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Research Article

Nutritional and Microbial Qualities of Fermented Cereal-Based Porridges Produced in Northern Benin

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Fermentation has been used for centuries to enhance the sensory and nutritional qualities and the antioxidant content of plant-based foods, making them beneficial for health. This study aims to investigate the microbiological and nutritional qualities of fermented porridges produced in northern Benin. Various nutritional tests and the identification of different microorganisms have gained insights into eight porridges produced in 9 localities of northern Benin. Lactic acid bacteria have the highest proportion among all microorganisms in fermented porridges, followed by the total mesophyll aerobic flora. *E. coli*, thermotolerant coliforms, and molds are not present in all porridges analyzed. Recorded data suggested that porridges have a variable microbial load depending on the collection municipalities. The dry matter of the eight types of porridge varies greatly, with akloui having 27.03 ± 3.83 g/100 g and fourra having 48.63 ± 3.83 g/100 g. The total ashes also differ significantly, with bita having 39.36 ± 4.67 g/100 g and sagagnèga having 63.19 ± 4.67 g/100 g. It is worth noting that all fermented porridges have a pH lower than 5, and the titratable acidity ranges from 0.01 ± 0.00 g to 0.02 ± 0.00 g. The brix degree varies from 0.46 ± 0.54 to 4.4 ± 0.54. The beta-carotene values of the 8 types of porridge vary from 0.037 ± 0.018 mg/g to 0.138 ± 0.018 mg/g, while the total sugars range from 1.926 ± 0.877 to 5.773 ± 0.877 g/100 g. The lipid content, when present, varies from 0.226 ± 0.029% to 0.408 ± 0.029%. Finally, the protein percentage of the porridge ranges from 7.061 ± 0.779 to 12.419 ± 0.779.

1. Introduction

Fermented cereal-based foods are a significant cultural heritage in sub-Saharan Africa, where some of the world's most decadent fermented foods can be found [1]. These cereal-based foods are staples, complementary, and weaning for infants and young children [2]. These products are crafted using equipment and raw materials that are readily available in the local area. However, the products and materials used vary from region to region [2], as with

fermented porridges [3]. Traditional food fermentation processes rely on a wide range of microorganisms and their enzymes to achieve the desired characteristics [2], which are often uncontrolled due to the preparation process. Fermented products are known to have health-promoting effects due to the presence of functional microorganisms. These microorganisms, such as Lacticaseibacillus, Lactobacillus, Levilactobacillus, and Bifidobacterium, can occur naturally and/or be added to various products [4]. Lactic acid fermentation has gained attention because it reduces contamination by pathogenic microbes by producing lactic acid and other antimicrobial metabolites, thereby decreasing the pH of fermented food products [5]. These spontaneously fermented foods have multiple health benefits [6] and help extend food availability beyond the production area and season, contributing to national and household food security [1]. Microorganisms in fermented products can have a multidirectional beneficial effect [4] and temporarily affect the gut microbiome [7]. This allows for modifying and modulating intestinal function, improving health, or reducing the risk of dysbiosis-related diseases.

In Benin, spontaneously fermented porridge, the manufacturing process of which remains empirical, constitutes an essential part of the daily diet. The significant variability of production conditions leads to fermented porridges of low and variable technological quality and, consequently, to fermented porridges of equally variable nutritional value. Indeed, the safety of these products is not always guaranteed because the cereals and oilseeds used to produce complementary foods could be contaminated with microorganisms and/or mycotoxins [8]. Undesirable microorganisms, toxins, and chemicals can cause food poisoning [8]. Pathogenic bacteria and viruses can cause many eating disorders. These pathogens include *Escherichia coli*, *Shigella* spp., *Salmonella* spp., *Staphylococcus aureus*, *Vibrio cholerae*, *Streptococcus* spp., *Bacillus cereus*, *Yersinia enterocolitica*, *Campylobacter* spp., *Listeria monocytogenes,* and *Clostridium perfringens* [9]. A good understanding of the nutritional quality and microbial diversity of cereal-based fermented porridges in northern Benin would be a prerequisite for developing and implementing evidence-based policies to improve food and nutrition security and have a standardized process. Therefore, this work aims to evaluate the nutritional, physicochemical, and microbiological parameters of microorganisms from fermented porridges produced and consumed in northern Benin.

2. Material and Methods

2.1. Sample Collection. A total of 147 samples of fermented porridges were collected for microbiological analysis. Three samples from each kind of porridge from the 49 producers and each sample were placed in sterile bags and kept in coolers with storage batteries. The samples were transported, stored at 4°C in the laboratory, and analyzed about 48 hours after collection. Forty-nine collected samples were used for physicochemical and nutritional analysis, taking one sample per type of porridge.

2.2. Microbial Analysis of Fermented Porridges. In the laboratory, 10 ml of each fermented porridge sample was mixed with 90 ml of sterile bacteriological peptone (Oxoid, Hampshire, England). The microbiological analysis focused on staphylococci, *E. coli*, *Salmonella* spp., coliforms, yeasts, molds, and total mesophilic aerobic flora. Decimal dilutions were made with peptone water (Bio-Rad, Paris, France) from the incubated suspension and used to count the bacteria. Baird–Parker agar (Biovar Diagnostics, France) with egg yolk [10, 11] was used for Gram-positive cocci. The enumeration of *E. coli* was carried out on TBX culture medium (Tryptone Bile X-Glucuronide) according to ISO standards. Total coliforms and thermotolerant coliforms were counted according to standard NF V08-050 and NF V08-060. Lactic flora was counted using MRS, and the fungal flora was counted using Dichloran Rose Bengal Chloramphenicol (DRBC) agar (BD, France). *Salmonella* spp. was identified according to ISO 6579-1 [12]. The frequency of contamination was calculated as the ratio of contaminated products to all products, and the prevalence was obtained as the ratio of strains isolated to all biological products tested according to the standard.

2.3. Physicochemical Characterization of Porridges. The dry matter content, pH level using the HI 8418 pH meter, titratable acidity, brix degree, and total minerals of the different types of porridge collected were detected by using the adaptation of a method previously described by Nout et al. [13].

2.4. Determination of Dry Matter (DM) Content. To determine the amount of dry matter, samples were placed in an oven at 105°C for 24 hours [14]. After that, they were weighed using a differential method. The dry matter content was determined by using the following formula: dry matter content (DM) (%) = $(P2 - P0)/(P1 - P0) \times 100$, where $P0$ is the weight of the empty crucible, $P1$ is the weight of the fresh sample, and $P2$ is the weight of the dried sample.

2.5. Determination of pH and Titratable Acidity. The modified method of Nout et al. [13] was used, and the tests were duplicated. A sample mix (10 g) and water (20 ml) were used to measure the pH. The titratable acidity was determined by titrating the suspension with 0.1N NaOH until the pH stabilized at 8.2. The results are expressed as a percentage of lactic acid on a dry basis. To calculate the percentage of lactic acid (b.s), the following formula was used: %lactic acid (b.s) = $V/Ma \times 0.9$, where V is the volume of 0.1 N NaOH in ml, M is the mass of the sample in g, and a is the dry matter content of the sample.

2.6. Assay of Ash Content. To determine a porridge sample's raw ash content, 5 g was carbonized and incinerated at 550°C for 24 hours [14]. The resulting substance is weighed after being cooled in a glass desiccator. The ash content is then calculated as a percentage of dry flour.

2.7. Determination of the Brix Degree. A refractometer (Sopelem 9596, France) calibrated with a pH 7 buffer solution was used to measure the brix degree. The measurement involved placing a drop of the wet sample on the lens of the refractometer and taking a direct reading after exposure to light.

2.8. Lipid Assay. Free lipids were assayed using the automated Soxhlet extraction apparatus (E-812/E-816HE, Buchi AG, Switzerland) [14]. It consists of extracting the free lipids from the sample for 4 hours with petroleum ether. Extraction is followed by drying in an oven at 105°C for one hour. The flasks are cooled in a desiccator and then weighed. The lipid content is expressed as a percentage on a dry basis.

2.9. Crude Protein Determination. The total nitrogen was measured by using the Kjeldahl method to analyze the crude proteins in porridge [15]. This involves mineralizing the sample, distilling the mineralized product, and titrating it. The resulting nitrogen content is multiplied by a conventional factor of 6.25 to determine the total protein content.

2.10. Distillation and Titration. After the mineralization process, excess soda is used to neutralize and alkalize the material. During this process, all ammonium ions are converted into ammonia, resulting in NH_3 being the only nitrogen present. The ammonia is then extracted through hydrodistillation with water vapor, and the vapors are collected in an adequately acidic medium containing boric acid. Subsequently, a sulfuric acid solution of known strength is added to the ammonia to determine the equivalence point through an indicator's color change. The ammoniacal nitrogen content is calculated by using the following formula: $N\,(\%) = ((V1 - V0) * T * 0.014 * 100)/m$, where $V0$ is the volume of acid poured into the blank, $V1$ is the volume of acid poured into the sample, T is the titer of sulfuric acid (0.5 Mol/l), and m is the test portion of the sample.

The crude protein content of the product can be determined by multiplying the nitrogen content value obtained by 6.25 for animal feed and 6.38 for dairy products. Furthermore, the nitrogen content equals N (%) multiplied by the protein factor.

2.11. Data Analysis and Processing. Minitab 16 software was used to analyze variance (ANOVA) to compare the means of chemical and microbiological variables in different study areas. To structure the means, Fisher's grouping test was used. The correlations between various chemical and microbiological variables were also conducted by using the same software. Statistical differences were determined using R software version 4.2.2 [16] with a probability value of less than 5% ($p < 0.05$).

3. Results

3.1. Microbiological Characterization of Fermented Porridges

3.1.1. Distribution of Microorganisms by Region. Figure 1 displays the distribution of microorganisms by region. The

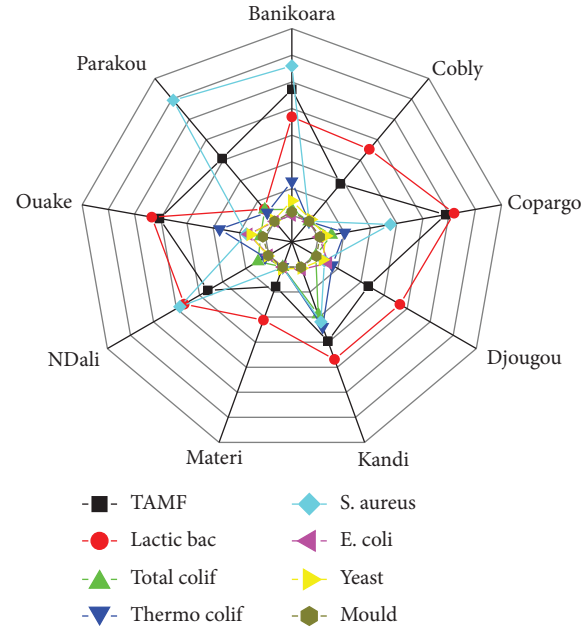

Figure 1: Distribution of microorganisms according to collection sites.

data indicate that lactic acid bacteria are the most prevalent in this study's porridge samples collected from municipalities. The total mesophilic aerobic flora (TMAF) is the second most prevalent. However, small amounts of *Escherichia coli*, total coliforms, and thermotolerant coliforms are present. The highest proportion of lactic acid bacteria (70%) was found in Matéri's porridges, followed by Cobly (64%) and Djougou (45%). Porridge from Parakou had a higher staphylococci prevalence (55%), followed by N'Dali (36%) and Banikoara (35%). Although *E. coli* was present in small amounts in all municipalities, the highest contamination was in Djougou's (7%) and Ouaké's (5%) porridges. However, *E. coli* was not found in Parakou, N'Dali, Copargo, Cobly, and Banikoara porridges.

3.1.2. Distribution of Microorganisms according to the Type of Porridge. The study found that different types of porridge contain varying numbers of microorganisms, including lactic acid bacteria, TMAF, staphylococci, yeasts, and coliforms (Figure 2). Lactic acid bacteria were the most prevalent, followed by TMAF, and not all porridges contained microorganisms such as *E. coli* and thermotolerant coliform molds. Overall, lactic acid bacteria were found in higher proportions than other microorganisms in all eight types of porridge. The contamination rates were highest in bobossou at 50%, followed by sagagnèga at 40%, koko at 36%, apkan at 34%, gbangba at 32%, akloui at 31%, fourra at 30%, and bita at 26%. TMAF was most frequently found in bobossou at a rate of 40%, followed by sagagnèga at 33% and apkan at 31%. Bita had the highest proportion of *E. coli* contamination at 5%, while akloui, bobossou, koko, and sagagnèga contained none. Yeasts were more prevalent in bobossou (6%), and staphylococci were more commonly encountered in gbangba (30%), followed by akloui (29%),

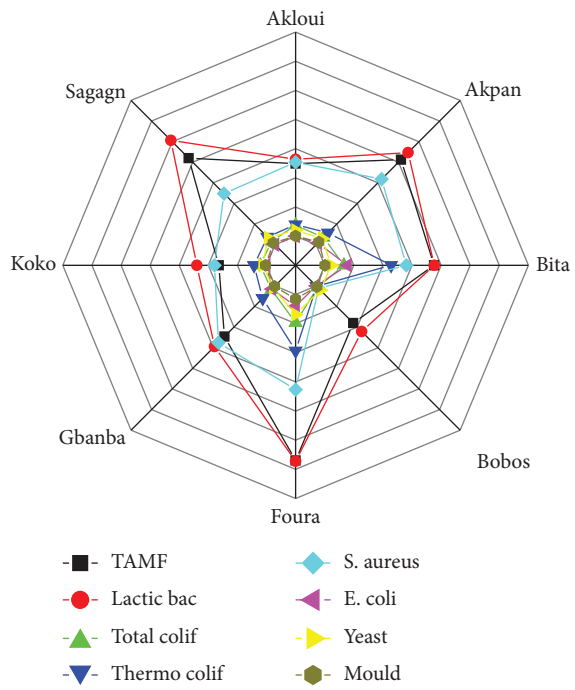

Figure 2: Distribution of microorganisms according to the type of porridge.

koko (27%), apkan (24%), bita (20%), sagagnèga (20%), fourra (17%), and bobossou (2%).

3.1.3. Correlation Matrix of Germs Depending on the Product and Locality. The correlation matrix of microorganisms found in the porridges is shown in Figure 3. This matrix indicates a correlation between different microorganisms. Strong correlations exist between thermotolerant coliforms and *E. coli* (0.95), total mesophilic aerobic flora and lactic acid bacteria (0.97), and total aerobic mesophilic flora and yeast (0.87), which suggests that the population of these microorganisms increases proportionally in the porridges. However, weak correlations are observed between *E. coli* and lactic acid bacteria (0.34), yeast and staphylococci (0.39), yeast and *E. coli* (0.28), mold and thermotolerant coliforms (0.21), and *E. coli* and mold (0).

Based on the visited municipalities, positive and negative correlations were discovered between microorganisms found in the porridges (Figure 4). Specifically, it was observed that strains of *Escherichia coli* have a negative correlation with staphylococci (−0.45) and total coliforms (−0.19). Moreover, molds and yeasts negatively correlate with coliforms and lactic acid bacteria with staphylococci. However, it was also found that yeasts and total coliforms positively correlate with molds and thermotolerant coliforms.

3.1.4. Isolation of Salmonella spp. according to Porridges. According to Table 1, *Salmonella* spp. was isolated from different types of porridge. Koko porridge had the highest percentage of *Salmonella* spp. at 21%, followed by bita and akloui porridge at 19%. Bobossou porridge had the least amount of *Salmonella* spp. at 3%. Fermented porridges had a higher presence of *Salmonella* spp. at 94% than non-fermented porridges at 53%.

3.1.5. Characterization of Porridges. Based on the analysis of the eigenvalues of the correlation matrix (Table 2) and the principal component analysis, it was found that the first two dimensions account for 68.02% of the variability of the microorganisms. This is a significant amount of information, exceeding the 50% threshold, which means that the first three dimensions can be effectively used to interpret the results of the PCA.

Based on Table 3 and Figure 5, the correlation between the three dimensions and initial variables was studied. The variables TMAF, lactic acid bacteria, and thermotolerant coliforms are positively correlated with axis 1, which explains 44.89% of the variability.

Therefore, in the porridges sold in the municipalities of this axis, TMAF, lactic acid bacteria, and thermotolerant coliforms were found simultaneously (Figure 5). Axis 2 explains 23.13% of the variability of microorganisms in the porridges. It is positively correlated with the "total coliform (TC)" variable and "staphylococci (Staph)" and negatively correlated with the "yeast" variable. Axis 2 suggests that the presence of "total coliforms" in the porridges is positively linked to that of "staphylococci." However, the presence of yeasts in the porridges is linked to the absence of total coliforms and staphylococci (Figure 5).

3.1.6. Porridge Typology. Three distinct categories of porridges were identified based on the ascending hierarchical classification dendrogram shown in Figure 6. Each category corresponds to a specific profile of porridges, determined by carefully selected criteria.

Three distinct porridge categories can be identified by analyzing the dendrogram of the ascending hierarchical classification (Figures 6 and 7). Each category corresponds to a specific porridge profile that meets precise and carefully chosen criteria.

There are 25 samples in group 1, which comprise 50% of the porridges. This group is characterized by staphylococci, TMAF, and lactic acid bacteria found in porridges. The porridges representing this group are koko from Djougou, N'Dali, and Ouaké, gbangba from Djougou, and akloui from Ouaké.

There are six porridge samples in group 2, which comprise 12% of the total sample. This group shows a significant association with total and thermotolerant coliforms in porridges. The representative porridges from this group are bita from Kandi and Copargo, apkan from N'Dali, koko from Kandi, and akloui from Parakou.

Out of the 19 participants, 38% belonged to group 3. This group mainly consumes porridge from Djougou, Banikoara, and Copargo communes. Their porridge contains microorganisms such as total aerobic mesophyll flora, lactic acid bacteria, yeasts, thermotolerant coliforms, molds, staphylococci, and *E. coli*. These microorganisms are present in bita

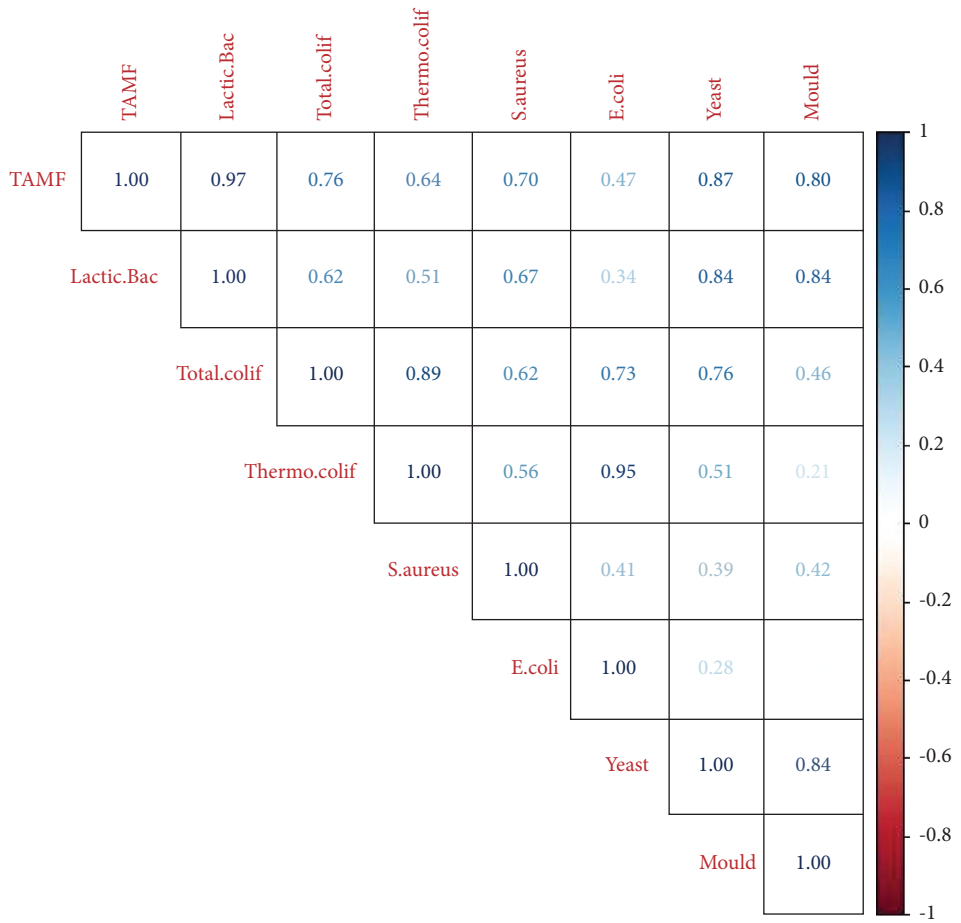

Figure 3: Correlation matrix of bacteria found in the different porridges.

porridge from Djougou, apkan from Banikoara, sagagnèga from Copargo, bita from Banikoara, and apkan from Copargo.

Table 4 shows the different microorganisms present in each group and their specific characteristics. Upon analysis, it was observed that the total mesophyll aerobic flora, lactic acid bacteria, and type 1 thermotolerant coliforms are closely associated with types 2 and 3. However, there is no apparent connection between staphylococci, *E. coli*, and molds. Furthermore, there is a relationship between types 1 and 2 regarding total coliforms, but not with type 3. Regarding yeasts, there is a correlation between types 1 and 2 compared to type 3.

3.2. Physicochemical and Nutritional Parameters of Fermented Porridges. Table 5 displays the physicochemical parameters based on the different types of fermented porridge and shows that the dry matter of the eight different types of porridge ranges from 27.03 ± 3.83 g/100 g for akloui to 48.63 ± 3.83 g/100 g for fourra. In all porridges, the water content is higher than the dry matter. Akloui's dry matter is significantly different from apkan and fourra, but not significantly different from bita, bobossou, gbangba, koko, and sagagnèga ($p < 0.0001$). The total ashes vary from 39.36 ± 4.67 g/100 g for bita to 63.19 ± 4.67 g/100 g for sagagnèga. Sagagnèga, akloui, bobossou, apkan, and fourra porridges have more than 50% ash in the 100 g sample. However, bita, koko, and gbangba have less than 50% ash in the 100 g sample. There is a significant difference between bita and sagagnèga ($p = 0.028$). All fermented porridges have an acidic pH of less than 5, ranging from 3.57 ± 0.09 for apkan to 4.44 ± 0.09 for bita. There is a significant difference ($p = 0.0001$) between akloui and apkan and between apkan and bita, fourra, gbangba, and koko. The titratable acidity ranges from 0.01 ± 0.00 g of lactic acid for akloui, apkan, bita, bobossou, fourra, gbangba, and koko to 0.02 ± 0.00 g of lactic acid for sagagnèga. There is a significant difference between akloui and sagagnèga ($p < 0.0001$), but no difference was observed between the other types of porridge. The brix degree ranges from 0.46 ± 0.54 for akloui to 4.4 ± 0.54 for sagagnèga. A significant difference exists between akloui, fourra, gbangba, and sagagnèga ($p = 0.0001$).

The nutritional parameters for different types of porridge are presented in Table 6. The beta-carotene values vary from 0.037 ± 0.018 mg/g to 0.138 ± 0.018 mg/g among the eight types of porridge. The highest value is for sagagnèga, followed by bobossou, gbangba, and fourra. Akloui has the lowest value. There is a significant difference between akloui, bobossou, and sagagnèga (p value 0.001), but no difference was observed between the other types of porridges. Total sugars range from 1.926 ± 0.877

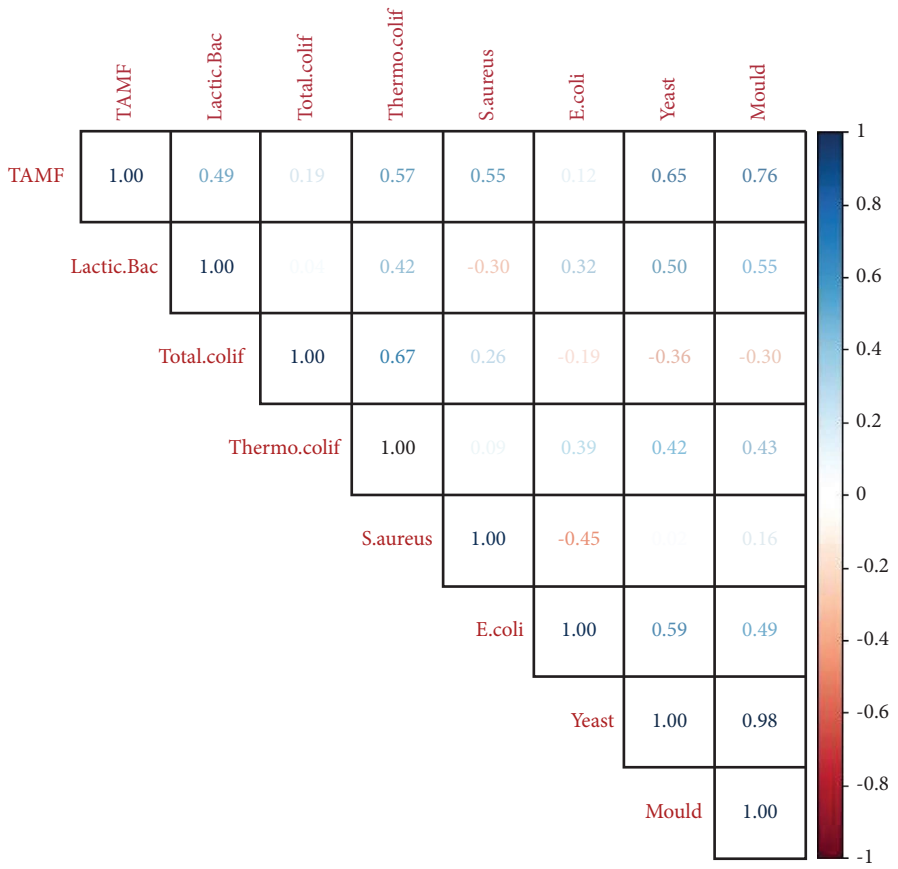

Figure 4: Correlation matrix of germs in the different municipalities visited.

Table 1: Isolation of *Salmonella* spp. according to the porridges.

Porridges	*Salmonella* spp.		Total	X^2	P value
	Presence	Absence			
Koko	21 (22.30)	6 (11.30)	27 (18.40)	14.929739	0.037
Fourra	8 (8.50)	10 (18.90)	18 (12.20)		
Bobossou	3 (3.20)	6 (11.30)	9 (6.10)		
Bita	19 (20.20)	5 (9.40)	24 (16.30)		
Sagagnega	6 (6.40)	6 (11.30)	12 (8.20)		
Apkan	9 (9.60)	9 (17)	18 (12.20)		
Akloui	19 (20.20)	8 (15.10)	27 (18.40)		
Gbangba	9 (9.60)	3 (5.70)	12 (8.20)		
Total	94 (100)	53 (100)	147 (100)		

Table 2: Evolution of the cumulative percentage of explained variance according to the first 6 factorial axes.

	Dim.1	Dim.2	Dim.3	Dim.4	Dim.5	Dim.6
Variance	2.693	1.388	0.811	0.589	0.313	0.206
% of variance	44.885	23.135	13.513	9.824	5.214	3.429
Cumulative % of the variance	44.885	68.020	81.533	91.357	96.571	100.000

to 5.773 ± 0.877 g/100 g, with bobossou having the highest value, followed by sagagnèga and gbangba. Akloui has the lowest value. Presently, the lipid content of the porridges varies from $0.226 \pm 0.029\%$ for fourra to $0.408 \pm 0.029\%$ for bita. The protein percentage ranges from 7.061 ± 0.779 to 12.419 ± 0.779. Gbangba has the highest protein value, followed by bita, bobossou, and akloui. The smallest value is observed in apkan. A significant difference exists between apkan, bita, bobossou, and gbangba porridges ($p < 0.0001$).

Table 3: Correlation between the starting variables and the factorial axes.

Variables	Dim.1	ctr	cos2	Dim.2	ctr	cos2	Dim.3	ctr	cos2
TMAF	0.851	26.873	0.724	−0.032	0.074	0.001	0.163	3.274	0.027
Lactic acid bacteria	0.698	18.102	0.488	−0.440	13.922	0.193	−0.269	8.911	0.072
Total coliform	0.511	9.688	0.261	0.560	22.619	0.314	−0.586	42.387	0.344
Thermotolerant coliforms	0.855	27.126	0.731	0.130	1.220	0.017	−0.029	0.102	0.001
S. aureus	0.438	7.120	0.192	0.665	31.862	0.442	0.559	38.519	0.312
Yeast	0.547	11.090	0.299	−0.649	30.303	0.421	0.235	6.807	0.055

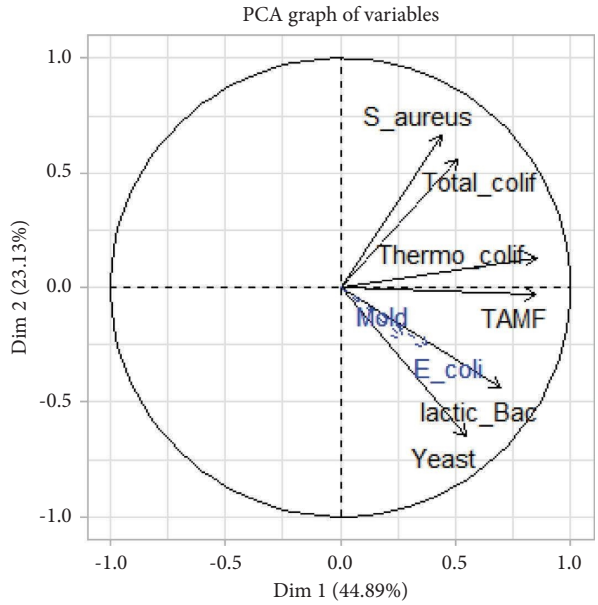

Figure 5: Correlation circle of principal component analysis variables.

3.3. Distribution of Microorganisms in Different Porridges. Three different colors represent three groups of interactions. The size of each group represents its importance. At the same time, the thickness of the line indicates the strength of the connection between the different groups. Bobossou is the least encountered porridge, and *E. coli* is the least identified bacterium in porridge. The most robust links are "TMAF" followed by "lactic acid bacteria," "yeast," "*S. aureus,*" and "*Salmonella* spp.," respectively (Figure 8).

4. Discussion

This study focuses on fermented cereal-based porridges produced and consumed in northern Benin. The study includes microbiological, physicochemical, and nutritional analyses. The results indicate a significant variation in the microbial composition and porridge characteristics across different communes. The porridges in Matéri have the highest proportion of lactic acid bacteria, followed by Cobly. Bobossou's fermented porridge has many lactic acid bacteria, followed by sagagnèga and koko. These porridges are recommended for consumption. However, porridges in Djougou and Ouaké (porridge bita, fourra, and apkan) are heavily contaminated by *Escherichia coli*. This is due to manual handling and the use of raw water after cooking. The fourra is left in the open air for preservation, diluted by hand, and mainly consumed without reheating, which increases the risk of contamination. The staphylococcal contamination of gbangba, akloui, koko, apkan, bita, sagagnèga, fourra, and bobossou porridges shows that although desirable microorganisms such as lactic acid bacteria are present, there are also potentially pathogenic microorganisms. This could be due to producers' lack of knowledge of HACCP, especially after cooking the porridge. In addition, lactic acid bacteria dominate fermented porridges in northern Benin with an average load of 6.7309 log CFU/g/ml, followed by total aerobic mesophilic flora with an average load of 6.7, and yeasts and molds with an average load of 7.9771. These microorganisms are responsible for the fermentation process of the porridges. According to Kagambega et al. [17], fermented cereal-based foods frequently contain lactic acid bacteria, yeasts, molds, and some *Bacillus* and *Escherichia coli* species. Lactic acid bacteria and yeasts are generally the predominant microorganisms found in most fermented products from cereals and cassava in West Africa, as proven by studies conducted by N'Tcha et al. [18]. The development of lactic acid bacteria is accompanied by the development of yeasts, which results from a symbiotic relationship between the two microorganisms. Recent studies conducted by Ponomarova et al. [19] have shown that yeasts allow the development of lactic acid bacteria through endogenous cross-feeding, resulting in a quickly

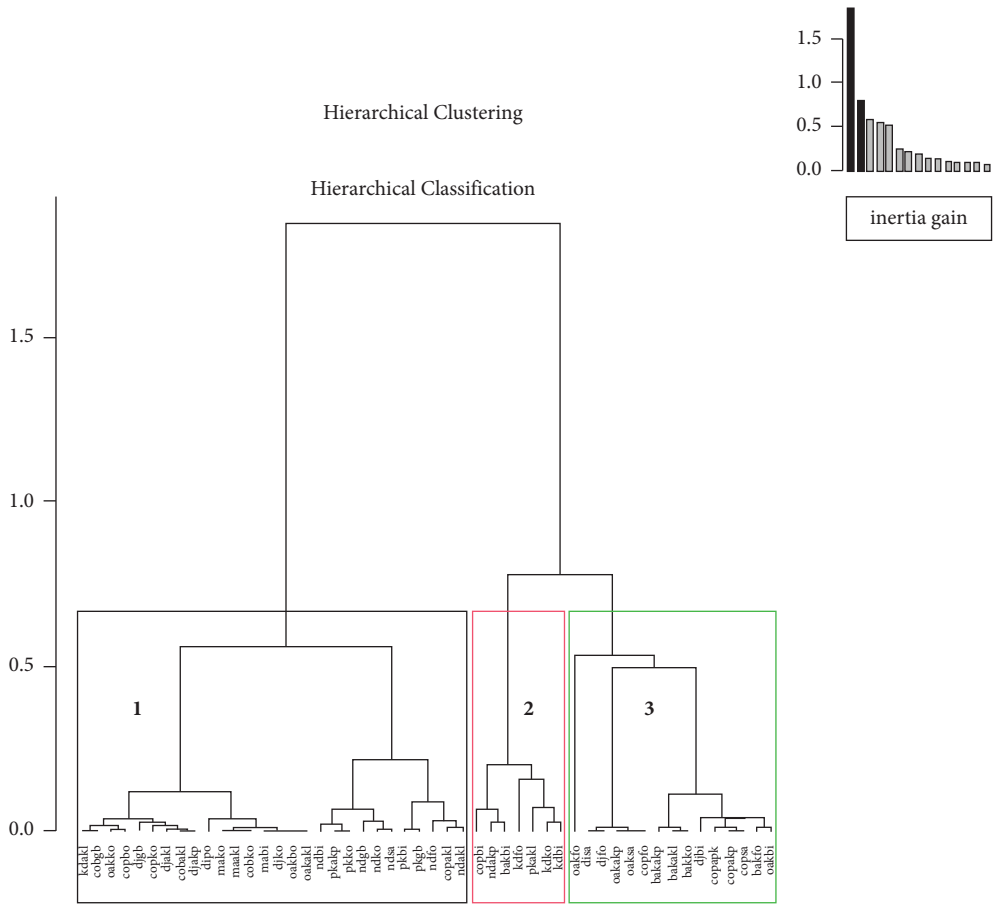

Figure 6: Hierarchical classification dendrogram of vendor categorization.

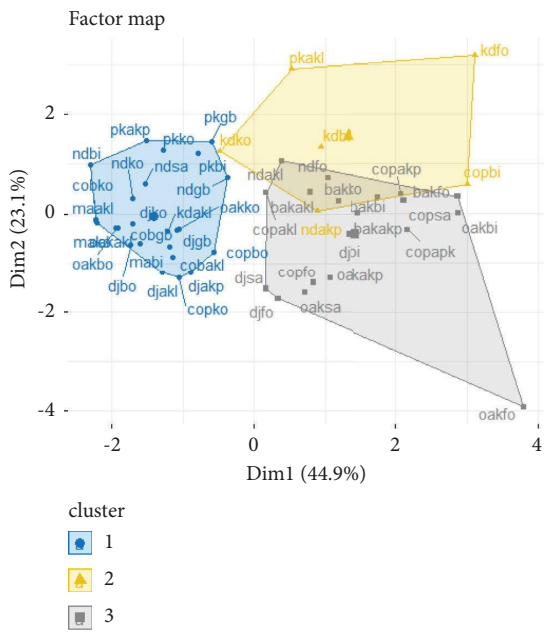

Figure 7: Grouping of saleswomen with the two axes.

Table 4: Microbiological characteristics of each group.

Cluster	Type 1 (50%)	Type 2 (12%)	Type 3 (38%)
TMAF	6.90 ± 0.06a	7.27 ± 0.10b	7.43 ± 0.02b
Lactic acid bacteria	6.98 ± 0.09a	7.23 ± 0.12ab	7.40 ± 0.03b
Total coliforms	4 ± 0.40a	7.06 ± 0.06b	5.67 ± 0.36a
Thermotolerant coliforms	3.04 ± 0.56a	7.10 ± 0.10b	6.24 ± 0.51b
S. aureus	6.02 ± 0.23a	7.07 ± 0.14a	6.95 ± 0.18a
Yeast	5.67 ± 0.09a	5.58 ± 0.15a	6.30 ± 0.08b
E. coli	1.03 ± 0.43a	2.86 ± 1.30a	3.73 ± 0.61a
Mold	4.09 ± 0.30a	4.89 ± 0.16a	3.99 ± 0.59a

The different letters a, b, and c present on the means of the same line indicate that these means are significantly different ($p < 0.5\%$).

Table 5: Physicochemical parameters according to the types of porridge.

Porridge	Akloui	Apkan	Bita	Bobossou	Fourra	Gbangba	Koko	Sagagnèga	SEM	p value
Dry matter	27.49a	46.86bc	27.03a	30.10ab	48.63c	34.21abc	30.86ab	33.64abc	3.83	0.0001
Total ash	55.46ab	54.84ab	39.36a	55.04ab	50.60ab	46.95ab	47.50ab	63.19b	4.67	0.028
pH	4.21b	3.57a	4.44b	3.98ab	4.33b	4.29b	4.34b	4.04ab	0.09	0.0001
Titratable acidity	0.01a	0.01ab	0.01a	0.01a	0.01ab	0.01a	0.01a	0.02b	0.00	0.0001
Brix degree	0.46a	1.65ab	2.00abc	1.73ab	3.97bc	3.85bc	1.01a	4.43c	0.54	0.0001

The letters a, b, and c on the means of the same line indicate that these means are significantly different. SEM, standard error of the mean.

Table 6: Nutritional parameters according to the types of porridge.

Porridge	Beta-carotene	Total sugars	Lipid content	Protein
Akloui	0.037a	1.926a	0.322	10.168ab
Apkan	0.045ab	3.096ab	0.269	7.061a
Bita	0.042a	2.535ab	0.408	12.419b
Bobossou	0.126bc	5.773b	0.308	11.051ab
Fourra	0.061ab	4.745ab	0.226	8.049a
Gbangba	0.062ab	5.074ab	0.265	12.812b
Koko	0.041a	2.005a	0.251	9.411ab
Sagagnèga	0.138c	5.700ab	0.235	9.469ab
SEM	0.018	0.877	0.029	0.779
P value	0.001	0.001	0.054	0.0001

The letters a, b, and c on the means of the same line indicate that these means are significantly different. SEM, standard error of the mean.

established community. Lactic acid bacteria (LAB) mainly perform lactic acid fermentation, which is essential for the preservation and safety of fermented foods, as proven by Awobusuyi et al. [20]. These microbes can produce and respond to neurochemicals, which are potentially helpful in treating anxiety and depressive disorders [21]. Thus, consuming fermented cereal-based porridges can positively impact the oral microbiota by lowering the pH and producing antioxidants that inhibit plaque growth, thereby reducing the risk of gum disease, tooth decay, and oral inflammation. Fermented products can also treat halitosis, metabolizing volatile sulfur compounds that cause unpleasant mouth odor [22, 23]. According to N'Tcha et al. [18], the presence of LAB in a medium creates an acidic environment that promotes the growth of yeasts, which produce vitamins and other compounds favorable for the proliferation of yeasts and bacteria. This acidity also inhibits the proliferation of pathogenic microorganisms, such as *E. coli*, which are absent in some collected porridges.

This study found a strong correlation between thermotolerant coliforms and *E. coli* ($r = 0.95$), as well as between total mesophyll aerobic flora and lactic acid bacteria ($r = 0.97$) and between total mesophyll aerobic flora and yeast ($r = 0.87$). However, there was a weak correlation between *E. coli* and lactic acid bacteria ($r = 0.34$), yeast and staphylococci ($r = 0.39$), yeast and *E. coli* ($r = 0.28$), mold and thermotolerant coliforms ($r = 0.21$), and *E. coli* and mold ($r = 0$).

It has been observed that certain strains of *Escherichia coli* have a negative correlation with staphylococci ($r = -0.45$) and total coliforms ($r = -0.19$). In addition, molds and yeasts are also negatively correlated with strains of total coliforms and lactic acid bacteria with staphylococci. This implies that the growth of one of these microorganisms can hinder or eliminate the growth of the other. However, yeasts and total coliforms positively correlate with molds and thermotolerant coliforms. Total coliforms and thermotolerant coliforms in food indicate fecal contamination [24]. This study found total and thermotolerant coliforms in

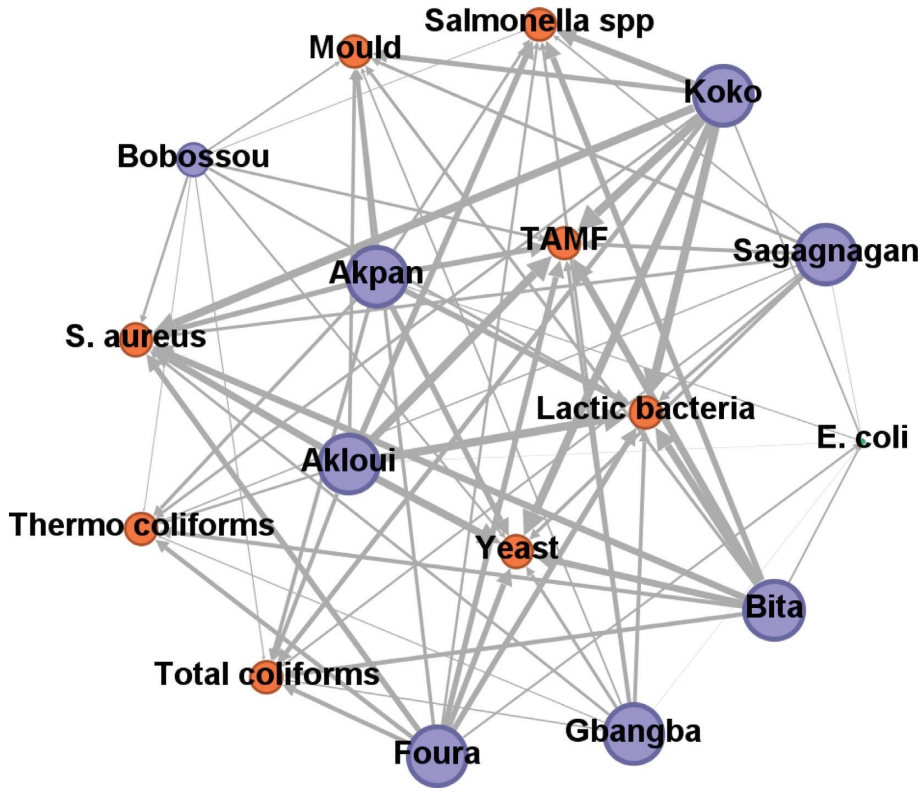

Figure 8: Network visualization of isolated microorganisms in the different porridge models.

fermented porridges, which suggests potential contamination by pathogenic *E. coli*. This is supported by the correlation between thermotolerant coliforms, *E. coli*, and total coliforms.

Koko porridge has the highest percentage of *Salmonella* spp. at 22.3%, followed by bita and akloui porridge at 20.2%. Conversely, bobossou porridge has the lowest amount of *Salmonella* spp. at only 3.2%. Most porridge samples (94%) were contaminated with *Enterobacteriaceae*, compared to only 54% of the porridges. The primary source of contamination may be unclean water used for washing dishes, utensils, and hands.

It is important to note that TMAF is an indicator of food quality, not safety, and cannot directly contribute to food safety assessment. However, it can give helpful information about the remaining shelf life of foods. In addition, the presence of *Enterobacteriaceae* in ready-to-eat prepared foods may be due to the safety of the environment in which the food is served. These findings align with the research conducted in Ethiopia by Bolaji et al. [25] on ready-to-eat foods contaminated with microorganisms such as *Salmonella* spp. and *E. coli*.

Staphylococci in the porridge indicate that humans have contaminated it. This contamination may be due to poor hygiene practices during production or consumption. In addition, concerns about the quality of the raw material should also not be neglected. Indeed, contaminated raw materials will not produce a safe product, especially fermented ones, without heat treatment. Hence, to minimize contamination, it is necessary to ensure appropriate harvesting dates, pay attention to the weather during harvesting, and reject batches of raw material whose visual quality deviates from the expected. The present research found staphylococci in all fermented tested porridges. This is likely due to the salespeople not wearing nose masks and gloves while handling the products. Through principal component analysis, fermented porridges could be grouped based on similarity. Three large groups could be observed: group 1 comprised of 50% of the porridge, group 2 comprised of 38% of the porridge, and group 3 comprised of 12% of the porridge. These findings differ from a study performed by N'Tcha et al. [18] on kpètè-kpètè, a traditional beer fermented in Benin. The variation in parameters measured from municipality and producer to producer explains the significant difference in groupings. Therefore, it is essential to define parameters to ensure the quality of fermented porridges for consumers.

The eight types of porridge have varying physicochemical and nutritional parameters. Dry matter, for instance, ranges from 27.03 ± 3.83 g/100 g for akloui to 48.63 ± 3.83 g/100 g for fourra. All porridges have higher water content than dry matter. Akloui's dry matter significantly differs from apkan and fourra, but not from bita, bobossou, gbangba, koko, and sagagnèga ($p = 0.0001$). These results are better than those of Kagambèga et al. [17], who found traditional porridge dry matter values to be between 7 and 10 g/100 g and added sugar to increase values.

Total ashes ranged from 39.36 ± 4.67 g/100 g for bita to 63.19 ± 4.67 g/100 g for sagagnèga. Sagagnèga, akloui,

bobossou, apkan, and fourra have over 50% ash in the 100 g sample, while bita, koko, and gbangba have less than 50%. The obtained results are higher than those of *Fatoumata* et al. [26], who found 2.81 ± 0.06 to 4.93 ± 0.08% ash in soumbala of soya sold in Côte d'Ivoire. The difference in raw materials used could explain this variation.

The pH of all fermented porridges is below 5. The pH varies from 3.57 ± 0.09 for apkan to 4.44 ± 0.09 for bita. So, all porridges have an acidic pH. A significant difference ($p = 0.0001$) exists between akloui and apkan and apkan and bita, fourra, gbangba, and koko. The recorded results are superior to those obtained by Coulibaly et al. [27]. Several authors [28, 29] believe that fermentation by lowering the pH of products to values below 4.0 limits the development of *Enterobacteriaceae* and other Gram-negative bacteria. The titratable acidity at akloui, apkan, bita, bobossou, fourra, gbangba, and koko is 0.01 ± 0.00% lactic acid and at sagagnèga is 0.02 ± 0.00% lactic acid. A significant difference exists between akloui and sagagnèga ($p = 0.0001$). On the other hand, no difference was observed among the other types of porridge. The results of this study are, on the other hand, lower than the 0.495 ± 0.01–0.405 ± 0.01% obtained by Coulibaly et al. [27] on the identification of non-Saccharomyces yeast strains isolated from traditional beer in the district of Abidjan (Côte d'Ivoire) and their ability to carry out alcoholic fermentation. The brix degree values vary between 0.46 ± 0.54 for akloui to 4.4 ± 0.54 for sagagnèga. A significant difference exists between akloui, fourra, gbangba, and sagagnèga ($p = 0.0001$). At this level, the results are much lower than the 11.7 ± 0.14°brix obtained by the authors in [25].

The beta-carotene values of the eight types of porridge vary from 0.037 ± 0.018 mg/g to 0.138 ± 0.018 mg/g. Sagagnèga has the greatest value, followed by bobossou, gbangba, and fourra. Total sugars vary from 1.926 ± 0.877 to 5.773 ± 0.877 g/100 g, with bobossou porridge having the highest value, followed by sagagnèga and gbangba. The lowest value was observed for akloui porridge. These values are much lower than those of Amoin et al. [30] on germinated and fermented compound flour (69.20 ± 0.8% and 67.80 ± 0.3%). This could be explained by these flours made from germinated and fermented cereals.

The protein levels (7.061 ± 0.779 and 12.419 ± 0.779%) found in the analyzed samples are much lower than those (33 ± 2.4 to 34.6 ± 2.6%) reported by *Fatoumata* et al. [26] in their study of fermented *Hibiscus sabdariffa* L. seeds, a condiment commonly used in West Africa. This difference in protein content could be attributed to the variation in raw materials and the lower dry matter content of the porridge-tested samples. Nonetheless, the protein levels are significantly higher than the reported 6.74 g/100 g DM and 2.34 g/100 g DM found in sorghum porridge [17]. Kagambèga et al. [17] also noted that traditional porridges usually contain less than 2.6 g/100 g DM of protein and less than 0.8 g/100 g DM of lipids. In comparison, the lipid content of the eight types of porridge tested in this study (ranging from 0.226 ± 0.029% to 0.408 ± 0.029% in fourra) is lower than that found in traditional porridge, as reported by Kagambèga et al. [17] in their study.

5. Conclusion

The porridge also contained beneficial microorganisms such as lactic acid bacteria, yeasts, and molds responsible for their fermentation and total mesophyll aerobic flora. Fermentation processes that involve various microorganisms have many benefits. However, if good production practices are not followed, there may be a risk of microbiological contamination in cereal-based porridge. Unfortunately, our research found potentially harmful microorganisms such as *Escherichia coli*, staphylococci, and *Salmonella* spp. in such porridges. This means that consuming such porridge can lead to food-borne infections. Therefore, it is crucial to inform food handlers about the risks associated with consuming contaminated food, including fungi, bacteria, and the toxins they can produce. This will make individual producers want to pay more attention to the sanitary safety of their food.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] P. G. Johansen, J. Owusu-Kwarteng, C. Parkouda, S. W. Padonou, and L. Jespersen, "Occurrence and importance of yeasts in indigenous fermented food and beverages produced in sub-saharan Africa," *Frontiers in Microbiology*, vol. 10, p. 1789, 2019.

[2] D. A. Kitessa, K. Bacha, Y. B. Tola, M. Murimi, S. Gershe, and M. Guta, "Microbial quality and growth dynamics in shameta: a traditional Ethiopian cereal-based fermented porridge," *Fermentation*, vol. 8, no. 3, pp. 124–2022, 2022.

[3] R. Karimou, H. Sina, B. Boya et al., "Capitalization of endogenous technologies for processing cereals-based fermented porridges in Northern Benin," *American Journal of Food Technology*, vol. 18, no. 1, pp. 37–44, 2023.

[4] K. Skowron, A. Budzyńska, K. Grudlewska-Buda et al., "Two faces of fermented foods-the benefits and threats of its consumption," *Frontiers in Microbiology*, vol. 13, Article ID 845166, 2022.

[5] S. Phiri, S. E. Schoustra, J. van den Heuvel, E. J. Smid, J. Shindano, and A. Linnemann, "Fermented cereal based Munkoyo beverage: processing practices, microbial diversity, and aroma compounds," *Public Library of Science One*, vol. 14, no. 10, Article ID e0223501, 2019.

[6] Y. Chen, F. Qin, and M. Dong, "Dynamic changes in microbial communities and physicochemical characteristics during fermentation of non-post fermented shuidouchi," *Frontiers in Nutrition*, vol. 9, Article ID 926637, 2022.

[7] C. Zhang, M. Derrien, F. Levenez et al., "Ecological robustness of the gut microbiota in response to ingestion of transient food-borne microbes," *The International School of Management Excellence Journal*, vol. 10, no. 9, pp. 2235–2245, 2016.

[8] L. Y Waré, A. P Nikièma, J. C Meile et al., "Microbiological safety of flours used in follow up for infant formulas produced

in Ouagadougou, Burkina Faso," *Agriculture Information Management System Microbiology*, vol. 4, no. 2, pp. 347–361, 2018.

[9] N. Bassimbaye, A. Tidjani, K. Gamougame et al., "Gastro-enterites en milieux des réfugiés au Tchad," *International Journal of Brain and Cognitive Sciences*, vol. 7, no. 2, pp. 468–478, 2013.

[10] A. C. Baird-Parker, "Foodborne salmonellosis," *The Lancet*, vol. 336, no. 8725, pp. 1231–1235, 1990.

[11] N. Dennaï, B. Kharrati, and M. El Yachioui, "Appréciation de la qualité microbiologique des carcasses de bovins fraîchement abattus," *Annales de Médecine Vétérinaire*, vol. 145, pp. 270–274, 2001.

[12] K. A. Mooijman, "The new ISO 6579-1: a real horizontal standard for detection of *Salmonella*, at last," *Food Microbiology*, vol. 71, pp. 2–7, 2018.

[13] M. R. Nout, F. M. Rombouts, and A. Havelaar, "Effect of accelerated natural lactic fermentation of infant good ingredients on some pathogenic microorganisms," *International Journal of Food Microbiology*, vol. 8, no. 4, pp. 351–361, 1989.

[14] Aacc, *American Association of Cereal Chemists Approved Methods*, AACC, Saint Paul, MN, USA, 1983.

[15] Aoac Association of Official Analytical Chemists, *Methods of Analysis for Nutrition Labeling*, AOAC, Airlington, TX, USA, 1993.

[16] R Core Team A, *Language and Environment for Statistical Computing*, R Foundation for Statistical Computing, Vienna, Austria, 2021.

[17] B. Kagambèga, H. Cissé, F. Tapsoba et al., "Bouillies fermentées traditionnelles à base de céréales au Burkina Faso: diversité, technologies de production et microorganismes à potentiel probiotique associés," *Revue des Sciences et de la Technologie*, vol. 25, no. 2, pp. 12–24, 2019.

[18] C. N'tcha, G. Vieira-Dalodé, A. P. Kayodé et al., "Caractérisation physico-chimique et microbiologique du « kpètè-kpètè » un ferment des bières traditionnelles produites au Bénin," *Annales des Sciences Agronomiques (ASA) du Bénin*, vol. 19, no. 2, pp. 69–88, 2015.

[19] O. Ponomarova, N. Gabrielli, D. C. Sévin et al., "Yeast creates a niche for symbiotic lactic acid bacteria through nitrogen overflow," *Cell Systems*, vol. 5, no. 4, pp. 345–357.e6, 2017.

[20] T. D. Awobusuyi, M. Siwela, U. Kolanisi, and E. O. Amonsou, "Provitamin A retention and sensory acceptability of amahewu, a non-alcoholic cereal-based beverage made with provitamin A-biofortified maize," *Journal of the Science of Food and Agriculture*, vol. 96, no. 4, pp. 1356–1361, 2016.

[21] A. R. Romijn, J. J. Rucklidge, R. G. Kuijer, and C. Frampton, "A double-blind, randomized, placebo-controlled trial of Lactobacillus helveticus and Bifidobacterium longum for the symptoms of depression," *Australian and New Zealand Journal of Psychiatry*, vol. 51, no. 8, pp. 810–821, 2017.

[22] O. E. Gungor, Z. Kirzioglu, and M. Kivanc, "Probiotics: can they be used to improve oral health?" *Beneficial Microbes*, vol. 6, no. 5, pp. 647–656, 2015.

[23] C. Voidarou, M. Antoniadou, G. Rozos et al., "Fermentative foods: microbiology, biochemistry, potential human health benefits and public health issues," *Foods*, vol. 10, no. 1, p. 69, 2020.

[24] M. Jobo, G. H. Yoon, S. N. Ogden et al., "Health system strengthening using problem solving for better health in Lesotho," *Research Square*, pp. 1–15, 2021.

[25] O. T. Bolaji, P. A. Adepoju, and A. P. Olalusi, "Economic implication of industrialization of a popular weaning food ogi production in Nigeria: a review," *African Journal of Food Science*, vol. 9, no. 10, pp. 495–503, 2015.

[26] C. Fatoumata, S. Soronikpoho, T. P. Souleymane, B. Kouakou, and D. K. Marcellin, "Caractéristiques biochimiques et microbiologiques de moutardes africaines produites à base de graines fermentées de *Parkia biglobosa* et de *Glycine max*, vendues en Côte d'Ivoire," *International Journal of Brain and Cognitive Sciences*, vol. 10, no. 2, pp. 506–518, 2016.

[27] W. H. Coulibaly, Z. B. Boli, K. M. Bouatenin, A. M. M'bra, S. H. Kouhounde, and K. M. Djè, "Identification of non-Saccharomyces yeast strains isolated from local traditional sorghum beer produced in Abidjan district (Côte d'Ivoire) and their ability to carry out alcoholic fermentation," *Bone Marrow Concentrate Microbiology*, vol. 22, no. 1, pp. 165–212, 2022.

[28] C. M. Muyanja, T. Langsrud, and J. A. Narvhus, "The use of starter cultures in the fermentation of bushera: a Ugandan traditional fermented sorghum beverage," *Uganda Journal of Agricultural Sciences*, vol. 9, no. 1, pp. 606–616, 2004.

[29] O. B. Oyewole, "Lactic fermented foods in Africa and their benefits," *Food Control*, vol. 8, no. 5-6, pp. 289–297, 1997.

[30] A. Amoin, E. Agbo, A. G. Dago, A. Gbogouri, D. Brou, and G. Dago, "Comparaison des caractéristiques nutritionnelles et rhéologiques des bouillies infantiles préparées par les techniques de germination et de fermentation," *International Journal of Brain and Cognitive Sciences*, vol. 9, no. 2, pp. 944–953, 2015.