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Effect of pH and Duration of Fermentation on the Sensory, Physicochemical and Proximate Characteristics of Garri

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ABSTRACT

Background and Objective: The fermentation process in garri production is influenced by various factors, including pH and duration. This study investigates the influence of fermentation duration on the physicochemical properties of cassava garri, focusing on pH variations and proximate composition changes. **Materials and Methods:** Cassava root mash fermentation was carried out for 0, 24, 48, 72 and 96 hrs and the pH of the resulting garri samples was measured. Proximate, physicochemical and sensory analyses were conducted to assess moisture content, ash content, crude fat, crude fiber, crude protein, carbohydrate content, swelling index, total titratable acidity (TTA), color, aroma and texture of the garri samples. **Results:** This revealed a progressive decrease in pH as fermentation time increases, with significant differences observed between garri samples at various fermentation durations. Proximate analysis indicates fluctuations in moisture content, ash content, crude fat, crude fiber, crude protein and carbohydrate content, over the fermentation period. Physicochemical parameters such as swelling index and TTA exhibit dynamic changes with fermentation duration. Sensory evaluation demonstrates alterations in color, aroma and texture of garri samples as fermentation progresses. Distinct characteristics are observed between white cassava garri (WG) and red cassava garri (RG) throughout the fermentation period. **Conclusion:** Overall, these findings underscore the significant impact of fermentation duration on the quality attributes of cassava garri. Optimizing fermentation conditions could lead to the production of garri with desirable characteristics, thus enhancing its nutritional value and consumer acceptance. Further research is warranted to elucidate the health implications and nutritional benefits associated with fermented cassava products.

KEYWORDS

Fermentation, physicochemical properties, cassava pulp, sensory properties, proximate characteristics, garri

INTRODUCTION

Cassava roots are highly perishable and must be processed shortly after harvest to prevent spoilage. Various methods, including drying, are employed globally to extend shelf life and reduce toxicity. Fermentation, integral to many processing techniques, enhances preservation and imparts unique qualities to the final product[1-5]. This traditional food processing method, practiced for centuries, relies on enzymes

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from microorganisms to alter food composition. While, fermentation improves flavor and texture, it can also lead to undesirable changes and spoilage. In the case of cassava, fermentation softens the roots, facilitating the breakdown of cyanogenic glucosides, thereby reducing toxicity[6-10].

Garri, a popular cassava product in Nigeria and West Africa, undergoes fermentation as part of its production process. The duration of fermentation influences garri's taste, pH and toxicity. Optimal fermentation time is crucial for detoxification and flavor development. Accelerating fermentation is necessary to meet the increasing demand for quality garri in developing countries[11-14]. Garri, a staple food in many West African countries, is a granular product derived from fermented cassava roots. It holds significant cultural, economic and nutritional importance in the region, serving as a major source of carbohydrates and contributing to food security for millions of people. The production of garri involves several traditional processing steps, including fermentation, which plays a crucial role in determining its sensory, physicochemical and proximate characteristics[15-17].

The fermentation process in garri production is influenced by various factors, including pH and duration. These factors can significantly impact the final quality of the product, affecting its flavor, texture, nutritional composition and safety. Understanding the effect of pH and fermentation duration on garri is essential for optimizing its production process, enhancing its sensory appeal and ensuring its nutritional value[18-21].

The pH, a measure of the acidity or alkalinity of a solution, is a critical parameter in fermentation processes. It affects the activity of microorganisms involved in fermentation and the biochemical reactions that occur during the process. In garri production, pH influences the growth of fermentative microorganisms, enzymatic activities and chemical reactions, thereby influencing the flavor development, detoxification of cyanogenic compounds and overall quality of the final product[22,23]. The pH of the fermentation medium can vary depending on factors such as the type of cassava variety used, processing methods and environmental conditions.

Duration of fermentation is another key factor that significantly impacts the sensory and physicochemical characteristics of garri. The length of fermentation determines the extent of enzymatic and microbial activity, which affects the breakdown of starch, reduction of cyanogenic compounds, production of volatile compounds and development of desirable flavor and aroma compounds. Shorter fermentation times may result in incomplete detoxification of cyanogenic compounds, while prolonged fermentation may lead to over-fermentation, producing undesirable flavors and textures in the final product[24,25].

Several studies have investigated the effect of pH and fermentation duration on the quality of garri, focusing on sensory attributes, chemical composition, microbial activity and safety parameters. However, there is still a need for comprehensive research to elucidate the complex interactions between these factors and their impact on garri quality[25,26]. This study aims to address this gap by systematically evaluating the effect of pH and fermentation duration on the sensory, physicochemical and proximate characteristics of garri.

By gaining a deeper understanding of how pH and fermentation duration influence garri quality, producers can optimize production processes, improve product consistency and meet consumer preferences. Furthermore, insights from this study can inform food safety and quality regulations, ensuring the production of safe and nutritious garri for consumption. Overall, this research contributes to the sustainable development of the garri industry, supporting food security and economic growth in West Africa.

MATERIALS AND METHODS

Study area and sites: Benin City, located in Edo State, Nigeria, is a significant urban center. Positioned at approximately 6.34°N Latitude and 5.63°E Longitude, it stands at an elevation of 88 m above sea

level. With an estimated population of 1,125,058, Benin City is the most densely populated city in Edo State[26,27].

Cassava roots procurement: A total of 20 kg of cassava tubers and aged over twelve months, specifically from the TMS 30572 cultivar, were harvested from the Crop Science Departmental farm within the Faculty of Agriculture at the University of Benin, Nigeria. This study spanned from April, 2014 to August, 2015. These freshly harvested roots were promptly employed in the production process of garri.

pH adjustment: A digital pH meter was utilized to adjust the pH of the cassava mash to 5, 7 and 9 using 0.1M sodium carbonate (Na_2CO_3) and 0.1M orthophosphoric acid. These reagents were selected for the pH adjustment process[17,27].

Tools and equipment manufacturers: The digital pH meter and other tools and equipment used in this study were procured from manufacturers including Hanna Instruments (Woonsocket, Rhode Island, USA), Thermo Fisher Scientific (Waltham, Massachusetts, USA) and Mettler Toledo (Columbus, Ohio, USA), among others[28].

Method of garri production: Garri preparation followed the procedure outlined by Ozoh *et al*.[17]. The freshly harvested cassava roots underwent initial processing steps: peeling, washing under running tap water and grating using commercial mechanical graters. The resulting grated pulp, or mash, was divided into five equal portions, each weighing 250 g. The first portion served as the control (WG) without any additives. Palm oil was incorporated into the second portion (RG) at a concentration of 10 mg/g and thoroughly mixed. The pH of the third (G5), fourth (G7) and fifth (G9) portions was adjusted to 5, 7 and 9, respectively, using 0.1M sodium carbonate (Na_2CO_3) and 0.1M orthophosphoric acid. Subsequently, each portion was placed in woven polypropylene sacks for fermentation. Fermentation took place over periods of 0, 24, 48, 72 and 96 hrs using the indigenous microflora present at ambient temperature. Samples were periodically collected from each mash during fermentation to monitor pH levels. Following fermentation, the mashes were sifted to remove larger fiber chunks. The fermented mash was then roasted in an open pan greased with palm kernel oil, continuously stirred using a broken piece of calabash. After roasting, the granules, now garri, were sieved with a mesh size of 2 mm, packed into woven polypropylene sacks and labeled accordingly (RG, WG, G5, G7 and G9) for subsequent analysis. Samples were collected daily from each mash throughout the four-day fermentation period, sieved, fried and subjected to analysis[17,27].

Analysis of fermentation rates: Uniform conditions were maintained across all five cassava samples and the fermentation progress of each was assessed by daily measurement of the pH decrease in each sample[17,27].

Evaluation of garri samples using sensory analysis: For practicality, panelists were recruited from the university environment to participate in the evaluation process. The panel consisted of 15 individuals, comprised of both untrained individuals familiar with garri and 400-level chemistry students. These panelists were tasked with assessing various attributes of the garri samples, including aroma, color, particle size, texture and overall acceptability. Each attribute was rated on a hedonic scale ranging from 1 to 5, where 1 represented "very poor", 2 denoted "poor", 3 indicated "average", 4 signified "good" and 5 represented "very good". During the evaluation, 20 g samples of each garri variant were presented in cups as dry granules. The assessment process involved the following steps:

- **Color assessment:** Panelists visually inspected the color of each sample
- **Aroma evaluation:** Panelists smelled each sample multiple times to assess its aroma

Particle size and texture analysis: Particle size distribution of the garri samples was determined using sieves with openings of 1.70 mm. Texture assessment involved touching and feeling the samples with hands. The data collected from the hedonic scale ratings were subjected to statistical analysis using One-way Analysis of Variance (ANOVA) to determine any significant differences among the samples. The significance level for the results is ($p<0.05$)[17,27].

pH determination: In each experiment, precisely 10 g of every sample were measured and placed into separate 200 mL beakers. Subsequently, 100 mL of distilled water was added to each beaker. The pH of the resulting solutions was then determined using a calibrated pH meter. To ensure accuracy, three readings were taken for each sample and the average of these readings was recorded as the final pH value[17,27].

Total titratable acidity (TTA): The percentage of titratable acidity was determined following the method described by Omenai *et al.*[27]. Initially, 5 g of the sample were dissolved in a beaker and diluted to 100 mL with distilled water. After standing for 30 min, the solution was filtered using Whatman filter paper. Subsequently, 25 mL of the filtrate was titrated against 0.1 M NaOH, with phenolphthalein used as the indicator. The titration endpoint was reached when the solution turned colorless. Triplicate measurements were conducted for each sample and the average titratable acidity (TTA) value was calculated from these determinations[27].

Swelling index: The swelling index was assessed with minor modifications to the procedure. Ten grams of the sample were meticulously transferred into a clean, dried and calibrated measuring cylinder. The garri was leveled gently by tapping and the initial volume was recorded. Following this, 50 mL of distilled water was added to the measuring cylinder containing the sample and the mixture was left undisturbed for 4 hrs. The swelling index (SI) was computed as the ratio of the final volume to the initial volume[17,27].

Proximate analysis of the garri: The proximate composition analysis was conducted following the methods described by Imoisi *et al.*[12,13]. The functionality of cassava flour, influenced by its starch and protein content, is critical in determining the formulation and characteristics of the final product. Therefore, the flours were analyzed for their functional properties, essential for creating value-added composite bakery goods. Protein content was measured using the micro-Kjeldahl method (N×6.25), while fat content was assessed through solvent extraction. Carbohydrate content was calculated by subtraction as referenced by Ajenu *et al.*[14].

Determination of moisture content: The moisture content was determined using the oven-drying method. Clean, dry Petri dishes were first weighed on a balance and their weights were recorded as W1. Approximately 5 g of the sample were then weighed into each dish and their weights were noted as W2. The dishes, now containing the sample, were placed in an oven set at 105°C and left to dry for about three hours. After drying, the Petri dishes were removed, cooled in a desiccator and weighed again to get the final weight, W3. This process was repeated until a constant weight was achieved. The moisture content, expressed as a percentage, was calculated using the following formula, adapted by Imoisi and Michael[29]:

$$\text{Moisture (\%)} = \frac{W2 - W3}{W2 - W1} \times 100$$

Where:

W1 = Initial weight of the empty Petri dish
W2 = Weight of the empty Petri dish plus sample before drying
W3 = Weight of the empty Petri dish plus sample after drying

Ash determination: Approximately 1 g of finely ground sample was accurately weighed into clean, dried crucibles with lids (W1). The organic matter in the sample was then burned off using an open flame until the sample was charred. The crucibles were then placed in a muffle furnace set at 550°C, with the lids removed and heated until the sample turned into a light grey or white ash. After cooling in a desiccator, the crucibles were weighed again (W2). The percentage of ash content was calculated using the following formula, adapted by Imoisi and Michael[29]:

$$\text{Ash (\%)} = \frac{\text{W2 - W1}}{\text{Weight of sample}} \times 100$$

Where:
W2 = Final weight of the crucible plus ash
W1 = Initial weight of the empty crucible

Crude fat determination: A clean, dry thimble was initially weighed (W1) and 5 g of oven-dried sample was added and reweighed (W2). A round-bottom flask was filled about three-quarters full with petroleum ether (boiling point 40-60°C). The Soxhlet extractor was then attached to a reflux condenser and the solvent was heated to a gentle boil. The thimble containing the sample was placed into the Soxhlet apparatus and the extraction was performed under reflux with petroleum ether (40-60°C) for over 6 hrs. After the extraction, the thimble was removed and placed in an oven at 100°C for 1 hr. It was then cooled in a desiccator and reweighed (W3). The percentage of fat content was calculated using the following equation, adapted by Imoisi and Michael[29]:

$$\text{Fat (\%)} = \frac{\text{Weight of fat}}{\text{Weight of sample}} \times 100 = \frac{\text{W2 - W3}}{\text{W2 - W1}} \times 100$$

Where:
W1 = Initial weight of the empty thimble
W2 = Weight of the thimble plus sample before extraction
W3 = Weight of the thimble plus sample after extraction

Crude protein determination: Approximately 1 g of each sample was weighed into a micro Kjeldahl digestion flask. To this, one selenium catalyst tablet and 15 mL of concentrated H_2SO_4 were added. The mixture was digested on an electro-thermal heater until it turned clear, all performed within a fume cupboard for safety. After cooling, the solution was diluted with distilled water to a total volume of 50 and 5 mL of this diluted solution were transferred to the distillation apparatus.

In a separate 100 mL conical flask (receiver flask), 5 mL of 2% boric acid and four drops of screened methyl red indicator were added. The digested sample was treated with 50% NaOH until it turned cloudy, indicating alkalinity. The solution was then distilled into the acid solution in the receiver flask, with the delivery tube submerged below the acid level. As distillation proceeded, the pink solution in the receiver flask turned blue, indicating the presence of ammonia. Distillation continued until about 50 mL remained in the round-bottom flask, after which the condenser was rinsed with distilled water. Finally, the solution in the conical flask was titrated with 0.1M HCl. The percentage of protein content was calculated using the following equations, adapted by Imoisi and Michael[29]:

$$\text{Nitrogen (wet) (\%)} = (A\text{-}B) \times 1.4007 \times 100 \text{ weight (g) of sample}$$

Where:
A = Volume (mL) of standard HCl×Normality of standard HCl
B = Volume (mL) of standard NaOH×Normality of standard NaOH

$$\text{Nitorgen (dry \%)} = \frac{\text{Nitrogen (wet \%)}}{100 - \text{moisture (\%)}}$$

$$\text{Protein (\%)} = \text{Nitrogen (dry \%)} \times 6.25 \text{ (protein nitrogen conversion factor)}$$

Crude fibre determination: The 2.0 g (W1) of the sample underwent defatting with petroleum ether in a separating funnel. The defatted sample was then transferred to a 1 L conical flask, where it was treated with 200 mL of boiling 1.25% H_2SO_4 and gently boiled for 30 min. After filtration through muslin cloth and thorough rinsing with hot distilled water, the filtered sample was returned to the flask with a spatula.

To this, 200 mL of boiling 1.25% NaOH was added and boiled gently for another 30 min. The mixture was filtered through muslin cloth again and the residue was washed with hot distilled water, followed by rinsing with 10% HCl once and twice with industrial methylated spirit. The resulting residue was transferred to a crucible, dried in an oven at 105°C, cooled in a desiccator and weighed (W2).

Subsequently, the residue was ashed at 550°C for 90 min in a muffle furnace, cooled in a desiccator and weighed again (W3). The percentage of crude fiber content was calculated using the following equation, adapted by Imoisi and Michael[29]:

$$\text{Crude fiber (\%)} = \frac{W2 - W3}{W1} \times 100$$

Where:
W1 = Weight of the sample used
W2 = Represents the weight of the crucible+oven-dried sample
W3 = Represents the weight of the crucible+ash

Determination of carbohydrate content: The percentage of carbohydrate content was determined using the equation referenced by Ajenu *et al.*[14,30].

$$\text{Carbohydrate (\%)} = 100\text{-\% (protein+fat+fibre+ash+moisture content)}$$

Determination of pasting properties of samples: The pasting properties of starch were evaluated using the Rapid Visco Analyser-Super 4 from Newport Scientific Pty. Ltd., Warriewood, New South Wales, Australia. The STDI test profile, following the Standard Method of the AACC (no. 61-02) for cereal flours, was employed to determine pasting characteristics. A slurry was prepared by mixing 3.5 g of flour with 25 mL of de-ionized water. Subsequently, a programmed heating and cooling cycle lasting 780 sec (13 min) was initiated. This cycle included holding the starch suspension at 50°C, heating to 95°C at a specified rate, maintaining at 95°C for a set duration, controlled cooling from 95 to 50°C and a final hold at 50°C. The resulting pasting curve was analyzed using RVA control software, specifically Thermocline for Windows (TCW), to extract parameters such as pasting temperature (PSTMP), peak viscosity (PV), peak time, hot paste viscosity (HPV), cool paste viscosity (CPV), breakdown (BD), setback (SB), stability ratio and setback ratio[22,27].

Statistical analysis: Statistical analysis was performed using the BMDP 2R program for stepwise multiple regression. Results were expressed as the mean of triplicate analysis[31,32].

RESULTS AND DISCUSSION

The fermentation occurred in acidic, neutral and alkaline conditions (pH 5 to 9). Despite its simplicity, this process is microbiologically intricate and transient. Grating disrupted cassava pulp structure, facilitating enzyme action and microbial activity. The pH and fermentation duration influenced starch and cyanogenic

Table 1: pH of cassava root mash as affected by duration of fermentation

	Garri sample				
Fermentation (hrs)	WG	RG	G5	G7	G9
0	5.29±0.51	5.31±0.34	5.00±0.04	7.00±0.04	9.00±0.02
24	5.09±0.29	5.20±0.37	4.88±0.02	4.70±0.62	4.41±0.39
48	4.73±0.13	4.96±0.11	4.57±0.25	4.33±0.33	4.29±0.15
72	4.37±0.17	4.68±0.39	4.30±0.27	4.25±0.70	4.21±0.06
96	4.26±0.53	4.55±0.10	4.26±0.89	4.21±0.23	4.19±0.01

Mean±SEM: Mean values±Standard error of means of three experiments, values are given on the weight basis, WG: Control sample with no additives, RG: Sample with palm oil added, G5: Sample with pH adjusted to 5, G7: Sample with pH adjusted to 7, G9: Sample with pH adjusted to 9 and TTA: Total titratable acidity

Table 2: Proximate, physicochemical and sensory analysis of garri as affected by 0 hr duration of fermentation

	Garri sample				
Parameter	WG	RG	G5	G7	G9
Moisture content (%)	9.89	9.92	9.90	9.91	9.90
Ash content (%)	1.84	1.89	1.85	1.87	1.80
Crude fat (%)	2.01	2.47	1.99	2.02	2.02
Crude fibre (%)	2.51	2.53	2.50	2.52	2.53
Crude protein (%)	2.13	2.20	2.13	2.14	2.17
Carbohydrate content (%)	81.62	80.97	81.63	81.54	81.78
Swelling index (%)	21.61	20.16	21.80	21.47	21.77
pH	5.37	5.47	5.31	5.48	5.50
TTA (%)	0.010	0.007	0.011	0.007	0.006
Colour	3.40	3.43	3.38	3.16	3.10
Aroma	3.00	3.21	3.01	3.11	3.25
Texture	3.20	3.71	3.16	3.20	3.18

WG: Control sample with no additives, RG: Sample with palm oil added, G5: Sample with pH adjusted to 5, G7: Sample with pH adjusted to 7, G9: Sample with pH adjusted to 9 and TTA: Total titratable acidity

glycoside reduction. Lactic acid bacteria likely drove pH decline via organic acid production. Natural fermentation in sample WG involved undesirable microorganisms, leading to pH decrease and odor production. However, fermentation was faster in G9, an alkaline environment, suggesting its favorability for microbial activity. The G9 fermentation significantly shortened fermentation time from 96 to 24 hrs, resulting in pH reduction.

Table 1 presents the pH values of cassava root mash samples across different fermentation durations (0, 24, 48, 72 and 96 hrs). Each cell represents the mean pH value±standard error of the mean (SEM) based on three experiments. The samples include WG (control with no additives), RG (with palm oil added), G5 (pH adjusted to 5), G7 (pH adjusted to 7) and G9 (pH adjusted to 9). The data show how pH changes over time during fermentation, reflecting the influence of additives and initial pH adjustments on the fermentation process.

Table 2 provides the proximate, physicochemical and sensory analysis of garri samples at 0 hr of fermentation. The parameters measured include moisture content, ash content, crude fat, crude fiber, crude protein, carbohydrate content, swelling index, pH, total titratable acidity (TTA), color, aroma and texture. The samples analyzed are WG (control with no additives), RG (with palm oil added), G5 (pH adjusted to 5), G7 (pH adjusted to 7) and G9 (pH adjusted to 9). The values for each parameter show slight variations among the samples, indicating the initial composition and characteristics of the garri before fermentation begins.

Table 3 presents the proximate, physicochemical and sensory analysis of garri samples after 24 hrs of fermentation. The parameters measured are moisture content, ash content, crude fat, crude fiber, crude protein, carbohydrate content, swelling index, pH, total titratable acidity (TTA), color, aroma and texture.

Table 3: Proximate, physicochemical and sensory analysis of garri as affected by 24 hrs duration of fermentation

	Garri sample				
Parameter	WG	RG	G5	G7	G9
Moisture content (%)	11.70	11.78	11.80	11.88	11.96
Ash content (%)	1.89	1.90	1.75	2.11	2.15
Crude fat (%)	1.29	1.85	1.21	1.09	1.06
Crude fibre (%)	2.56	2.60	2.50	2.62	2.69
Crude protein (%)	2.20	2.25	2.21	2.34	2.35
Carbohydrate content (%)	80.36	79.67	80.53	79.96	79.79
Swelling index (%)	22.44	21.22	22.42	23.29	23.31
pH	5.21	5.31	5.17	4.45	4.44
TTA (%)	0.013	0.011	0.014	0.026	0.027
Colour	3.79	3.91	3.72	4.34	4.57
Aroma	4.01	4.11	3.90	4.25	4.35
Texture	3.36	3.88	3.47	4.01	4.28

WG: Control sample with no additives, RG: Sample with palm oil added, G5: Sample with pH adjusted to 5, G7: Sample with pH adjusted to 7, G9: Sample with pH adjusted to 9 and TTA: Total titratable acidity

Table 4: Proximate, physicochemical and sensory analysis of garri as affected by 48 hrs duration of fermentation

	Garri sample				
Parameter	WG	RG	G5	G7	G9
Moisture content (%)	11.91	11.91	11.93	11.97	11.98
Ash content (%)	1.93	1.98	2.01	2.14	2.17
Crude fat (%)	1.10	1.43	1.18	1.03	1.01
Crude fibre (%)	2.50	2.71	2.38	2.68	2.71
Crude protein (%)	2.24	2.29	2.22	2.34	2.36
Carbohydrate content (%)	80.32	79.64	80.28	79.84	79.77
Swelling index (%)	22.48	21.40	22.42	23.34	23.32
pH	4.41	4.93	4.62	4.37	4.33
TTA (%)	0.022	0.015	0.017	0.029	0.033
Colour	4.17	4.19	3.89	4.34	4.58
Aroma	4.39	4.41	4.26	4.37	4.39
Texture	4.20	4.31	4.11	4.22	4.25

WG: Control sample with no additives, RG: Sample with palm oil added, G5: Sample with pH adjusted to 5, G7: Sample with pH adjusted to 7, G9: Sample with pH adjusted to 9 and TTA: Total titratable acidity

The samples include WG (control with no additives), RG (with palm oil added), G5 (pH adjusted to 5), G7 (pH adjusted to 7) and G9 (pH adjusted to 9).

Table 4 presents the proximate, physicochemical and sensory analysis of garri samples after 48 hrs of fermentation. The parameters measured include moisture content, ash content, crude fat, crude fiber, crude protein, carbohydrate content, swelling index, pH, total titratable acidity (TTA), color, aroma and texture. The garri samples are WG (control with no additives), RG (with palm oil added), G5 (pH adjusted to 5), G7 (pH adjusted to 7) and G9 (pH adjusted to 9).

Table 5 presents the proximate, physicochemical and sensory analysis of garri samples after 72 hrs of fermentation. The parameters measured include moisture content, ash content, crude fat, crude fiber, crude protein, carbohydrate content, swelling index, pH, total titratable acidity (TTA), color, aroma and texture. The garri samples are WG (control with no additives), RG (with palm oil added), G5 (pH adjusted to 5), G7 (pH adjusted to 7) and G9 (pH adjusted to 9).

Table 6 provides the proximate, physicochemical and sensory analysis of garri samples after 96 hrs of fermentation. The garri samples analyzed are WG (control with no additives), RG (with palm oil added), G5 (pH adjusted to 5), G7 (pH adjusted to 7) and G9 (pH adjusted to 9).

Table 5: Proximate, physicochemical and sensory analysis of garri as affected by 72 hrs duration of fermentation

	Garri sample				
Parameter	WG	RG	G5	G7	G9
Moisture content (%)	11.93	11.98	11.95	11.97	11.98
Ash content (%)	1.99	2.00	2.07	2.15	2.18
Crude fat (%)	1.05	1.32	1.09	1.01	0.97
Crude fibre (%)	2.63	2.71	2.53	2.66	2.72
Crude protein (%)	2.36	2.33	2.29	2.35	2.35
Carbohydrate content (%)	80.04	79.66	80.07	79.86	79.80
Swelling index (%)	22.19	21.81	22.10	22.37	22.11
pH	4.39	4.67	4.40	4.26	4.19
TTA (%)	0.030	0.017	0.022	0.039	0.043
Colour	4.37	4.29	4.36	4.04	4.10
Aroma	4.55	4.59	4.50	4.50	4.53
Texture	4.14	4.30	4.05	4.12	4.00

WG: Control sample with no additives, RG: Sample with palm oil added, G5: Sample with pH adjusted to 5, G7: Sample with pH adjusted to 7, G9: Sample with pH adjusted to 9 and TTA: Total titratable acidity

Table 6: Proximate, physicochemical and sensory analysis of garri as affected by 96 hrs duration of fermentation

	Garri sample				
Parameter	WG	RG	G5	G7	G9
Moisture content (%)	11.72	11.99	11.98	11.99	11.99
Ash content (%)	2.15	2.17	2.11	2.20	2.22
Crude fat (%)	0.96	1.21	0.98	0.85	0.84
Crude fibre (%)	2.74	2.83	2.69	2.82	2.83
Crude protein (%)	2.35	2.36	2.33	2.33	2.37
Carbohydrate content (%)	80.08	79.44	79.91	79.81	79.76
Swelling index (%)	22.10	21.62	22.00	22.06	21.87
pH	4.30	4.60	4.31	4.22	4.19
TTA (%)	0.034	0.018	0.031	0.041	0.044
Colour	4.60	4.65	4.58	3.91	4.03
Aroma	4.57	4.60	4.56	4.50	4.51
Texture	4.04	4.21	3.79	4.07	3.57

Values are given on a dry weight basis, WG and RG are white and red cassava garri, respectively while, G5, G7 and G9 are cassava 'garri' obtained at pH 5, 7 and 9, respectively, WG: Control sample with no additives, RG: Sample with palm oil added, G5: Sample with pH adjusted to 5, G7: Sample with pH adjusted to 7, G9: Sample with pH adjusted to 9 and TTA: Total titratable acidity

These Table (1-6) provide detailed insights into the pH levels, proximate composition, physicochemical properties and sensory evaluation of garri under various fermentation conditions and durations.

Cassava (*Manihot esculenta* Crantz) is a vital staple crop in many tropical regions, providing a significant source of carbohydrates for millions of people worldwide. One of the primary processed products derived from cassava is garri, a fermented food product widely consumed in West Africa. The fermentation process of cassava roots into garri involves microbial activity, enzymatic reactions and chemical transformations, leading to changes in the physicochemical properties of the final product. In this discussion, the findings from the study on the effect of fermentation duration on the pH, proximate composition, physicochemical and sensory properties of garri was analyzed[33,34].

Table 1 demonstrates a notable decline in pH levels across various cassava mash samples within 24 hrs of fermentation. Samples G5, G7 and G9 saw significant decreases in pH, influencing the pH of resulting 'garris'. This rapid fermentation notably impacted proximate, physicochemical and sensory properties, particularly in samples G7 and G9. Adjustment of the pH shortened fermentation time without causing noticeable damage, albeit not leading to drastic reductions in final pH levels. The swelling index remained relatively consistent across samples, with adjustments in pH showing minimal effects[35,36]. Notably, samples

fermented at neutral and alkaline pH levels (G7 and G9) exhibited swelling indexes within an optimal range for high-quality garri production. The gradual reduction in swelling index over fermentation duration suggests an ongoing breakdown of macromolecules by fermentative microorganisms. Titratable acidity increased with fermentation time, particularly in samples G7 and G9 at 24 hrs, before normalizing at later stages, possibly due to neutralization reactions between basic compounds and fermentative acids[17,27]. Starch content decreased gradually during fermentation, with faster reduction observed in samples G7 and G9 at 24 hrs, attributed to microbial utilization of free sugars before targeting starch. Increased moisture, ash, crude fiber and crude protein content were observed across all samples, particularly pronounced in G7 and G9, possibly due to microbial biomass increase during fermentation[37,38]. While color, texture, aroma and overall acceptability generally improved with fermentation duration, samples G7 and G9 exhibited peak color and aroma at 48 hrs before diminishing, possibly due to pH levels aligning with those of other samples at later stages. Overall, fermentation duration positively influenced the quality attributes of 'garris', with RG fermented for 96 hrs receiving the highest acceptability ratings, followed by G9 fermented for 48 hrs, emphasizing the importance of extended fermentation periods for optimal product quality[33,39].

The pH of garri samples decreased progressively with increasing fermentation duration. At the onset of fermentation (0 hr), the pH ranged from 5.00 to 9.00 across different samples, indicating variations likely due to differences in cassava variety and initial microbial load. The decrease in pH over time can be attributed to the production of organic acids through microbial metabolism, particularly lactic acid, which is a common byproduct of fermentation[17,40]. Lactic acid bacteria are known to dominate during the early stages of fermentation, leading to a decline in pH as they convert sugars into lactic acid. This trend is evident in the gradual decline in pH from approximately 5.00 to 4.19 after 96 hrs of fermentation.

The pH reduction has significant implications for the safety, shelf-life and sensory attributes of garri. Lower pH values inhibit the growth of pathogenic microorganisms, enhancing the microbiological safety of the product[41,42]. Additionally, acidic conditions contribute to the development of desirable flavor profiles and preservation of the product during storage. However, excessive acidification can also lead to sourness, which may affect consumer acceptability. Therefore, monitoring and controlling pH during fermentation is critical for ensuring the quality and safety of garri.

The proximate analysis provides insights into the nutritional composition of garri and how it evolves during fermentation. Moisture content increased gradually with fermentation duration, likely due to water absorption and microbial activity. Conversely, the ash content remained relatively stable or exhibited slight variations, reflecting the mineral content of the cassava roots and the fermentation process's impact on mineral retention. The increase in moisture content and stable ash content suggests minimal losses of minerals during fermentation, which is desirable for maintaining the nutritional quality of garri[42,43]. The changes in crude fat, crude fiber and crude protein content during fermentation may be attributed to enzymatic activities, microbial metabolism and chemical transformations occurring in the cassava mash. The reduction in crude fat content could be due to lipid hydrolysis and subsequent microbial utilization, while the fluctuations in crude fiber and protein content may result from enzymatic breakdown and microbial synthesis of organic compounds. These changes contribute to the overall nutritional profile of garri, influencing its energy content, dietary fiber content and amino acid composition[44].

Carbohydrate content and starch content are essential parameters in cassava-based products, as cassava is primarily valued for its high carbohydrate content and starch yield. The data indicate relatively stable carbohydrate content throughout fermentation, with minor fluctuations observed in starch content. The stability of carbohydrate content suggests the efficient conversion of cassava starch into fermentable sugars and subsequent utilization by fermentative microorganisms. Starch hydrolysis is a critical step in the production of garri, as it facilitates the release of sugars that serve as substrates for microbial fermentation, leading to the production of organic acids and other metabolites[33].

Physicochemical parameters such as swelling index and total titratable acidity (TTA) provide additional insights into the chemical composition and functional properties of garri. Hydrogen cyanide is a toxic compound naturally present in cassava, which must be reduced to safe levels through processing and fermentation. The swelling index is a measure of the water absorption capacity and gelatinization properties of starch in garri. The gradual increase in swelling index observed during fermentation indicates the breakdown of starch granules and the formation of gel-like structures, leading to increased water absorption and viscosity. This phenomenon contributes to the textural properties and sensory characteristics of garri, influencing its mouthfeel and overall acceptability[41].

Total titratable acidity (TTA) reflects the acidity level of garri, primarily attributed to the presence of organic acids generated during fermentation. The data show variations in TTA values across different fermentation durations, reflecting changes in microbial activity, acid production and buffering capacity. The acidity of garri plays a crucial role in flavor development, preservation and microbial stability, highlighting the importance of controlling acidity levels during fermentation[42,45].

Sensory evaluation provides valuable information on the organoleptic properties and consumer acceptance of garri. Color, aroma and texture are key sensory attributes that influence consumer preference and purchase decisions[46,47]. The data demonstrate changes in sensory attributes throughout fermentation, with variations observed in color intensity, aroma profile and textural properties. These changes reflect the complex interplay of biochemical reactions, microbial metabolism and sensory perception during fermentation, highlighting the dynamic nature of garri production and its sensory characteristics[48].

The findings from this study have several implications for garri production and consumption. Understanding the dynamics of fermentation and its impact on the physicochemical and sensory properties of garri is essential for optimizing production processes, improving product quality and enhancing consumer satisfaction[46,49]. Key factors to consider include fermentation duration, microbial inoculation, processing conditions and post-fermentation treatments. By controlling these factors, producers can tailor garri characteristics to meet consumer preferences, market demands and regulatory standards.

Furthermore, promoting awareness of the nutritional benefits and safety aspects of fermented cassava products such as garri is crucial for promoting their consumption and contributing to food security and dietary diversity in tropical regions. Garri is not only a valuable source of energy but also contains essential nutrients, dietary fiber and bioactive compounds with potential health benefits. By incorporating garri into diverse diets and culinary practices, consumers can enjoy its nutritional value while supporting local food systems and agricultural livelihoods.

CONCLUSION AND RECOMMENDATIONS

The study provides valuable insights into the fermentation dynamics, physicochemical properties and sensory characteristics of garri, highlighting its significance as a staple food in tropical regions. Further research is warranted to explore additional factors influencing garri quality, such as microbial diversity, fermentation kinetics and post-harvest processing methods. By advancing our understanding of garri production and consumption, we can harness the full potential of this versatile and nutritious food product to improve livelihoods, promote food security and enhance human well-being in diverse cultural contexts. Based on the pH variations observed during fermentation, it is recommended to monitor and control pH levels throughout the fermentation process to optimize product safety, quality and sensory attributes.

SIGNIFICANCE STATEMENT

This study highlights the crucial role of fermentation duration in shaping the physicochemical properties of cassava garri, a staple food in many regions. By investigating pH variations and proximate composition changes, the research sheds light on how different fermentation periods affect the nutritional quality and sensory attributes of garri. The findings emphasize the importance of optimizing fermentation conditions to produce garri with desirable characteristics, thereby enhancing its nutritional value and consumer acceptance. Further exploration is needed to understand the health implications and nutritional benefits associated with fermented cassava products, offering valuable insights for food scientists and producers.

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