their role in protein synthesis, tissue repair, and immune system support. In Nigerian ginger, leucine was identified as the most concentrated [33]. The Ivorian clone is the richest in these different amino acids.

The ash content of our ginger samples is similar to that of leached ginger but lower than that of pure ginger [34]. Ash content indirectly indicates a product's mineral salt content. These minerals are supplied to the plant by the soil. Its variability can therefore be influenced not only by cultivation methods such as the addition of organic fertilizers and minerals during production, but also by the nature of the soil, such as its organic and mineral composition. Based on the data from the authors cited above, our ginger samples can be described as low in ash and therefore in minerals.

Mineral analysis of the four ginger clones revealed that they are rich in calcium, magnesium, sodium, potassium, iron, and zinc. Potassium is the most abundant element in the four clones, as is also the case with the yellow and white varieties from Nigeria [33]. Significant amounts of minerals such as Ca, Mg, K, and Fe were also found in ginger [9]**.** Therefore, despite the low ash content of the different ginger clones we are studying, they can provide a significant portion of the body's mineral requirements.

The polyphenol content of our ginger clones was lower than that obtained from ginger rhizomes in Cameroon [35], which had values of 136.44 ± 28.44mg/100 g EAG . The polyphenol content of ginger can vary depending on the harvest season, the drying stage of the plant, or even the storage conditions prior to distribution during cultivation [35]**.** Polyphenols are a family of complex molecules that plants produce naturally to defend themselves against various attacks. In human nutrition, they are considered powerful antioxidants that can help neutralize free radicals responsible for certain types of cell damage [36]. Polyphenols contribute to the nutritional and organoleptic quality of plant-based foods such as color, astringency, aroma and bitterness [37]. As a result, the KCBL ginger clone with the highest polyphenol content would be the best in terms of polyphenol intake in the diet.

With regard to sugar content, studies on the polysaccharide activity of ginger have reported a maximum value of 2.94% in fresh ginger, which is negligible compared to our results [38]. However, Wang's work found a polysaccharide content of 22.18% in fresh ginger and 68% in dried ginger [9, 39]. The sugar content may depend on the extraction method, but also on light, temperature, irrigation, season, soil, and cultivation practices [40].

Our swelling power results are consistent with those for Ivorian ginger starch [27]. The low swelling power of starch between 60° and 80°C and an increase above 85°C is due to the strength and stability of the starch granules and denaturation at temperatures above 80°C.

5. Conclusion

This study has provided important biochemical information on the proximate composition, mineral content, and amino acid profile of four ginger clones circulating and consumed in Burkina Faso. These four clones appear to be good sources of nutrients, minerals, essential amino acids, and phenolic compounds. Their use as spices, juices, preserves, or food supplements is therefore very promising. However, the Ivorian clone appears to have many nutritional advantages that could explain its presence and preference in Burkina Faso. Determining the pungent compounds in the clones could complete this nutritional picture.

Compliance with ethical standards

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Disclosure of conflict of interest

Authors have declared that no competing interests exist.

Authors' Contributions

This work was carried out in collaboration among all authors. All authors contributed equally to the conception and design of this study. All authors read and approved the final manuscript.

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