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RESEARCH ARTICLE

Optimization of the production process and nutritional composition of Zambian Munkoyo and Chibwantu Non-Alcoholic Beverages

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Abstract

This study investigated the optimization of production procedures and nutritional content of Munkoyo and Chibwantu, traditional Zambian non-alcoholic beverages. Key production parameters, such as, pH, Total Titratable Acidity, viscosity, and Total Soluble Solids were evaluated for optimization, while analyses for proximate composition, calcium, iron, and zinc were conducted to assess nutrient content. Results revealed no significant differences in fermentation outcomes between extracts from 100 g and 150 g of dried Munkoyo root ($p > 0.05$), with pH levels ranging from 3.53 to 3.77 and TTA below 1%. Nutritional analyses indicated that Munkoyo contains 2.7 to 4.1 mg/100 g of calcium, 0.04 to 0.05 mg/100 g of iron, and 0.19 to 0.38 mg/100 g of zinc, while Chibwantu provides 2.4 to 4.7 mg/100 g of calcium, 0.03 to 0.05 mg/100 g of iron, and 0.25 to 0.46 mg/100 g of zinc. The low mineral content suggests supplementation with nutrient-rich ingredients. This research lays a foundation for quality standards and supports the sustainability of Munkoyo root, aiding the growth of Zambia's traditional beverage market.

Keywords: Munkoyo, Chibwantu, nutritional content, production optimization, sustainability.

1.0 Introduction

Fermented foods and beverages, particularly those derived from cereals, legumes, tubers and milk, are essential components of global diets (1). In Zambia, non-alcoholic fermented cereal beverages (NFCBs) such as Munkoyo and Chibwantu, primarily produced from maize, play vital cultural and nutritional roles (2,3). Both Munkoyo and Chibwantu are significant sources of essential nutrients with Munkoyo containing approximately 4.5 ± 2.2% carbohydrates and providing 26.2 Kcal/100 g of energy (4,5). Although the nutritional content of Chibwantu is less documented, it is presumed to be similar due to shared production techniques and ingredients. However, despite the widespread consumption of these beverages, particularly as energy-giving foods, the nutritional profile of commercially produced Munkoyo and Chibwantu has not been thoroughly verified. This gap highlights the need for systematic evaluation of their nutritional content and efficacy as dietary sources.

Munkoyo and Chibwantu as NFCBs are a source of B-group vitamins, including thiamine, niacin and folic acid, which serve as co-factors in the metabolism of carbohydrates, fats and proteins, facilitating their conversion into usable energy (6). The World Health Organization (WHO) and the Food and Agriculture Organization (FAO) recommend specific daily intakes of these B-vitamins, underscoring their importance for overall health (7,8). Moreover, NFCBs provide vital minerals such as iron, zinc and calcium, which are essential to enhance immune function, mitigate oxidative stress and maintain bone health (9). Spontaneous fermentation associated with production of these NFCBs significantly improves the bioavailability of these minerals by degrading anti-nutritional factors like phytic acid (10,11). Additionally, fermentation yields probiotics that offer gut health benefits, support immune function and potentially reduce the risk of various diseases (12). Given the increasing urban demand for these beverages, it is essential to ensure that Munkoyo and Chibwantu are produced consistently with high-quality and safety standards. Consequently, assessing their nutrient content and optimizing production methods were two key objectives of this study.

Previous studies have thoroughly documented traditional production procedures for Munkoyo and Chibwantu. For instance, Phiri et al. (2019), Mik (2018) and Mukuma (2014) have elucidated various methods of preparation, emphasizing the lack of standardization and the regional variations in these processes. The absence of standardized production procedures creates inconsistencies in product quality and nutrient content, necessitating the optimization of these methods. The standardization of production techniques is critical not only to ensure consistent product quality but also to improve production efficiency and safety, which is essential in a context where the Munkoyo root is increasingly endangered due to over-harvesting and rising demand. In this study, standardization referred to recipe standardization, which can be summarized in three phases i.e., recipe verification, product evaluation and quantity adjustment (13). Production process optimization was described as the adjustment of production conditions and raw materials to achieve desired outcomes, such as maximizing product quality or profitability (14).

The production of Munkoyo and Chibwantu follows specific steps to ensure consistency and quality of the beverages. Initially, both beverages require maize that is either ground into flour (for Munkoyo) or coarsely milled into grits (for Chibwantu). The primary ingredient, the Munkoyo root (*Rhynchosia spp*), serves as a source of enzymes essential for fermentation. The maize meal or grits are mixed with water and cooked for at least 45 minutes to gelatinize the starch, thereby creating a suitable substrate for fermentation (15). Following this, Munkoyo root or other enzyme sources are added to facilitate starch hydrolysis, converting the starches into fermentable sugars. Subsequently, the mixture undergoes spontaneous fermentation at ambient temperature for at least 24 hours, during which lactic acid bacteria (LAB) proliferate, initiating the fermentation process. This fermentation not only contributes to desirable flavour development but also enhances the nutritional profile of the beverages (16). After fermentation, the beverages can be filtered, packaged and cooled ready to be consumed. Traditionally, these beverages were sold in local markets;

however, increasing urban demand has led to commercialization, resulting in the use of plastic bottles as packaging material prior to distribution (5).

Standardization and optimization of these production procedures is critical due to the endangered Munkoyo roots and the growing variety of consumer demands. By establishing standardized ingredient proportions and processing techniques, producers can produce consistently high-quality beverages while preventing the over-exploitation of scarce raw materials. Thus, the objectives of this study were to assess the nutrient content of commercially produced Munkoyo and Chibwantu and to optimize and standardize their production processes. This comprehensive approach aimed to ensure that these healthy products are both efficient to produce and accessible to consumers, thereby supporting public health through enhanced dietary options.

2.0 Materials and Method

2.1 Study Design

An experimental laboratory-based design was used to carry out nutrient analyses and optimization of the production process of Munkoyo and Chibwantu beverages.

2.2 Study Site

The study was conducted at the Food Science Research Centre (FSRC) of the National Institute for Scientific and Industrial Research (NISIR) in Lusaka, Zambia, in collaboration with the University of Zambia's Department of Food Science and Nutrition (FSN).

2.3 Materials

Whole white maize and dry Munkoyo roots, purchased from Soweto Market in Lusaka, served as primary raw materials for the production of Munkoyo and Chibwantu beverages. The study utilized a hammer mill to grind maize, an analytical balance (Model Sartoris CPA225D, Germany) for precise weighing, a sieve with a pore size 45 micrometer (µm) (ASTM E11 standard/ ISO 565/3310-1) for filtering Munkoyo root extracts and a calibrated Thermo-hygrometer (Model TTH-2410, Terminator, China) for monitoring temperature and humidity conditions throughout the study period.

2.4 Methods

2.4.1 Modification and standardisation of production process of Munkoyo and Chibwantu

This study aimed at optimizing the production processes of Munkoyo and Chibwantu and standardizing the brewing procedure, like, refining the use of Munkoyo root. Literature reviewed include; Mukuma, (2014), Mik, (2018) and Phiri, (2020), (1,15,17) Phiri's (2020) method was selected for modification due to inclusion of specific raw material quantities, in contrast to the descriptions provided by Mik (2018) and Mukuma (2014), which lacked quantitative details. Mik (2018) detailed soaking durations for Munkoyo roots, while Mukuma (2014) focused on fermentation durations without specifying ingredient amounts. Despite having similar processing steps as illustrated in Figure 1, Phiri's method yielded thick beverages (viscosity over 120 centipoise (cpsi)), necessitating dilution to achieve a suitable consistency for consumption. This dilution was not indicated in Phiri's method, highlighting the need for modification. Viscosity was a critical parameter, aiming at meeting the required and acceptable standard for cereal-based beverages, which should not exceed 60 cpsi (18). The standardized parameters derived from Phiri's procedure encompassed modification of quantities of maize meal, maize grits and Munkoyo root necessary for producing 10 litres of beverage. Additionally, the volume of potable water required for hydrolysate extraction was adjusted. Furthermore, modifications were made to cooking time, cooling temperature, hydrolysis duration and extraction time to improve product quality.

2.4.2 Preparation of Maize Meal and Grits

Whole white maize was ground with a hammer mill to produce maize meal and grits for the preparation of Munkoyo and Chibwantu, thereafter, particle size was determined.

2.4.3 Preparation of Munkoyo Root Extract

A portion of shredded Munkoyo root was weighed and soaked in potable water for 1 hour to obtain the extract. The extract was then filtered through a 45 micrometer (µm) pore size sieve to eliminate root strands and yield a clear liquid.

2.5 Optimization of the usage of Munkoyo root in production of Munkoyo or Chibwantu

Trials were conducted in triplicate following Phiri's (2020) procedure to prepare Munkoyo and Chibwantu beverages, yielding three products: Munkoyo (ML1), Chibwantu 1 (CL1) from maize grits and Chibwantu 2 (CL2) from a 3:1 ratio of maize grits to maize meal, as per Mik (2018) and Phiri et al. (2020). Thereafter, a modified procedure was implemented, reducing maize meal from 1500 g to 1000 g and dry shredded Munkoyo root from 150 g to 100 g for 10 litres of beverage. The hydrolysate extraction water volume was increased from 1 L to 2 L and the soaking time was extended from 20 to 60 minutes, while maintaining the water temperature at 60 °C. The extract was added at a cooling temperature of 50 °C, as monitored with a calibrated thermometer. To evaluate the effects of 100 g versus 150 g of Munkoyo root extract, two samples of each beverage were prepared and fermented at room temperature for 72 hours, with one sample receiving 100 g and the other 150 g of dry shredded Munkoyo root extract. Physico-chemical parameters were monitored at 24-hour intervals, which included; pH, percent total titratable acidity as lactic acid (% TTA), viscosity and total soluble solids (TSS) measured in degrees Brix (°Brix). The complete production procedure is illustrated in Figure 2.

2.6 Physico-chemical analyses

2.6.1 Particle size Determination

Particle size was determined on the ground maize meal and maize grits using AOAC Method 965.22. This parameter significantly influences access to nutrients and the properties of the final product. The particle size of maize meal and maize grits was determined using available sieves in the Laboratory that ranged from 0.6 -3.55 mm pore size.

2.6.2 Determination of pH, Total Titratable Acidity, Total Soluble solids and Viscosity

Total titratable acidity, pH, total soluble solids and viscosity were determined using standard AOAC procedures from the 19th Edition (AOAC, 2012). Viscosity was measured with a Brookfield Synchro-lectric RVT Viscometer (Model 74, USA) using spindle number 2 at 20 rpm, with a calculation factor of 20.

2.7 Nutrient content of commercially and laboratory produced Munkoyo and Chibwatu

In October 2023, ten samples of commercially processed Munkoyo and Chibwantu were purchased from supermarkets and small shops in Kalingalinga township and Town Centre, Lusaka. Additionally, three products (Munkoyo, Chibwantu 1, and Chibwantu 2) were prepared in the laboratory, with Chibwantu 1 made from maize grits only and Chibwantu 2 produced with a 3:1 ratio of maize grits to maize meal (15,17). Munkoyo was prepared solely from maize meal. All products were analyzed together with the commercially produced samples, thus yielding a total of 13 samples for nutrient content comparison.

2.7.1 Analyses

Proximate composition, which included moisture, crude protein, crude fat, crude fiber, total ash, and carbohydrates, were determined for each sample using standard AOAC procedures from the 19th Edition (AOAC, 2012). Selected minerals of public health concern in Zambia, specifically iron, calcium and zinc, were also analyzed following the AOAC 2012 procedures.

2.8 Statistical Analysis

Data analysis was conducted using the Statistical Package for Social Sciences software (IBM SPSS Statistics version 24; SPSS Inc., Chicago, IL, USA) and Microsoft Excel 2019. Qualitative data concerning the modification and standardization of the production process were depicted using process flow charts. Quantitative data from nutritional analyses were reported as means with standard deviation (SD). A one-way analysis of variance (ANOVA) was conducted at an α level of 5% on nutritional data from 13 beverages to assess significant differences, with the Least Significant Difference (LSD) calculated when ANOVA revealed mean variability. A two-tailed independent samples t-test evaluated the effects of two quantities of Munkoyo root extract (100 g and 150 g) on TTA, pH and viscosity after 72 hours of fermentation. This comparison assessed variations in the production of 10 L of each product.

2.9 Ethical Clearance

Ethical clearance for the study was obtained from the Tropical Disease Research Centre (TDRC) Ethics Review Committee, Ndola, Zambia, with the reference number TDREC/040/02/23.

3.0 RESULTS

Here we present results for the modified and standardised production process, optimization of usage of Munkoyo root and nutrient content of commercially and laboratory-produced Munkoyo and Chibwatu beverages. Prior to the trials on process standardisation and optimization, particle size of the maize meal and maize grits were determined.

3.1 Particle size distribution

The particle size of maize meal for Munkoyo production ranged from 0.6 mm to 1.25 mm, achieving 100% passage rate through the 1.25 mm sieve and 83.4% retention in the receiving pan. For Chibwantu, maize grit sizes were between 2.36 mm and 3.55 mm, with passage rates varying from 72% to 100%. Additionally, 18.8% of the grits passed through the 1.25 mm sieve and 1.4% through the 0.6 mm sieve, with 0.18% retained in the receiving pan, indicating variability in the particle sizes of the grits.

3.2 Modification and Standardisation of Brewing process of Munkoyo and Chibwantu

Three products were prepared: Munkoyo (ML1), Chibwantu 1 (CL1) and Chibwantu 2 (CL2). ML1 and CL1 were made using maize meal and grits, respectively, while CL2 utilized a 3:1 ratio of maize grits to maize meal. The procedure involved heating 10 litres of water to 60 °C, gradually adding 1 kg of maize meal or grits with continuous stirring for 60 minutes until complete gelatinization, followed by cooling to 50 °C and adding the prepared Munkoyo root extract as described in 2.4.3. The mixture was then allowed to hydrolyze for 2 hours before transferring to plastic buckets for spontaneous fermentation lasting 72 hours. The same production process was applied to CL2 using 750 g of maize grits and 250 g of maize meal. The modified process steps and quantities used in the optimized production process are shown in Figure 3. Additionally, the optimized and standardized components of the production process are indicated on the same production process flow chart.

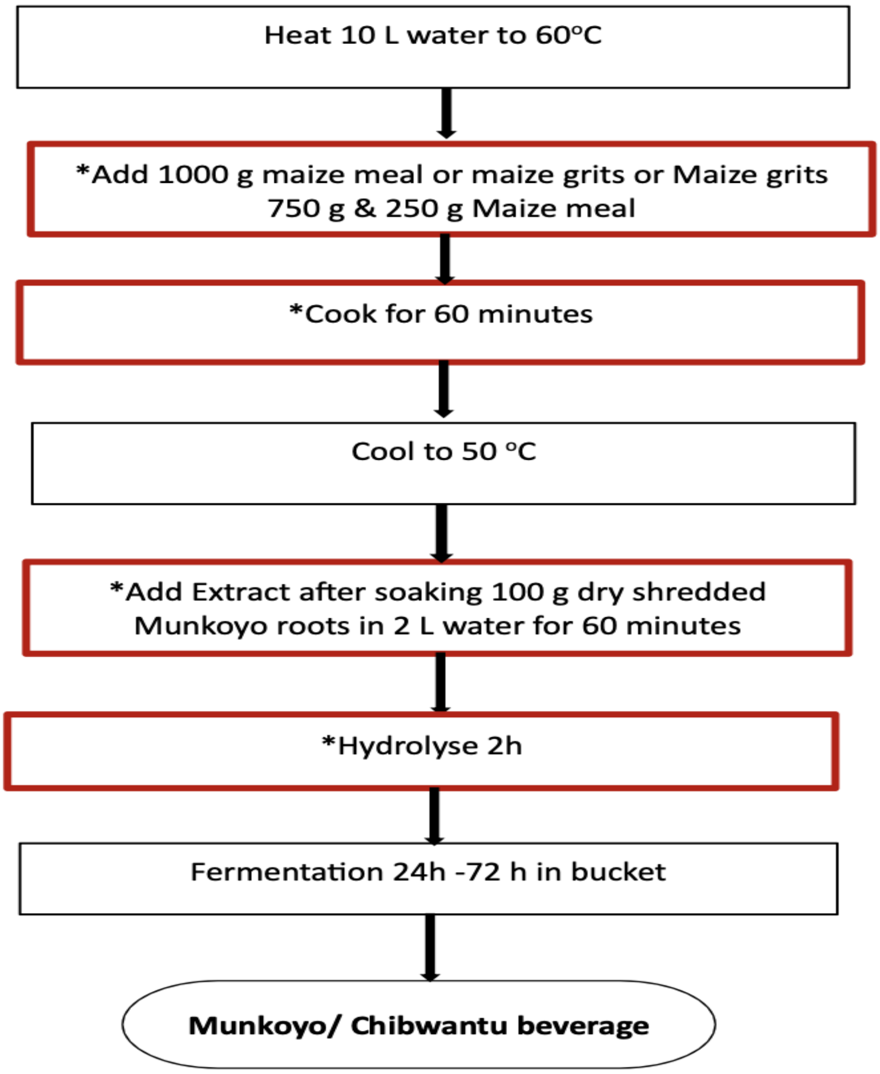

Figure 3: Optimized Production process of Munkoyo and Chibwantu
** Optimized and standardised components of the production process*

3.3 Optimization of the usage of Munkoyo root

Two levels of root quantity were used to produce Munkoyo and Chibwantu i.e., 100 g and 150 g of dried shredded Munkoyo root. The pH, % TTA, viscosity and TSS were analysed for Munkoyo and Chibwantu beverages to evaluate the effectiveness of the two root quantities. Changes in %TTA, viscosity and TSS (°Brix) between the samples were subjected to a two-tailed independent samples t-test to assess statistical differences in each parameter between the two root extract amounts for each product.

3.3.1 Trends in physico-chemical parameters during Fermentation

After 72 hours of fermentation, the laboratory-produced Chibwantu (CL1 and CL2) displayed similar viscosities, decreasing from 20 cpsi to 10 cpsi for both beverages made with 100g and 150g of dried shredded Munkoyo root. In contrast, the viscosity of Munkoyo (ML1) decreased from 30 cpsi to 20 cpsi for the same amounts of Munkoyo root. These findings indicate a statistically significant difference ($p < 0.05$) between the two product groups. pH values ranged from 3.53 to 3.77 across the three products, with Munkoyo showing substantial drops from initial values of 7.19 and 7.06 to 4.37 and 4.29 for the 100 g and 150 g concentrations, respectively, after 24 hours. Chibwantu pH reductions were smaller, with CL1 at 6.62 and CL2 at 6.20 after 24 hours fermentation from 7.06 and 7.03 initial values. % TTA for CL2 was consistent at 0.77%, while CL1 had values of 0.67% and 0.65% for the 100 g and 150 g extracts, respectively after 72 hours. Munkoyo showed a % TTA of 0.9% for both concentrations, with no significant differences between the two products ($p > 0.05$) after 72 hours. The TSS measured in °Brix were highest in Munkoyo, with values of 6.1 and 6.0 for 100g and 150g Munkoyo extracts, respectively. In contrast, CL2 recorded the lowest TSS at 5.3, observed with both quantities of Munkoyo extract after 72 hours. The TSS results indicated no significant differences based on extract concentrations ($p > 0.05$) among all three products after 72 hours.

3.4 Nutrient content of commercially and laboratory produced Munkoyo and Chibwantu

Nutrient analyses were conducted on 13 beverages, i.e., one (1) laboratory-prepared Munkoyo and two (2) Chibwantu made using a modified and standardized procedure and 10 commercially purchased products (2-Munkoyo and 8-Chibwantu) from Lusaka traders. Laboratory-produced Chibwantu denoted as CL1 and CL2 were prepared from maize grits and a 3:1 maize grits to meal ratio, respectively, while the laboratory-prepared Munkoyo was designated ML1. Commercial products were labelled as MC and CC. Analyses focused on proximate composition, calcium, iron, and zinc levels.

3.4.1 Munkoyo Samples

The nutritional composition results for both laboratory and commercially produced Munkoyo are presented in Table 1. Laboratory-produced ML1 exhibited the highest levels of crude protein, crude fat, and crude fiber, with values of 0.78%, 0.66%, and 0.91%, respectively. In contrast, MC1 showed the lowest crude protein and crude fat content at 0.70% and 0.11%. Although MC2 had the lowest crude fiber content at 0.42%, it recorded the highest carbohydrate and energy values at 6.68% and 31.1 Kcal/100g, respectively. Statistical analyses revealed significant differences in crude protein, crude fat, crude fiber, and carbohydrate content among these three Munkoyo products, ($p < 0.05$). The average energy content for commercially produced Munkoyo was 29.6 Kcal compared to 30.7 Kcal/100g for laboratory-produced Munkoyo, showing no significant difference between these values ($p = 0.097$).

Table 1: Nutrient content of laboratory and commercially produced Munkoyo

Parameter	ML1	MC1	MC2
% Moisture	92.0 (0.74)^a	92.1 (0.06)^a	91.8 (0.30)^a
% Total Ash	0.24 (0.01)^a	0.13 (0.01)^b	0.19 (0.02)^b
% Crude Protein	0.78 (0.02)^a	0.70 (0.02)^b	0.77 (0.02)^a
% Crude Fat	0.66 (0.02)^a	0.11 (0.02)^b	0.14 (0.02)^b
% Crude Fibre	0.91 (0.23)^a	0.88 (0.02)^a	0.42 (0.01)^b
% Carbohydrates	5.41 (0.52)^a	6.08 (0.27)^b	6.68 (0.24)^b
Energy (Kcal/100 g)	30.70 (2.10)^a	28.07 (1.04)^a	31.06 (1.06)^a
Calcium (mg/100 g)	3.78 (0.18)^a	4.14 (0.91)^b	2.67 (0.14)^c
Iron (mg/100)g	0.063 (0.01)^a	0.041 (0.01)^a	0.054 (0.00)^a
Zinc (mg/100 g)	0.368 (0.02)^a	0.376 (0.02)^a	0.187 (0.01)^b

- *Results are on wet (as is) basis*
- *Means and standard deviation in parentheses. Means in a row that do not share the same letter are significantly different.*
- *Significant differences are compared in a row (α level of 5 %)*
- *ML1 – Laboratory produced Munkoyo.*
- *MC1 and MC2 – Commercially produced Munkoyo*

Furthermore, data analyses revealed no significant differences in moisture content among the three Munkoyo products ($p > 0.05$). The moisture content was 92.0% for ML1, 92.1% for MC1, and 91.8% for MC2. Iron content was not significantly different among the three products ($p = 0.078$), while calcium and zinc levels differed significantly ($p < 0.05$). MC1 had the highest content at 4.14 mg/100 g calcium and 0.376 mg/100 g zinc, compared to MC2's lowest values of 2.67 mg/100 g and 0.187 mg/100 g, respectively. On average, commercially produced Munkoyo contained 0.05 mg/100 g iron and 0.28 mg/100 g zinc.

3.4.2 Chibwantu Samples

Table 2 presents the nutritional composition results for Chibwantu beverages. The mean crude protein content for laboratory-produced Chibwantu was 0.91%, compared to 0.70% for commercially produced samples, with ANOVA indicating significant differences ($p < 0.05$). The crude protein content of commercially produced Chibwantu samples CC4, CC7, CC8, CC9, and CC10 ranged from 0.68% to 0.74% and was not significantly different ($p > 0.05$), while samples CC5 and CC6 had crude protein contents of 0.50% and 0.59%, respectively, which were statistically different from the other commercially produced samples ($p < 0.05$). The mean energy content for commercially produced Chibwantu was 41.5 Kcal/100 g, significantly higher than the laboratory-produced value of 39.8 Kcal/100 g ($p < 0.05$). The energy content for laboratory samples CL1 and CL2 was 36 Kcal/100 g and 43.5 Kcal/100g, respectively, which were significantly different ($p < 0.05$). For samples CL1, CC4, CC6, and CC8, energy content ranged from 36-41 Kcal/100g without significant difference ($p > 0.05$), while CL2, CC3, CC5, CC7, CC9, and CC10 had higher energy values of 42.8-45 Kcal/100g, also not significantly different ($p > 0.05$).

Total ash content for CL1 and CL2 was 0.33% and 0.31%, respectively, while commercially produced Chibwantu ranged from 0.09 - 0.15%, with no significant differences found ($p > 0.05$). Calcium content varied from 2.4 - 4.7 mg/kg, with CL1, CL2, CC4, and CC8 displaying similar values around 4.32 - 4.7 mg/kg ($p > 0.05$). Laboratory-produced Chibwantu had iron contents of 0.062 mg/kg and 0.067 mg/kg, and zinc contents of 0.583 mg/kg and 0.553 mg/kg, which were not significantly different ($p > 0.05$). In contrast, commercially produced Chibwantu had iron content ranging from 0.031 mg/kg to 0.045 mg/kg and zinc content from 0.25 mg/kg to 0.458 mg/kg, showing significant differences ($p < 0.05$), with averages of 0.04 mg/100 g iron and 0.33 mg/100 g zinc. Overall, the laboratory-produced Chibwantu displayed superior crude protein, iron, and zinc content compared to commercially produced beverages, which exhibited higher energy content.

4.0 Discussion

Munkoyo and Chibwantu are traditional Zambian non-alcoholic beverages that provide energy, and nutritional benefits (5,19). Thus, the findings from this study provided valuable insights into optimizing the production process of Munkoyo and Chibwantu beverages and standardizing critical production parameters such as pH, % TTA, viscosity and TSS, which are essential for non-alcoholic beverage quality (20). The results showed no significant difference in the fermentation outcomes between extracts from 100 g and 150 g of dried Munkoyo root ($p > 0.05$), with the pH for products using 100 g ranging from 3.53 to 3.77 after 72 hours, the same with previous findings (21,22).

The TTA remained below 1% (0.8 – 1%), indicating the beverages' safety (23–25). The recommendation to use 100 g of dried Munkoyo root per 10 litres represents a shift from earlier guidelines of 150 g (15). Establishing these optimal parameters is critical for addressing the over-utilization of Munkoyo root, which is threatened with extinction in Zambia and the Democratic Republic of Congo (5).

The study's emphasis on standardization aimed at, ensuring consistent product quality and defined shelf life, contributing to the development of standardized protocols for small and medium enterprises (SMEs) and providing a foundation for scaling-up production. Variations from previous studies (1,15,17) were

harmonized, focusing on ingredient quantities and specific production parameters. Furthermore, the analysis of particle size revealed that the maize meal complied with FAO/WHO Codex Alimentarius standards, with over 95% of the particles passing through a 1.70 mm sieve. Uniform particle sizes enhance mixing efficiency, positively impacting the quality of the final product (26,27). Compliance with FAO/WHO standards regarding particle size not only improves mixing efficiency and product quality but also significantly influences consumer perceptions and preferences. Consumers frequently associate adherence to these standards with increased safety and quality assurance, subsequently affecting their willingness to select products that meet these criteria (28,29).
Moreover, by integrating findings from previous studies and establishing standard operating procedures, this research lays a solid foundation for enhancing both the nutritional quality and safety of these traditional beverages. The optimization of production processes not only benefits the manufacturers but also promotes the sustainability of Munkoyo root. Overall, the insights gained could significantly benefit SMEs, facilitate informed decision-making and contribute to market growth of traditional fermented beverages in Zambia.

Non-alcoholic beverages are important and appreciated because they contribute to household nutrition and perform a particular function in hydrating the body (19). Thus, this study has generated information on nutritional composition of commercially produced Chibwantu which was previously limited to Munkoyo. The study established that their energy contributions are approximately 1.0 % to 1.3% of the Recommended Dietary Allowance (RDA) for adult men from 19 years and older when consuming 100 g of Munkoyo and 1.4 % to 2.2% for adult women with 100 g of Chibwantu consumption (8). Analyzed mineral content showed that Munkoyo contains 2.7 to 4.1 mg/100 g of calcium, 0.04 to 0.05 mg/100 g of iron, and 0.19 to 0.38 mg/100 g of zinc, while Chibwantu contains 2.4 to 4.7 mg/100 g of calcium, 0.03 to 0.05 mg/100 g of iron, and 0.25 to 0.46 mg/100 g of zinc (4). This difference in nutrient content may stem from variations in moisture content and particle size between the main ingredients, i.e., maize meal for Munkoyo and maize grits for Chibwantu.

Despite their nutritional value, the protein and mineral content remains low, suggesting the potential for enhancing these beverages by supplementing with nutrient-rich ingredients such as soy, whey and Moringa oleifera leaf powder (30,31). Furthermore, both beverages possess beneficial probiotic properties due to their fermentation process (1,15,17,23,32,33). The findings from this study are crucial for establishing quality standards and regulations for Munkoyo and Chibwantu in collaboration with the Zambia Bureau of Standards, which are currently lacking. The data can also assist in updating the Zambian Food Composition tables and serve as a reference for nutritional labelling and recommendations for these traditional beverages.

In developing standards for Zambian Munkoyo and Chibwantu, it is essential to reference general international standards for non-alcoholic fermented beverages (NFCBs) and guidelines from countries producing similar beverages, such as Obushera from Uganda, Togwa from Tanzania and Mahewu from South Africa (21,34,35). These comparative standards can provide valuable insights into best practices for quality control, nutritional labelling and safety regulations, ensuring that Zambian Munkoyo and Chibwantu meet both local and international benchmarks. By incorporating these reference points, the development of standards can be more robust and aligned with global trends in the production and consumption of traditional beverages, ultimately benefiting consumer awareness and public health.

In conclusion, this study underscored the significance of optimizing production processes for Munkoyo and Chibwantu beverages by using essential parameters such as pH, total titratable acidity, viscosity and total soluble solids. It established that 100g of dried Munkoyo root suffices for producing high-quality beverages, addressing safety and nutritional concerns while reducing dependency on this over-utilized resource. Compliance with FAO/WHO standards regarding particle size is integral to enhancing mixing efficiency and overall product quality. Such improvements are essential, as they have the potential to positively influence consumer perceptions and preferences by ensuring the safety and quality of the products.

The study also integrated insights from prior research and proposed standardized operating procedures, forming a strong foundation for improving production processes. These efforts promote the sustainability of Munkoyo root and empower SMEs to make informed decisions, fostering growth in Zambia's traditional beverage market. Furthermore, the findings enhance consumer awareness, inform regulatory measures and highlight opportunities for nutritional improvements based on variations in mineral content, suggesting the need for further research to optimize formulations and enhance nutritional profiles.

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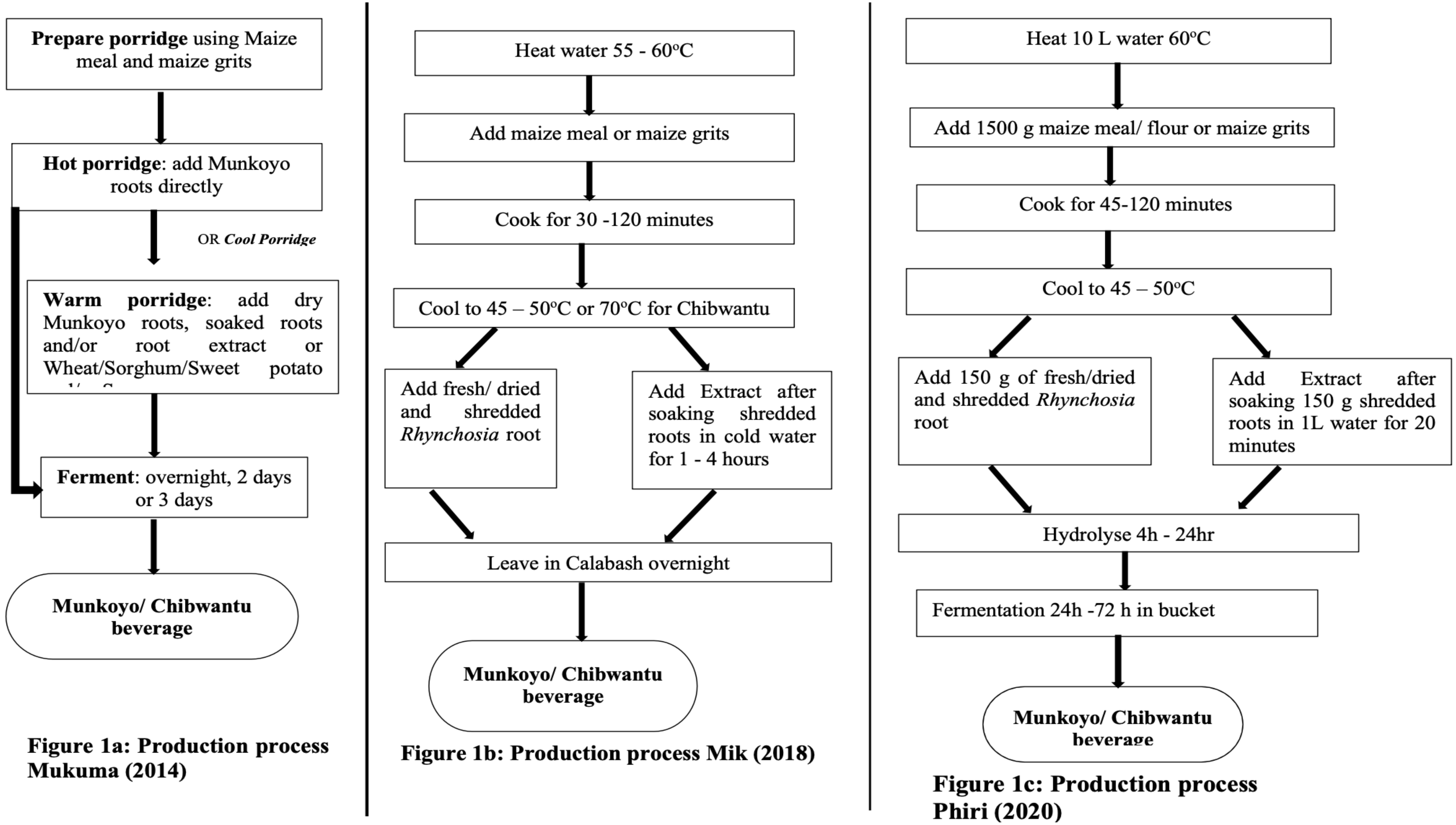

Figure 1a: Production process Mukuma (2014)

Figure 1b: Production process Mik (2018)

Figure 1c: Production process Phiri (2020)

Figure 1: Flow diagrams of three production processes of Munkoyo and Chibwantu beverages

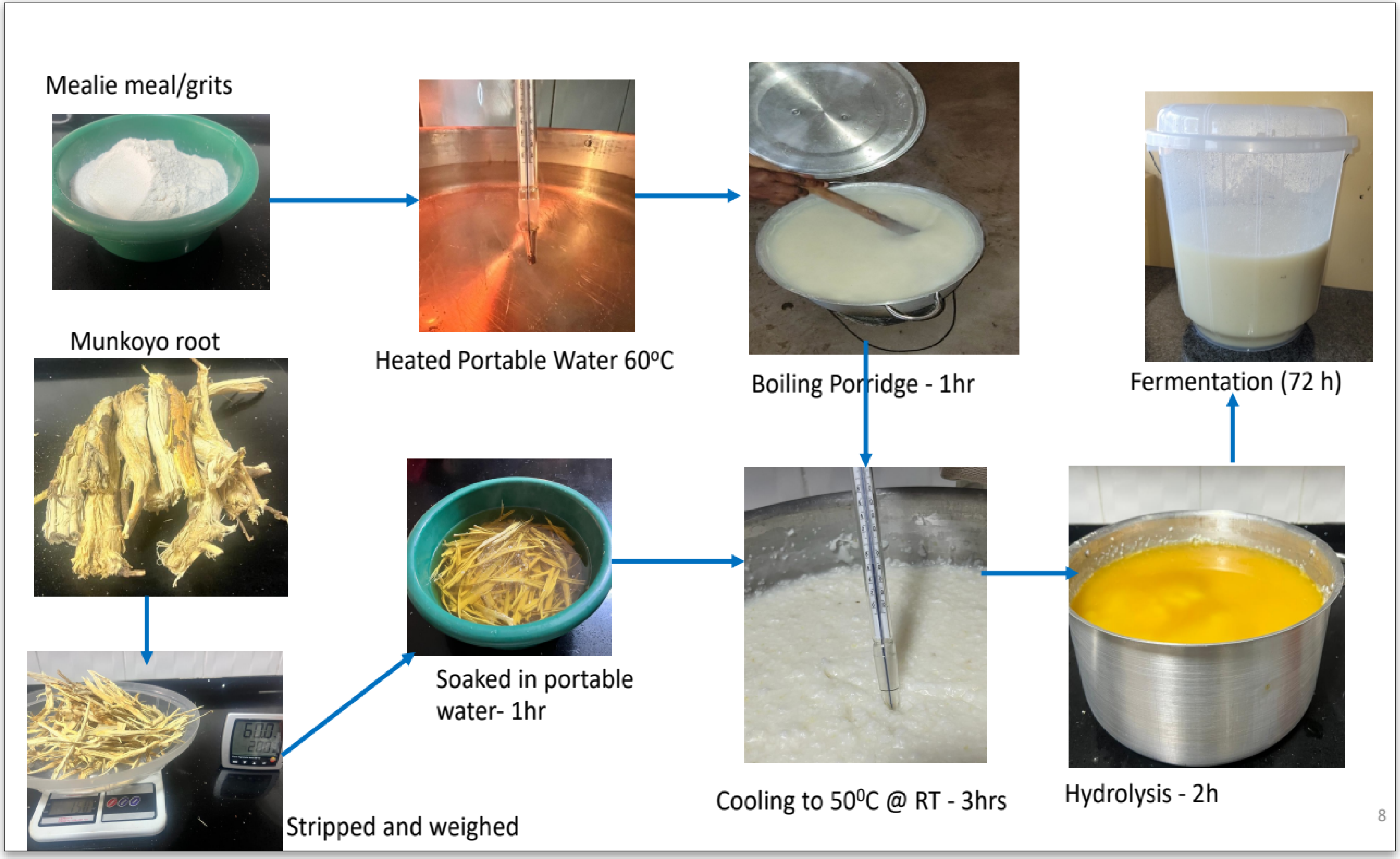

Figure 2: Production process flow chart of Munkoyo and Chibwantu

Table 2: Nutrient content of laboratory and commercially produced Chibwantu

Parameter	CL1	CL2	CC3	CC4	CC5	CC6	CC7	CC8	CC9	CC10
% Moisture	90.4 (0.08)^{a}	88.4 (0.03)^{b}	87.5 (0.45)^{c}	89.0 (0.48)^{b}	88.0 (0.03)^{b}	90.1 (0.35)^{a}	88.1 (0.72)^{b}	87.7 (0.10)^{c}	87.8 (0.07)^{c}	88.1 (0.13)^{b}
% Total Ash	0.33 (0.03)^{a}	0.31 (0.17)^{a}	0.12 (0.03)^{b}	0.09 (0.01)^{c}	0.10 (0.02)^{c}	0.09 (0.02)^{c}	0.12 (0.00)^{b}	0.15 (0.01)^{b}	0.19 (0.01)^{d}	0.13 (0.01)^{b}
% Crude Protein	0.86 (0.02)^{a}	0.95 (0.02)^{c}	0.86 (0.02)^{a}	0.74 (0.02)^{b}	0.50 (0.10)^{d}	0.59 (0.02)^{e}	0.68 (0.02)^{b}	0.74 (0.02)^{b}	0.74 (0.02)^{b}	0.76 (0.20)^{b}
% Crude Fat	0.68 (0.03)^{e}	0.71 (0.02)^{a}	0.82 (0.20)^{b}	0.14 (0.02)^{c}	0.72 (0.02)^{a}	0.73 (0.02)^{a}	0.82 (0.02)^{b}	0.18 (0.02)^{c}	0.53 (0.02)^{d}	0.76 (0.00)^{a}
% Crude Fibre	1.11 (0.02)^{c}	1.33 (0.11)^{d}	2.15 (0.02)^{e}	1.83 (0.02)^{a}	1.92 (0.04)^{b}	1.72 (0.03)^{f}	1.92 (0.02)^{b}	1.84 (0.02)^{a}	1.93 (0.03)^{b}	2.03 (0.02)^{g}
% Carbohydrates	6.62 (0.18)^{a}	8.33 (0.28)^{b}	8.55 (0.13)^{b}	8.20 (0.96)^{b}	8.76 (0.11)^{b}	6.77 (0.24)^{a}	8.36 (0.20)^{b}	9.39 (0.23)^{c}	8.84 (0.20)^{b}	8.21 (0.24)^{b}
Energy (Kcal/100 g)	36.04 (0.56)^{a}	43.51 (0.86)^{b}	45.02 (0.78)^{b}	37.02 (0.10)^{a}	43.52 (0.66)^{b}	36.01 (0.70^{a}	43.66 (0.90)^{b}	41.11 (0.75)^{b}	43.09 (0.70)^{b}	42.75 (1.06)^{b}
Calcium mg/Kg	4.32 (0.58)^{a}	4.37 (0.48)^{a}	2.56 (0.21)^{b}	4.32 (0.20)^{a}	3.33 (0.42)^{c}	3.24 (0.43^{c}	2.67 (0.11)^{b}	4.70 (0.83)^{d}	3.66 (0.04)^{c}	2.40 (0.15)^{b}
Iron mg/Kg	0.062 (0.01)^{a}	0.067 (0.01)^{a}	0.031 (0.01)^{b}	0.042 (0.00)^{c}	0.040 (0.00)^{c}	0.045 (0.01^{c}	0.043 (0.01)^{c}	0.044 (0.01)^{c}	0.036 (0.01)^{b}	0.039 (0.00)^{b}
Zinc mg/Kg	0.583 (0.10)^{a}	0.553 (0.03)^{a}	0.250 (0.03)^{b}	0.429 (0.05)^{d}	0.310 (0.11)^{c}	0.313 (0.07)^{c}	0.253 (0.02)^{b}	0.458 (0.06)^{d}	0.352 (0.07)^{e}	0.265 (0.09)^{b}

- *Results are on wet (as is) basis*
- *Means and standard deviation in parentheses. Means in a row that do not share a letter are significantly different.*
- *Significant differences are compared in a row (α level of 5 %)*
- *CL1 and CL2– Laboratory produced Chibwantu*
- *CC3 to CC10 – Commercially produced Chibwantu*