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Determination of Hydrocyanic Acid Content and Nutritional Value of Sun-Dried Cassava Flour (Akambaranga) in Burundi

Séverin Sindayikengera[1,2], Nadine Niyokwizera[1], Josiane Manirakiza[2,3], Vestine Ntakarutimana[4], Libérata Nizigiyimana[4], Mélance Ntunzwenimana[2,3], Jonathan Niyukuri[1,2*]

[1]Food Science and Technology Research Center (CRSTA), Department of Food Science and Technology (STA), Faculty of Agronomy and Bioengineering (FABI), University of Burundi (UB), Bujumbura, Burundi
[2]East African Nutritional Sciences Institute (EANSI), Bujumbura, Burundi
[3]Research Centre for Animal, Plant and Environmental Sciences (CRAVE), Department of Animal Health and Productions, Faculty of Agronomy and Bio-Engineering, University of Burundi, Bujumbura, Burundi
[4]Department of Chemistry, Research Center of Natural Sciences and Environment (CRSNE), Faculty of Sciences, University of Burundi, Bujumbura, Burundi
Email: *jonaniyu@gmail.com

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Abstract

In Burundi, cassava flour is obtained through several types of preparation, including sun-drying, which gives the flour its name. The aim of this work is to determine the level of hydrocyanic acid and the nutritional value of Akambaranga. The hydrocyanic acid content was determined by the Association of Official Analytical Chemists (AOAC, 2019) and International Organization for Standardization (ISO 2164, 1975) methods, aflatoxins by the AOAC (2019) method, proteins by Kjeldahl by the AOAC (1990) method, reducing sugars and total sugars by the Luff-Schoorl reagent method and minerals by Atomic Absorption Spectrophotometry (AAS) by the AOAC (2019) method. Hydrocyanic acid was found at a level (1.35 ± 0.16 mg/kg) below Codex Alimentarius standards (<10 mg/kg), and aflatoxins were undetectable. Proteins were found in very low quantities (1.60 ± 0.57mg/kg), so Akambaranga cannot be a source of this nutrient. Total sugars and reducing sugars are in sufficient quantity. However, of the mineral salts (iron, calcium, magnesium, sodium, potassium, manganese, phosphorus, copper and zinc) analyzed, only iron (253.43 ± 148.60 mg/kg) is sufficient for daily requirements. All others need to be fortified. Proteins and minerals need to be fortified or supplemented for Akambaranga-based meals. These results will help to improve nutritional value for both consumers and manufacturers, and thus reduce malnutrition.

Keywords

Hydrocyanic Acid, Akambaranga, Nutritional Needs, Fortification, Cassava

1. Introduction

Cassava, one of the main tuber crops grown in many countries, is a staple food for many populations, especially in tropical and subtropical countries. Cassava is the world's fourth most important staple food after rice, wheat and maize, and is eaten by over a billion people worldwide [1]. Most of the world's cassava production is destined for human consumption, the other main uses being animal feed and the starch industry [2] [3]. Global cassava production was estimated at 25 million tonnes in 2012, of which 146 million tonnes, or 57%, came from Africa [4]. Global cassava production was estimated at 25 million tonnes in 2012, of which 146 million tonnes, or 57%, came from Africa [5]. In Burundi, according to the results of the Burundi National Agricultural Survey, over 80% of the population lives or depends on agriculture for its survival [6]. According to the same source, cassava is one of the most important staple foods among tuber crops. Cassava roots are processed into products such as Ubuswage, Imikembe, Inyange, Ikivunde, and Akambaranga [7]. Data on cassava show that it is deficient in protein, vitamins and minerals, which limits its use as a staple food. Added to this is its content in hydrocyanic acid, which is toxic to the consumer. In high doses, they can lead to death, and when consumed in low doses but on a chronic basis (diet based almost exclusively on cassava products, without accompanying proteins), they can block the absorption of iodine by the thyroid glands, resulting in the formation of goiter [8]. They can also lead to retarded growth (cretinism) and psychomotor development in children, visual problems and muscle fatigue [3].

Fortunately, various cassava processing operations eliminate the vast majority of cyanides, or reduce them to levels that are non-toxic for consumption [9] [10]. Although drying is one of the operations carried out to process cassava, contributing to improved textural qualities and the elimination of cyanide [3] [11], its derivatives, *i.e.*, chips and flour, as well as other cassava products, show deficiencies linked to levels of requirements essential for human health [3]. With this in mind, a study was conducted to determine the nutritional value of cassava flours, Akambaranga, prepared in Burundi. Global objective was to contribute to the reduction of malnutrition that could be due to the high consumption of cassava products in the regions studied, and more specifically to determine the nutritional composition of Akambaranga flour. The results of this study will allow consumers to know how to supplement their menu of Akambaranga flour and thus reduce malnutrition.

2. Methodology

2.1. Presentation and Delimitation of the Study Area

Makamba Province is one of the 18 provinces of Burundi, located at 4 degrees 13' south latitude and 29˚80' east longitude. It is bordered to the northeast by Rutana Province and to the northwest by Bururi and Rumonge Provinces. It borders Tanzania, Kigoma Region to the south and southeast, and the DRC to the west. It covers an area of 1960 km^2. It is territorially divided into 6 communes, including Kayogoro, Kibago, Mabanda, Makamba, Nyanza-Lac and Vugizo.

2.2. Materials and Methods

2.2.1. Determination of the 3 Communes

The study was carried out in 3 communes that were chosen after a province-wide survey had been carried out to find out which ones consume and process Akambaranga flour more than the others. Three municipalities for each type of flour preparation were selected after conducting a survey throughout the former province which aimed to find out which ones consume and process more than others one the flour of Akambaranga, Inyange and Ikivunde. To be more representative, the sample size was calculated based on the population of the former commune of Nyanza which is more populated and the size is applied to other communes. According to the 2024 census, it amounted to 225,893 inhabitants [12]. Applying the Giezendanner formula [13], we found a workforce of 383.

$$n = \frac{t^2 \cdot N}{t^2 + (2e)^2 (N-1)}$$

n: sample size, t: risk of error linked to the confidence interval which is equal to (1.96), N: parent population (total population) of the former most populated commune of Nyanza: 225,893, e: desired absolute precision expressed as a fraction of 1 ($e = 0.05$). Since the respondents were adults, 48% [14], those over 18 years old were 184. In order to have a greater representativeness, we counted 200 people based on one person per household. The same household shares the preparation techniques. For the 6 municipalities of the former province, the survey was carried out on 1200 households in proportion to 200 households per municipality.

In order to obtain representative samples, all communes in the province of Makamba were surveyed, from which three hills per commune were randomly selected, while that the province of Makamba was chosen using the non-probabilistic method. The results of this survey enabled us to determine 3 communes (Kayogoro, Mabanda and Makamba) on which we will continue sampling for analysis of nutritional values (**Figure 1**).

2.2.2. Collecting Samples for Analysis

After identifying the communes of Kayogoro, Mabanda and Makalmba, 3 hills in these communes were selected for sampling of Akambaranga cassava roots. For Mabanda, the Musenyi, Mara and Kayogoro hills were sampled; for Kayogoro, the Butare, Gatabo and Kabizi hills; and for Makamba, the Canda, Gisenyi and Murago hills. These samples were then taken from cassava-producing and consuming households who practise drying. In each of the 5 households on the hill, 500 g cassava chips were collected. The samples were then stored at room temperature in the microbiology laboratory of the Faculty of Agronomy and Bioengineering at

University of Burundi, before being sent to various laboratories for analysis.

2.3. Chemical Analysis Methods

2.3.1. Determination of Hydrocyanic Acid Glucoside Content

Hydrogen cyanide was determined using the method described in ISO standard [15] at the chemical analysis laboratory of the National Center for Food Technology (CNTA). The glycosidic hydrocyanic acid content was expressed in milligrams per 100 g of sample as follows:

$$0.54\left(V_0 - V_1\right) \times \frac{250}{100} \times \frac{100}{m} = 135\left(V_0 - V_1\right)/m$$

where: m is the mass, in g, of the test sample.

V_0 is the volume, in ml, of the 0.1 N silver nitrate solution used for the determination.

V_1 is the volume, in ml, of the 0.1 N silver nitrate solution used for the blank test.

2.3.2. Water Content Determination

Following the AOAC (2019) method, samples were weighed (P_0) using a precision balance in the microbiology laboratory at the Faculty of Agronomy and Bioengineering. They were dried in an oven at 105˚C for 24 h, and then were cooled in a desiccator and weighed (P_1); the water content was determined according to the following formula:

$$\text{Water content} = \frac{\left(P_0 - P_1\right) \times 100}{P_0}$$

2.3.3. Determination of Aflatoxin Content

In the CNTA laboratory, aflatoxins were determined according to the AOAC method (2019) comprising extraction, purification on an immuno-affinity column and quantification using a calibration after analysis by High Performance Liquid Chromatography (HPLC) equipped with a fluorescence detector, a vacuum pump, an automatic injector and a column. Biological detection of aflatoxins was achieved by inhibiting the growth of *E. coli* C600 on a nutrient substrate, by inhibiting the growth of sensitive *E. coli* C600 on agar agar, and by monitoring their diffusion.

2.3.4. Determination of Total Sugar Content (TSC) and Reducing Sugar Content (RSC)

The total and reducing sugar contents of the samples were determined by the Luff-Schoorl reagent method as described by Taufik et Guntarti [16] at the Burundi Institute of Agronomic Sciences (ISABU). Results were expressed as % total and reducing sugars per 100 g of sample (% TSC/100 g and % RSC reducing sugars/100 g).

2.3.5. Protein Content Analysis (TPr)

Proteins were determined using the total nitrogen assay, according to the AOAC

(1990) Kjeldahl standard as describe at Burundi Institute of Agronomic Sciences (ISABU). Results were obtained by multiplying total nitrogen by 6.25 (nitrogen-to-protein conversion coefficient) and expressed as % protein per 100 g sample (% protein/100 g).

2.3.6. Determination of Mineral Content

Mineral element contents were determined according to the official method (AOAC 2019) at ISABU. The dry sample digestion method was used, where 10 g of test sample of each element was weighed, dried, ground and used in the analyses. Element content was determined by atomic absorption spectrophotometer (AAS). Results are expressed in mg per 1000 g of sample (mg/1000g).

2.4. Data Analysis

Statistical analyses of the results obtained were carried out using IBM SPSS Statistics 20. An analysis of variance (ANOVA) was performed to calculate significant differences in the data at the $\alpha = 0.05$ threshold. The ANOVA was completed by Duncan's multiple comparison test, to detect levels of difference, and results were expressed as mean values ± standard error (SE). Hierarchical clustering analysis (HCA) was applied to classify hills according to the physico-chemical composition of their samples.

3. Results and Discussion

3.1. Place of Consumption of Akambaranga Flour in the Province of Makamba

Figure 1 shows the daily frequency of Akambaranga paste consumption in Makamba province. In the communes of Mabanda, Kayogoro and Makamba, over 60% consume Akambaranga once a day. The same results show that less than 5% manage to go a whole day without eating Akambaranga paste. In the other communes, large proportions can go a whole day without eating Akambaranga paste. The commune of Vugizo comes first, with 40%, Kibago 22% and Nyanza Lac 20%. Figure 2 also shows that over 60% of people in the communes of Kayogoro, Makamba and Mabanda consume cassava paste at least once a day throughout the week. However, in the commune of Vugizo, 5% of the population can go a whole week without consuming Akambaranga. Overall, more than 40% of the population of Makamba province consume Akambaranga flour at least once a day for a whole week. As cassava is not rich in nutrients, this monoconsumption exposes them to the risk of malnutrition. Studies have classified Makamba province as one of the provinces most affected by global acute malnutrition (GAM) [6].

Based on the percentage of the population that consumes Akambaranga flour most frequently, here's the ranking in order of size: Kayogoro > Makamba > Mabanda > Kibago > Vugizo > Nyanza Lac. The first 3 communes (Kayogoro, Makamba and Mabanda) were the sites where samples were collected for analysis of the hydrocyanic acid content and nutritional value of Akambaranga.

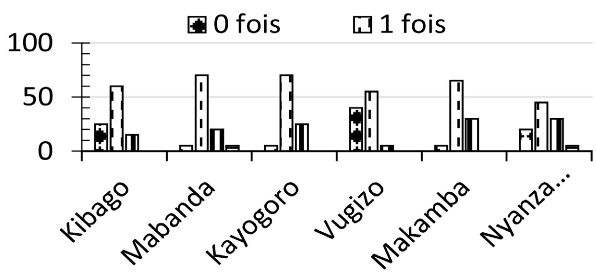

Figure 1. Frequency of daily consumption of Akambaranga in Makamba province.

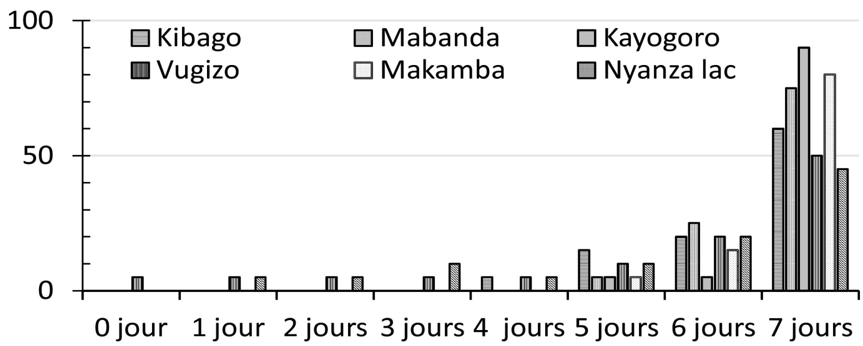

Figure 2. Weekly consumption frequency of Akambaranga in Makamba province.

3.2. Nutritional Value of Akambaranga Flour

3.2.1. Water Content

The results show that water content differs significantly ($p < 0.05$) from one commune to another. Mean contents ranged from 7.66% ± 0.02% to 9.13% ± 0.08%. They were 7.66% ± 0.02%; 8.57% ± 0.03%; 9.13% ± 0.08% respectively for the communes of Makamba, Kayogoro and Mabanda. Similar levels were also reported in cassava roots in the commune of Bassila (Nord-Bénin) [17]. This variation in water content from one commune to another is due to the length of time it takes to dry the cassava, which can vary from one household to another. Drying stabilizes the finished product by considerably reducing its water content, an essential criterion for storage and preservation under controlled conditions until marketing and consumption [2] [3] [9]. These values are below the limit value (≤13%) set by the Codex Alimentarius for edible cassava flour [18]. These results show that Akambaranga flour could be preserved without its water content, which is an element favoring the development of microorganisms or other biochemical reactions.

3.2.2. Aflatoxin Content

The results showed that the samples did not contain aflatoxins, and if they did, they were not in detectableq uantities. However, in a study conducted in Kivu 6 Congo, the presence of *Aspergillus flazus LINK*, *Aspergillus flauus oryzne*, *Aspergillus niger*, *Aspergillus glnucus cheonlieri* [19] secrete aflatoxin. Thus, the results of this work show that Akambaranga flour can be used and consumed without fear of the danger of aflatoxins. Factors likely to favor the proliferation of certain molds responsible for aflatoxins such as climate, poor preservation and poor storage [20] must be checked out.

3.2.3. Chemical Composition of Akambaranga Produced in Makamba Province

1) Hydrogen cyanide content

Mean levels were 1.28 ± 0.03 mg/kg; 1.59 ± 0.01 mg/kg; 1.18 ± 0.07 mg/kg respectively for the communes of Mabanda, Kayogoro and Makamba. And the mean levels between samples differed significantly ($p < 0.05$). This variation can be explained by the fact that the samples analyzed did not come from cassava with the same level of bitter cyanogenic compounds. These results are similar to those reported by Odunfia [21]. However, the results recorded were below the safety level recommended by the Food and Agriculture Organization of the United Nations and the Codex Alimentarius CX/CF 18/12/13 [22] stipulating that the safety limit for hydrocyanic acids in cassava must not exceed 10 mg of cyanide equivalents per kilogram of dry weight [23].

Table 1. The chemical composition of Akambaranga produced in three communes of Makamba province (In each column, values with different letters mean that are significantly different ($p < 0.05$)).

Parameters	Mabanda	Kayogoro	Makamba	Average
H_2O (in %)	9.13 ± 0.08^a	8.57 ± 0.03^b	7.66 ± 0.02^c	8.45 ± 0.53
HCN (in mg/kg)	1.28 ± 0.03^b	1.59 ± 0.01^a	1.18 ± 0.07^c	1.35 ± 0.16
Protein (in %)	1.15 ± 0.12^b	2.45 ± 0.28^a	1.20 ± 0.02^b	1.60 ± 0.57
Total sugars (in %)	4.64 ± 0.20^c	6.50 ± 0.02^a	6.01 ± 0.05^b	5.72 ± 0.72
Reducing sugar (in %)	2.99 ± 0.04^b	3.19 ± 0.03^a	2.62 ± 0.04^c	2.93 ± 0.21
Fe (in mg/kg)	476.33 ± 2.07^a	148.18 ± 1.97^b	135.78 ± 1.34^c	253.43 ± 148.60
Ca (in mg/kg)	557.73 ± 3.81^a	452.99 ± 75.19^b	490.59 ± 3.93^b	500.44 ± 38.20
Mg (in mg/kg)	399.84 ± 6.84^c	543.51 ± 2.54^a	447.87 ± 0.90^b	463.74 ± 53.18
Na (in mg/kg)	619.79 ± 92.50^c	686.84 ± 1.13^b	818.23 ± 0.99^a	708.29 ± 73.30
K (in mg/kg)	5178.16 ± 6.89^b	2974.02 ± 6.71^c	8530.47 ± 0.86^a	5.560.88 ± 1.90
Mn (in mg/kg)	2.39 ± 0.086^a	1.17 ± 0.14^c	1.38 ± 0.03^b	1.65 ± 0.50
P (in mg/kg)	851.00 ± 2.55^a	632.10 ± 5.26^b	439.35 ± 1.75^c	640.82 ± 140.12
Cu (in mg/kg)	1.66 ± 0.03^c	1.80 ± 0.07^b	2.10 ± 0.03^a	1.59 ± 0.39
Zn (in mg/kg)	4.84 ± 0.17^b	5.21 ± 0.35^a	3.51 ± 0.06^c	4.52 ± 0.67

2) Mineral content

Eight mineral salts (Fe, Ca, Mg, Na, K, Mn, P and Cu) were analyzed in akambaranga flour. Most of the mineral salts studied were found to be very low in relation to human daily requirements (**Table 1**). Only iron, whose content varied from 135.78 ± 1.34 to 476.33 ± 2.07 mg/kg (knowing that the paste prepared in one kg of cassava flour is consumed by 4 people, one person will have 63.35 mg/250g), was sufficient for human nutrition. The study also revealed that environmental effects are highly preponderant. Significant differences ($p < 0.05$) in iron content were found in this order: 476.33 ± 2.07 mg/kg > 135.78 ± 1.34 mg/kg > 148.18 ± 1.97 mg/kg respectively for flours from the commune of Mabanda, Makamba and Kayogoro. These values are significantly lower than those recorded for fresh cassava (14.8 ± 0.11 mg/kg) by Nzigamasabo & Zhou [24] but also to those of Bradbury [25] and Montagnac *et al.* [26]. The fermentation of cassava roots process to produce Akambaranga flour results in a significant increase in iron. Given that the recommended iron intake ranges from 14.8 to 30 mg/day [27], Akambaranga is a good source of iron and can contribute to consumers' well-being by covering their iron requirements. However, analysis of calcium (Ca) showed very low levels compared with human requirements. While it has been reported that the recommended daily calcium intake for a child aged 9 to 18 is 1300 mg/day and 900 mg/day for an adult [28], Akambaranga flour had an average content of 500.44 ± 38.20 mg/kg. As for iron, environmental conditions, especially soil richness, had a significant influence ($p < 0.05$) on commune levels. This suggests that Akambaranga flour should be enriched with calcium, as the latter is an essential element in many vital bodily functions such as blood coagulation, maintenance of blood pressure, building and maintenance of bones and teeth, cofactor in enzymatic processes, etc [29].

With regard to magnesium, the [24] study revealed that the average levels between samples differed significantly ($p < 0.05$) depending on the commune of origin. Levels in descending order were 543.51 ± 2.54 mg/kg > 447.87 ± 0.90 mg/kg > 399.84 ± 6.84 mg/kg tested respectively in flour from Kayogoro, Makamba and Mabanda. Similar levels were found by [7] [11] in another research study. Akambaranga flour is not a good source of magnesium, as an adult man needs 460 mg/day of it [29]; which implies fortification of this flour. Similar trends were also observed in the determination of sodium (Na) levels in akambaranga flour. These averages were 619.79 ± 92.50 mg/kg > 686.84 ± 1.13 mg/kg > 818.23 ± 0.99 mg/kg in the communes of Mabanda, Kayogoro and Makamba respectively. These results are close to those recorded for fresh cassava (800 mg/kg) of [30]. However, they are significantly higher than those recorded by [31] [32]. That said, while the daily sodium intake for an adult is estimated at 2000 mg/day [33], from which Akambaranga requires sodium fortification to cover daily human needs. Briefly, it is imperative to fortify cassava flour with various nutrients from other foods rich in these nutrients. For example, amaranth has shown to enrich cassava with protein and zinc [34].

The results on potassium (K) levels also showed a very low value (5560.88 ± 1979.72 mg/kg) compared with the estimated requirements of 5000 mg/day for a child and 4000 mg/day for an adult [35]. According to those authors, deficiencies lead to chronic kidney disease, muscle contraction and, if persistent, heart failure. Manganese, too, which is a cofactor of several enzymes in the human organism, has been characterized by insufficient levels to meet daily requirements. Although it is present in trace form in the body, the level of 1.65 ± 0.50 mg/kg (**Table 1**) is far less than 9 mg/day required for an average person weighing 70 kg [36]. Depression of mucopolysaccharide synthesis and reduced mitochondrial manganese superoxide dismutase activity have been reported to cause skeletal abnormalities, as has congenital ataxia due to abnormal inner ear development and abnormal brain function [37].

Phosphorus (P) was also analyzed during this study. **Table 1** shows the levels according to commune of origin and daily human requirements. Significant differences ($p < 0.05$) were recorded as follows: 851.00 ± 2.55 > 632.10 ± 5.26 > 439.35 ± 1.75 mg/kg; respectively for the commune of Mabanda, Kayogoro and Makamba. Knowing that the recommended nutritional intake of phosphorus is 800mg/d for an adult [38], this content is too low in Akambaranga flour. However P is essential to the human organism. It plays several roles in mammals, including bone growth; cellular metabolism for energy and signaling through ubiquitous phosphorylation reactions; structures (phospholipid membranes and skeletal tissue), protein synthesis and nucleic acids (DNA and RNA); and oxygen supply via 2,3-diphoshoglycerate [39]-[42]. This shows that a poor diet alters the proper functioning of the human organism.

For copper, the trends were the same as for the other mineral salts in terms of environmental effect. The absorption of mineral salts into the plant depends on availability in soil. Thus, significant differences ($p < 0.05$) of copper were observed in flours from different communes. Flour from Mabanda, Kayogoro and Makamba had copper contents of 1.66 ± 0.03 mg/kg; 1.80 ± 0.07 mg/kg and 2.10 ± 0.03 mg/kg respectively. Values ranging from 6.2 to 50 mg were reported by Montagnac *et al.* [26]. Given that the recommended dietary intake of copper is 1.5 to 3.0 mg for adults and 0.4 to 0.6 mg for children aged 0 to 6 months [43]-[45] and no one can consume one kg per day, Akambaranga flour cannot be a good source of copper. Its daily consumption, as shown in **Figure 1**, should be accompanied by other copper-rich foods to avoid copper deficiency disease.

During this study, results on zinc revealed mean zinc contents ranging from 3.51 ± 0.06 to 5.21 ± 0.35 mg/kg, with significant differences ($p < 0.05$). These averages were 3.51 ± 0.06 mg/kg; 4.84 ± 0.17 mg/kg and 5.21 ± 0.35 mg/kg respectively for the communes of Makamba, Mabanda and Kayogoro. Compared with the results of other studies, zinc content varies widely. Significantly higher levels (22.01 ± 0.2; 14.00) were recorded by Nzigamasabo & Zhou [7] et Montagnac *et al.* [26] in fresh cassava. This is normal, as it depends on the richness of the soil. The recommended daily allowance of zinc is 14 mg for pregnant women, 1.6 to 3.6 mg per day for children and 4 to 5 mg per day for adults [29], Akambaranga flour is not a good source of zinc for pregnant women, but it is for children and adults. However, it needs to be fortified with zinc to cover the daily requirements of pregnant women.

This low mineral salt content in this flour can be amplified by antinutrients present in different foods. Phytate has been reported to occur as a strongly negatively charged ion over a wide pH range and therefore chelate positively charged minerals such as iron, zinc, magnesium, manganese, and copper [46]. Many vegetables consumed in Africa contain anti-nutrients. [47] [48]. Cowpea, spider plant, wild jute, amaranth, ethiopian kale have been reported to contain significant levels of condensed tannins, total phenolics, total oxalates, soluble oxalates, insoluble oxalates and phytates [49]. Not to mention the antinutrients of other minerals like iodine. Studies have shown that glucosinolates interfere with the absorption of iodine by the thyroid gland and cause iodine deficiency and goiter [50].

3) Protein content

Table 1 show that cassava flour, especially akambaranga flour, is too low in this macronutrient. The average content is 1.60 ± 0.57 mg/kg. Since a normal person can consume 250 g, this means they will consume 0.4 mg, or 0.0004 g. According to the WHO, protein requirements for adult men and women are 0.6 g/kg/day, while a pregnant woman's protein requirements are up to 1.52 g/kg/day [51]. As a result, daily consumption of these foods by children and pregnant women compromises the growth of both child and foetus. To improve consumer health, particularly that of children and pregnant women, it is essential to consume foods that are very rich in protein, either as side dishes or by fortifying flour. This means that raw cassava is not a good source of protein, and needs to be fortified with this nutrient. Protein deficiency can be the cause of albumin loss, regeneration and replacement, surgical shock, burns, blood loss, nutritional edema, wound healing, liver failure and anesthetic injury. The protein's function has attracted relatively little attention [52] [53].

4) Total and reducing sugar content

Akambaranga flour was found to contain 5.72 ± 0.72% of what? However, the results showed that they differed significantly ($p < 0.05$) from one commune to another, the decreasing order being: 6.50% ± 0.02% > 6.01% ± 0.05% > 4.64% ± 0.20%, respectively for the communes of Makamba, Kayogoro and Mabanda. This variation could be explained by the fact that the samples analyzed came from different locations. Sunshine can vary in these locations, which has a significant impact on yield [54] through photosynthesis [55].

This study also included the determination of reducing sugars. The analysis revealed that Akambaranga flour contained 2.93% ± 0.21% reducing sugars. Depending on the commune of origin, the comparison test for average reducing sugar levels showed that these differed significantly ($p < 0.05$) between samples. The highest content was observed in Kayogoro Akambaranga (3.19% ± 0.03%), followed by Mabanda (2.99% ± 0.04%) and the lowest in Makamba (2.62% ± 0.04%). Slightly lower results (3.37%) were recorded by Nzigamasabo and Zhou [30] in fresh cassava. However, all analyses revealed higher levels of reducing sugars than those (0.019%) reported by other authors [56] [57] for fresh cassava. This increase in the sugar content of Akambaranga (fermented cassava) compared with fresh cassava could be due to the hydrolysis of starch by the water contained in cassava and the enzymes it contains [58] [59].

3.3. Comparison of Hills by Principal Component Classification (PCA)

As shown in **Figure 3**, the ascending hierarchical tree analysis, using Euclidean distance and Ward's criterion, produced a dendrogram of three groups:

The first group comprises the Mara, Musenyi and Kayogoro hills. The results of the chemical composition analysis of the Mara and Kayogoro hills showed a high degree of similarity, classifying them in one sub-group; while the Musenyi hill deviates slightly from this, forming another sub-group. The high sodium content (758.55 mg/kg) of Musenyi's Akambaranga compared to those of Mara (551.675 mg/kg) and Kayogoro (549.155 mg/kg) could explain this difference. The second group comprises three hills: Canda, Gisenyi and Mihongo. The results obtained on the chemical composition of the Gisenyi and Mihongo hills are very similar and form a sub-group. The Canda hill is a subgroup in its own right. These two subgroups were probably formed due to the high total sugar content of the Canda samples (6.1%), compared with those from Gisenyi (5.99%) and Mihongo (5.93%). The third group comprises the hills of Gatabo, Butare and Kabizi. The chemical composition results for the Gatabo and Kabizi hills are very similar and form a subgroup, while those for the Butare hill form a subgroup distinguished by its Ca (538.44 mg/kg) and Zn (5.75 mg/kg) content. Ca and Zn contents are 434.77 mg/kg and 4.96 mg/kg respectively for Gatabo, and 385.768 mg/kg and 4.91 mg/kg for Kabizi.

As a result, these three groups are similar. The big differences are in mineral salts, which is understandable, as these are taken from the soil. These differ from one commune to the next.

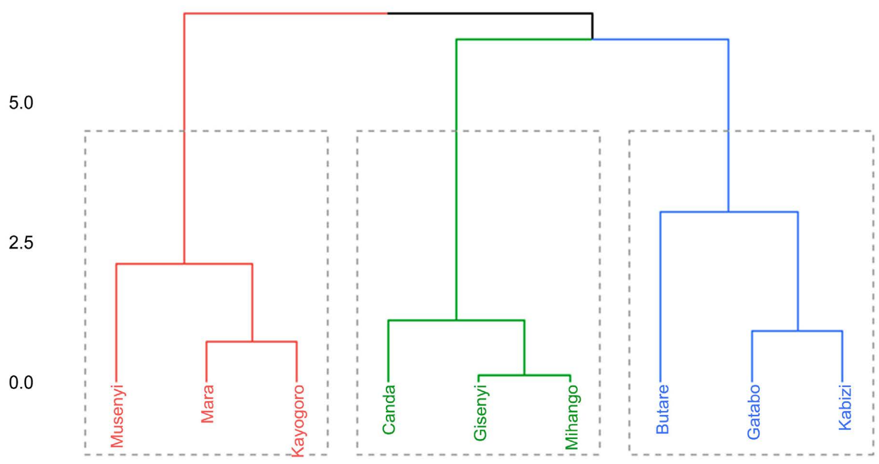

Figure 3. Classification of hills by degree of resemblance.

4. Conclusion

The results of this study revealed that akambaranga flour was safe for consumers in terms of hydrocyanic acid and aflatoxin content, which were respectively below

(1.35 ± 0.16 mg/kg) and non-detectable in relation to Codex Alimentarius standards (<10 mg/kg and non-detectable respectively). Akambaranga flour was found to contain very little protein, ruling it out as a source of this element. Total and reducing sugars, as cassava is rich in starch, are sufficient. The same study revealed very low levels of mineral salts, such as calcium, magnesium, sodium, potassium, manganese, phosphorus, copper and zinc deficiency in these mineral salts affects several body functions, such as growth, physiological, hormonal and immune regulation. Only iron (253.43 ± 148.60 mg/kg) shows values that qualify akambaranga as a food source for combating iron-deficiency diseases such as anemia. Thus, fortification of this flour is essential to ensure the good health of consumers. These results will enlighten decision-makers, industrialists and consumers on the combinations to be made to combat malnutrition caused by exclusive consumption of akambaranga.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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