

Optimisation of a Nonalcoholic Malted Beverage (*Pyer-kushu*) Produced from Blends of Sorghum Varieties Using a Mixture Design Technique

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ABSTRACT

Purpose: Global concern over diet health effects is increasing, especially in Africa, where traditional dishes deeply rooted in cultural practices and beliefs are popular among the population. Thus, the production of a nonalcoholic malted beverage 'pyer-kushu' from the blends of sorghum varieties was investigated.

Research Method: A D-optimal mixture design (constraining malted 'koyanga' red (MRS) and 'moskwa' white (MWS) sorghum to 10–20% each, unmalted 'koyanga' red (URS) and 'moskwa' white (UWS) to 30–40%) generated 12 formulations. Each formulation was produced via traditional malting and brewing, then analysed for key physicochemical properties, mineral content, microbial load, and sensory qualities (50-member panel hedonic evaluation). Statistical analysis (ANOVA and mixture regression models) identified significant formulation effects and optimal sorghum blend ratios.

Findings and Values: The physicochemical and mineral contents were pH (3.84–5.62), total solid (8.80–19.16%), total soluble solid (5.33–6.06 °Brix), titratable acidity (0.22–0.35%), specific gravity (1.00–1.06), foaming capacity (10.00–40.00%), viscosity (4.68–5.57 cP), sodium (21.00–23.66 mg/100g), calcium (3.60–6.10 mg/100g), manganese (28.66–40.00 mg/100g), iron (5.93–9.13 mg/100g), and phosphorus (2.00–3.66 mg/100g). The total plate count was between 5.9×10^4 and 1.12×10^5 cfu/ml. The optimum formulation is 20.00% MRS, 12.90% MWS, 30.00% URS, and 37.10% UWS, achieving high desirability, balanced nutrition, and acceptability. This study provides a scientific approach to improve the nutritional profile and consistency of traditional African beverages, specifically 'pyer-kushu', to combat malnutrition and boost local economies.

Keywords: Malted beverage, Mixture design, Nonalcoholic, Optimisation, Sorghum varieties, Traditional drink

INTRODUCTION

In recent times, there has been a growing global concern about consumers' increasing interest in the health effects of their diets. This trend is particularly evident in Africa, where a significant portion of the population embraces various dishes that are deeply rooted in their traditional heritage, cultural practices, and beliefs (Onyeaka *et al.* 2021).

Nigeria, for example, boasts a multitude of such foods, with their availability and popularity varying depending on the region, ethnic group, and tribal customs. Each ethnic

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community has its own unique culinary traditions, and the process of urbanisation has led to even more diversity in the types of foods consumed and the methods of preparation (Onyeaka *et al.* 2021). As a result of this wide variety of indigenous foods and culinary practices, it has become challenging to pinpoint a single dish as a national staple in Nigeria. Food, being an essential requirement for human survival, not only provides vital energy and nutrients but also reflects people's attitudes and perspectives towards themselves. It represents a fundamental necessity for human existence. Furthermore, food plays a significant role in shaping cultural identity and fostering societal cohesion (Chen & Antonelli 2020).

The indigenous community of Garaha town in the Hong Local Government Area of Adamawa State, Nigeria, has traditionally made and enjoyed 'Pyer-kushu,' a traditional cereal-based nonalcoholic malted beverage. This wholesome drink is primarily crafted from sorghum (*Sorghum bicolor*) and boasts impressive nutritional value. The term 'pyer-kushu' derives from the Kilba language and signifies that it falls between 'Kunun zaki' and 'Burukutu' in terms of beverage categorisation. Notably, 'pyer-kushu' stands out for its delightful taste and purity, as it does not contain any preservatives, additives, colourants, or sweeteners. It serves as a versatile drink, suitable for consumption at any time of day, and is cherished by both adults and children as a breakfast beverage. Additionally, it doubles as a refreshing treat for entertaining guests, often acting as an appetiser and a favoured choice at social gatherings.

Beyond its delicious taste, 'pyer-kushu' offers essential minerals and vitamins that contribute to overall well-being and stimulate bodily functions. It is important to emphasise that 'pyer-kushu' remains a nonalcoholic malted beverage that does not undergo complete fermentation. Indigenous foods in Nigeria come in various forms, encompassing liquids, solids, and semi-solids (Evans *et al.* 2013). These nourishing dishes are typically prepared using locally sourced food crops, including roots, tubers, fruits, and vegetables. Notable examples include

cereal-based porridges, often referred to as 'Ogi' in Nigeria, and various dishes made from cereals such as maize, sorghum, millet, and rice. Liquid indigenous foods are particularly diverse, with options ranging from fermented to unfermented varieties, including 'burukutu,' palm wine, 'pito,' and many others. In rural areas, these traditional drinks have a special place, especially during festive occasions when the locals adore their refreshing flavours.

In the production of the 'pyer-kushu' drink, it is essential to focus on internal resources and identify a type of sorghum with favourable malting characteristics that can yield high-quality products. Standardising the production processes is also crucial in this endeavor. In this context, the application of suitable experimental designs and statistical methods becomes pivotal. Hussein *et al.* (2019) emphasised the importance of optimising process parameters to gain better control over quality, productivity, and cost aspects of the process. Therefore, determining the optimal design necessitates the utilisation of a well-planned experiment, which exposes the process to various levels of design parameters.

Mixture designs stand out as specialised experimental designs that provide precise insights when the response varies based on the relative proportions of components (Beg 2021). This design is regarded as more efficient than traditional methods like one-factor-at-a-time and response surface experiments, as it considers independent factors as proportions of different mixture components (Beg 2021). These designs are particularly valuable when striving to identify optimal factor settings for products existing in a mixed form.

The utility of this mixture design approach has been successfully demonstrated in practical applications such as optimising polymers and other materials (Homkhiew *et al.* 2013, Rostamiyan *et al.* 2014, Attia *et al.* 2021), determining food additive content (Gama *et al.* 2019, Dias *et al.* 2021), and evaluating the bioactivities of functional foods (Bertin *et al.* 2020, Houketchang Ndomou *et al.* 2023). However, there has been limited or no scientific

work dedicated to standardising the production processes of 'pyer-kushu' drink.

Therefore, the primary objective of this study was to create a nonalcoholic malted drink, 'pyer-kushu,' that is both natural and nutritionally rich. This indigenous malted beverage has the potential to address hunger, malnutrition, and nutrient deficiencies by providing essential nutrients. Furthermore, the cultivation and production of sorghum for this purpose can contribute to diversifying the economy by creating numerous income opportunities for local brewers, farmers, and brewing industries and serving as a source of foreign exchange.

MATERIALS AND METHODS

Materials

The varieties of sorghum used in this study, 'Koyanga' red and 'Moskwa' white were purchased from Garaha, Hong Local Government Area of Adamawa state. The experiment was carried out in the Department of Food Science and Technology Laboratory, Moddibo Adama University Yola, Adamawa State, Nigeria. The chemicals and reagents for the experiment are of analytical grade and were all obtained from this laboratory.

Sample preparation (malting processing)

The malting processing was carried out by following the procedure outlined by Badau *et al.* (2006). The sorghum varieties were steeped at 32°C for 12 hours, with the steeping liquor changed every 6 hours. After the steeping, the grains were submerged in a 0.1% solution of commercial bleach, specifically 3.5% sodium hypochlorite. After sterilisation, the grains were wrapped in a damp cotton cloth and placed on a wet jute bag. The grains were allowed to germinate at 32°C for 72 hours. During germination, water was sprayed onto the grains, and agitated by a wooden rod. The grains were moistened twice daily for 48 hours, then sprayed and turned over in the afternoon. After germination, the grains were dried in an oven at 50°C for 24 hours. The dried grains were then polished to remove shoots and rootlets, which were separated from the kernels by rubbing the mixture between palms over a mesh sieve.

The experimental design

Based on the previous studies, some of the important facts about the characteristics of 'pyer-kushu' drink, the limits for malted 'koyanga' red sorghum (MRS) and 'Moskwa' white sorghum (MWS) were set to 10% for the lower limit and 20% for the upper limit. On the other hand, the constraints of unmalted 'koyanga' red sorghum (URS) and 'Moskwa' white sorghum (UWS) were set to 30% for the lower limit and 40% for the upper limit. This was done to allow for a comprehensive analysis of how these variations affect the physicochemical and mineral properties of the beverage. These constraints were chosen based on the preliminary work and field survey carried out on the product. Because the experimental space is irregular, the classical mixture design approach, such as the simplex design, cannot be applied (Rambali *et al.* 2003). Therefore, a D-optimal mixture design was selected.

A D-optimal design is a form of experimental design. Its aim is to ensure that the number of experimental runs is as low as possible; yet, the design still results in high-quality, predictive models. D-optimal designs are not about being optimal in any overall sense but rather about being optimal from the perspective of the runs that have been chosen and from the perspective of using as few runs as possible (Montgomery 2017). In contrast to conventional mixture designs that demand many more experimental runs and employ standard simplex-lattice or simplex-centroid designs, the D-optimal approach selects just a few experimental points that best estimate the mixture response surface. Sergis & Ouellet-Plamondon (2022) reported that the D-optimal design minimises the number of necessary experimental runs while still providing high-quality predictive models. Squeo *et al.* (2021) further reported that D-optimal design facilitates the inclusion of constraints (for example, to ensure a balanced ratio of fortifying ingredients) without necessitating a full factorial or simplex design. The D-optimal design guarantees the evaluation of the most important formulations while ensuring that the quality of the final product is not adversely affected. This optimisation also allows us to

reduce the number of points that must be evaluated in the experiment and guarantees that the proportions under consideration at each point are estimated with sufficient reliability, which results in the savings of both time and money.

The mixture of the two sorghum varieties will apparently affect the “pyer-kushu” drink, and then a third-order interaction between the two sorghum varieties and the “pyer-kushu” drink was expected. Therefore, the following special cubic model was proposed and used to analyse the effects of the mixture of the two sorghum varieties on the “pyer-kushu” drink:

$$Y = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{14} X_1 X_4 + \beta_{23} X_2 X_3 + \beta_{24} X_2 X_4 + \beta_{34} X_3 X_4 + \beta_{1234} X_1 X_2 X_3 X_4 \quad (1)$$

where Y is the response; X_1, X_2, X_3, X_4 are the proportions of different flour types (MRS, MWS, URS, UWS); $\beta_1, \beta_2, \beta_3, \beta_4$ are the linear coefficients representing the effect of individual ingredients; $\beta_{12}, \beta_{13}, \beta_{23}, \beta_{34}$ are the interaction coefficients representing the combined effects of two ingredients; and β_{1234} indicates complex interactions.

The candidate points were chosen by the software, and from the candidate points, 8 runs were chosen to establish the model, 2 runs were used to measure the lack of fit, and 2 runs were replicated for the experimental error, so a total of 12 runs were generated. The D-optimal mixture design and response results are shown in Table 1.

Production of “pyer-kushu”

One kilogram (1 kg) of each variety was milled into grits, and another 1 kg was used to produce malted flour. Based on the experimental run proportions (Table 1), the unmalted grits were weighed and mixed with water to form a slurry.

The slurry was allowed to settle for 12 hours, and the fluid was decanted, leaving the grits behind. The decanted fluid was then poured into a pot and placed on the fire to boil at 100°C. The left-behind grits were then transferred to the boiling filtrate and allowed to cook for 30 minutes at

100°C and cool to about 43°C.

Next, the malted milled sorghum flour was weighed to the required proportion as specified in the experimental run table, mashed in hot water at 60°C for 20 minutes, and cooled. After that, the cooked grit and the cooled mash were mixed and cooked for about 10 minutes at 100°C, and they were allowed to stay overnight. The mixture was then filtered to obtain fine, thin wort; then, it was pasteurised at 73°C for 5 minutes and hot-filled into packaging material. The flow chart in Figure 1 provides a visual representation of these steps, while Figure 2 shows the produced “pyer-kushu” samples.

Physicochemical analysis of “pyer-kushu”

The pH values of the samples were measured with a digital pH metre (Model: EQ-610, Equip-Tronics), in accordance with the AOAC (2016) method. The procedures outlined by Hussein & Filli (2018) were used to determine the total solids, total soluble solids (% Brix), and titratable acidity. The specific gravity bottle was used to determine the specific gravity, while the foaming capacity was expressed as a percentage rise in volume, as reported by Falade & Okafor (2015). The viscosity of the “pyer-kushu” samples was determined using a Brookfield DV2T digital viscometer at 25 °C and a shear rate of 100 s⁻¹, following standard analytical protocols. Using atomic absorption spectroscopy, the mineral elements sodium (Na), iron (Fe), manganese (Mn), calcium (Ca), and phosphorus (P) were determined as described by the AOAC (2016) method.

Microbial analysis of ‘pyer-kushu’

The materials utilised in the experiment underwent sterilisation through autoclaving at a pressure of 1 kg/cm² (121°C) for 15 minutes. Glassware was sterilised using dry heat at a temperature of 160°C for 60 minutes. To maintain a sterile working environment, the workplace was meticulously cleaned with antiseptic measures to reduce microbial presence.

The prepared media were sterilised at 1 kg/cm² (121°C) for 15 minutes and then placed in a

Table 1. The D-optimal mixture design for ‘pyer-kushu’ drink

S/N	Experimental mixture				Response	
	MRS	MWS	URS	UWS	R1	R2
A	20.00	12.90	30.00	37.10	X_1	X_1
B	13.70	13.40	39.20	33.70	X_2	X_2
C	16.20	10.00	35.30	38.50	X_3	X_3
D	10.00	10.00	40.00	40.00	X_4	X_4
E	20.00	10.00	40.00	30.00	X_5	X_5
F	13.70	13.40	39.20	33.70	X_6	X_6
G	18.50	16.20	35.30	30.00	X_7	X_7
H	17.00	20.00	30.00	33.00	X_8	X_8
I	15.30	15.50	33.70	35.60	X_9	X_9
J	10.00	18.20	35.30	36.40	X_{10}	X_{10}
K	10.00	20.00	40.00	30.00	X_{11}	X_{11}
L	13.20	16.80	30.00	40.00	X_{12}	X_{12}

Where: MRS = malted red sorghum (“Koyanga”); MWS = malted white sorghum (“Moskwa”); URS = unmalted red sorghum; UWS = unmalted white sorghum. R1 and R2 are responses. X_i denotes the values of each response.

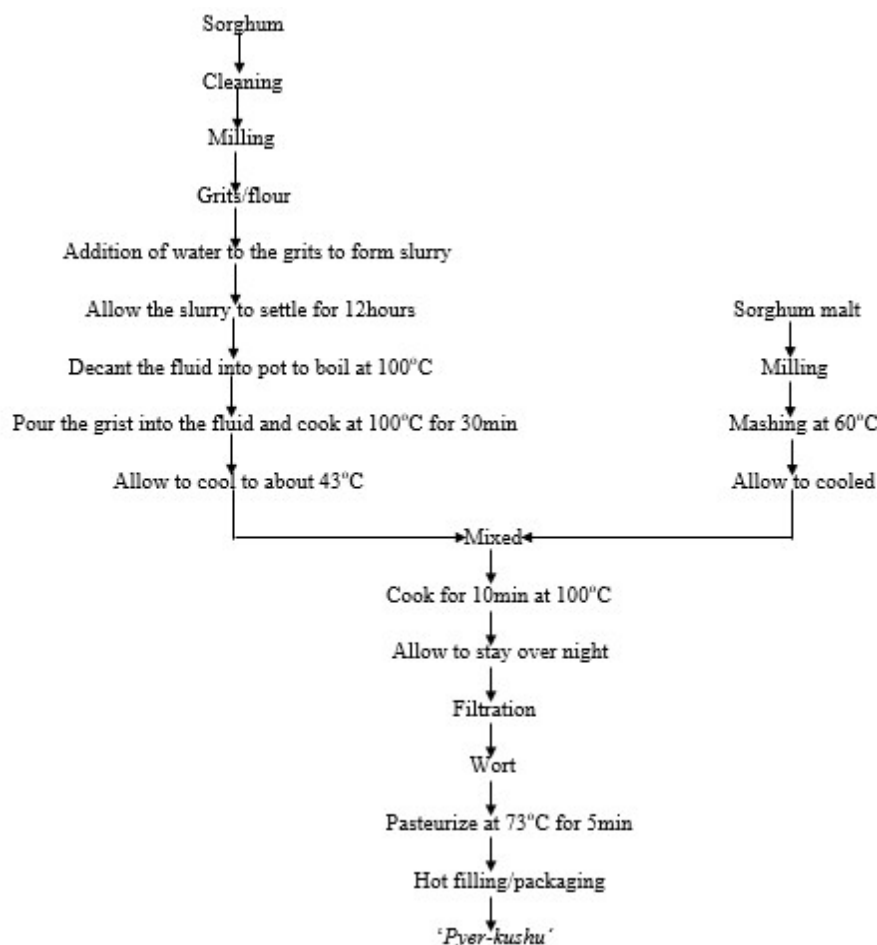
**Figure 1. Flow Chart for ‘Pyer-kushu’ Production Process**



Figure 2. ‘Pyer-kushu’ drinks

water bath at 100°C to prevent gelling before application, following the method outlined by Msheliza *et al.* (2018).

A Bunsen burner was employed for “heat fixing” smears and sterilising equipment such as wire loops. Inoculation techniques, including streaking and pour plating, were employed for the cultivation and subculture processes.

One (1 g) of ‘pyer-kushu’ sample was meticulously transferred into a bottle with 9 mL of distilled water to create the stock solution, following the procedure outlined by Jideani & Jideani (2006). Subsequently, 1 mL of the stock solution was aseptically transferred into successive bottles containing sterile distilled water using a sterile pipette.

This transfer was carried out sequentially from the first to the second bottle, then from the second to the third, and finally from the third to the fourth, continuing until the necessary serial dilution was achieved.

From the prepared sample, 1 mL of the diluent from a test tube was transferred in aseptic conditions into a cleaned and sterilised labelled

plate using a sterile pipette, following the pour plate count method. The lid of each plate was aseptically opened to introduce approximately 15 mL of molten medium (nutrient agar) into the plate (Petri dish), ensuring complete coverage of the bottom of the plate.

The mixture was gently swirled, allowed to cool, and solidified before being incubated at 35°C for 24 hours, as per the methodology described by Jideani & Jideani (2006). The number of microorganisms per gram of the original sample (colony-forming unit per millimeter [Cfu/mL]) was determined using Equation 2.

$$\text{Cfu/mL} = \frac{\text{Number of colonies}}{\text{Volume transferred to the plate}} \times \text{Dilution blank factor} \quad (2)$$

Sensory evaluation of ‘pyer-kushu’

Fifty semi-trained panellists, comprising students of food science and technology as well as members of the local community, were carefully chosen to participate in the sensory evaluation of the ‘pyer-kushu’ drink.

Selection criteria included their familiarity with the sensory qualities of ‘pyer-kushu’, availability for the entire evaluation period, interest,

willingness to participate, and a lack of allergies or sensitivities to the product being assessed. The panellists were instructed to rank the products based on various quality attributes, including appearance, sweetness, flavour, mouthfeel, sourness, bitterness, and overall acceptability. A 7-point hedonic scale was employed for this purpose, where 1 represented 'dislike very much,' and 7 represented 'like very much,' following the scale described by Iwe (2010).

The 'pyer-kushu' drink samples, labelled from A to N, were served to the panellists in transparent plastic containers. To ensure an unbiased evaluation, the panellists were instructed to rinse their mouths with fresh room-temperature water provided before each serving. The containers with the samples were strategically spaced to prevent crowding and facilitate independent judgement.

Statistical analyses

The Design Expert software (Version 11.0, Stat-Ease Inc., Minneapolis, USA) was utilised to calculate the D-optimal design points within the experimental domain for the proposed model, selected from the candidate runs. All experiments were conducted in triplicate, and the results were presented as means $\pm$ standard error.

An analysis of variance (ANOVA) was performed to assess significant differences in measurements using SPSS statistical analysis software (Version 20.0 for Windows; SPSS Inc., Chicago, IL, USA) with a confidence level of 95%. The significance of differences between means was determined through Duncan multiple tests, and a difference was deemed significant at ($p < 0.05$).

RESULTS AND DISCUSSION

Physiochemical properties of 'pyer-kushu' drink

The results obtained from the physiochemical analysis of 'pyer-kushu' drinks are presented in Table 2. The results show a significant difference

($p < 0.05$) observed in the pH, total solids, total soluble solids, titratable acidity, viscosity, and specific gravity. But the result obtained for the foam capacity of the samples shows no significant difference. The results showed that the pH of the 'pyer-kushu' drink samples was slightly acidic, and it ranged from 4.39 to 5.62, with sample A having the highest value and sample I having the lowest pH value. These findings suggest that the acidity level of the 'pyer-kushu' drinks may vary among different samples, thereby suggesting that 'pyer-kushu' drinks may have a tart or sour taste profile.

The pH values are somewhat lower than those reported by Abdel Moneim *et al.* (2017), with a range of 6.43–6.39. Akonor *et al.* (2014) reported a range of pH values for malt drinks produced from roasted maize from 5.01 to 5.21, and Obuzor & Ajaezi (2010) also reported that the pH values of some commercial carbonated malt beverages range from 4.4 to 4.6.

These findings suggest that the pH values of the samples in this study fall within the expected range for malt drinks and carbonated beverages. It is important to note that variations in pH values can occur due to differences in production methods and ingredients used.

The total solid content represents both soluble and insoluble material in the 'pyer-kushu' drinks. The percentage total solid content of the 'pyer-kushu' drink ranges from 8.80 to 19.16. Sample B had the highest value (19.16), while sample F had the lowest value (8.80). The samples showed significant differences ($p < 0.05$). The values were significantly higher than the 5.38% reported by Hosseini *et al.* (2012) for non-alcoholic malt drinks prepared from oats and barley.

These variations in ingredients and filtration process may result in different levels of soluble and insoluble material in the 'pyer-kushu' drinks, leading to the observed differences in total solid content. Additionally, it is important to note that the higher total solid content in the 'pyer-kushu' samples may have implications for the taste, texture, and overall quality of the drink.

The total soluble solids in food drinks represent the dissolved solids as sugar. The total soluble solids of 'pyer-kushu' drink ranged from 5.33 to 6.06°Brix. Sample M had the highest value (6.06), while sample L had the lowest value (5.33). These values were within the 3.20 to 12.30°Brix range that Akonor *et al.* (2014) reported for non-alcoholic malt beverages made with roasted malted maize. However, the variation in total soluble solid levels among the samples may be attributed to differences in the production process or ingredient composition. It is important to note that total soluble solids levels can affect the taste and sweetness of a drink, so these values provide insight into the flavour profile of 'pyer-kushu'.

Titrateable acidity acts as a preservative and also imparts taste. The titrateable acidity of the 'pyer-kushu' drink shows a significant difference ($p < 0.05$) and ranges from 0.22 to 0.35. The highest titrateable acidity was obtained from sample A (0.35) and the lowest from sample I (0.22). These variations in titrateable acidity levels suggest that the different samples of the 'pyer-kushu' drink may have distinct flavours and levels of acidity. These values also suggest that 'pyer-kushu' drink is an unfermented product and, therefore, non-alcoholic. The findings from Akonor *et al.* (2014) further support the conclusion that 'pyer-kushu' is a non-alcoholic product, similar to other malt beverages made with roasted malted maize.

The specific gravity of 'pyer-kushu' drink samples ranged from 1.00 to 1.06. Samples A, C, and J gave the highest specific gravity value (1.06), while sample F had the lowest value (1.00). These results corroborated the range of 1.012–1.045 reported by Abdel Moneim *et al.* (2017) for malted drinks produced from sorghum. The specific gravity of all the 'pyer-kushu' samples indicated that the drink is non-alcoholic, as they are unfermented and comparable to the specific gravity of water. Samuel & Usman (2020) also reported a specific gravity of 1.02–1.05 in malt drinks produced from the blends of sorghum and millet, which shows close comparability to what was obtained for these 'pyer-kushu' samples. These findings suggest that the specific gravity values obtained

for the 'pyer-kushu' samples are consistent with previous research on malted drinks made from sorghum and other grains. This further supports the conclusion that the 'pyer-kushu' drink is non-alcoholic and similar in composition to other malted beverages.

The foam capacity of the samples ranged from 10 to 40%. Samples B, C, and I recorded the highest percentage foam capacity value (40%), while samples E and G had the lowest (10%). The foam capacity of the 'pyer-kushu' produced correlates with the range of 10–50% reported by Samuel & Usman (2020) for malted drinks produced from the blends of sorghum and millet. Consumers view the formation of foam in beverages as a crucial quality indicator, which depends on factors such as malt source and brewing method (Kordialik-Bogacka & Antczak 2011). The range of 10–50% reported by Samuel & Usman (2020) aligns with the foam capacity observed in the 'pyer-kushu' samples, suggesting the consistency of the foam capacity results obtained in this study.

The viscosity of the 'pyer-kushu' drink samples showed a significant difference ($p < 0.05$) and varied from 4.68 to 5.34 cP. Sample I had the highest viscosity (5.34 cP), while sample G had the lowest (4.68 cP). The higher viscosity compared to those reported by Samuel & Usman (2020) suggests that the ingredients used in 'pyer-kushu' may contribute to its thicker consistency and greater resistance to flow. This could be attributed to variations in processing methods or the specific types and proportions of sorghum and millet used in the blends.

Viscosity determines the rheological flow property of the drink, which is essential in food processing as it changes significantly during heating, cooling, homogenising, and concentration (Polachini *et al.* 2023). A thicker consistency and greater resistance to flow may enhance the texture, mouthfeel, and stability of the drink, contributing to consumer satisfaction.

The summary of the ANOVA for the physicochemical properties of the 'pyer-kushu' drink is presented in Table ???. A represents

Table 2. Physicochemical properties of ‘pyer-kushu’ drink

S/N	MRS	MWS	URS	UWS	pH	%TS	%TSS	%TTA	SG	%FC	Viscosity (cP)
A	20.00	12.90	30.00	37.10	5.62 ± 0.26 ^a	16.06 ± 0.76 ^b	5.60 ± 0.12 ^{cd}	0.35 ± 0.01 ^a	1.06 ± 0.01 ^a	30.00 ± 0.01 ^b	4.85 ± 0.05 ^{gh}
B	13.70	13.40	39.20	33.70	4.43 ± 0.14 ^{fg}	19.16 ± 1.10 ^a	5.80 ± 0.01 ^b	0.24 ± 0.01 ^{gh}	1.05 ± 0.01 ^{ab}	40.00 ± 0.01 ^a	5.07 ± 0.01 ^{de}
C	16.20	10.00	35.30	38.50	5.07 ± 0.04 ^{bc}	14.30 ± 0.61 ^{bcd}	5.40 ± 0.01 ^{ef}	0.29 ± 0.01 ^{cdef}	1.06 ± 0.01 ^a	40.00 ± 0.01 ^a	4.72 ± 0.02 ⁱ
D	10.00	10.00	40.00	40.00	5.03 ± 0.05 ^{bc}	12.53 ± 1.11 ^{cdef}	5.60 ± 0.01 ^{cd}	0.26 ± 0.01 ^{fgh}	1.03 ± 0.01 ^{abcd}	20.00 ± 0.01 ^c	4.88 ± 0.08 ^g
E	20.00	10.00	40.00	30.00	4.52 ± 0.22 ^{def}	12.26 ± 0.67 ^{def}	5.80 ± 0.01 ^b	0.28 ± 0.03 ^{def}	1.04 ± 0.01 ^{abc}	10.00 ± 0.01 ^d	5.02 ± 0.03 ^{de}
F	13.70	13.40	39.20	33.70	4.59 ± 0.18 ^{def}	8.80 ± 0.61 ^h	5.40 ± 0.01 ^{ef}	0.32 ± 0.01 ^{abc}	1.00 ± 0.01 ^d	30.00 ± 0.01 ^b	5.00 ± 0.03 ^{ef}
G	18.50	16.20	35.30	30.00	5.59 ± 0.10 ^b	10.76 ± 0.77 ^{fgh}	5.60 ± 0.01 ^{cd}	0.25 ± 0.01 ^{fgh}	1.02 ± 0.01 ^{bcd}	10.00 ± 0.01 ^d	4.68 ± 0.01 ⁱ
H	17.00	20.00	30.00	33.00	5.03 ± 0.04 ^{bc}	14.80 ± 0.84 ^{bc}	5.50 ± 0.01 ^{de}	0.31 ± 0.02 ^{bcd}	1.03 ± 0.01 ^{abcd}	20.00 ± 0.01 ^c	5.15 ± 0.01 ^{bcd}
I	15.30	15.50	33.70	35.60	4.39 ± 0.01 ^g	13.66 ± 0.76 ^{cde}	5.40 ± 0.01 ^{ef}	0.22 ± 0.01 ^h	1.04 ± 0.01 ^{abc}	40.00 ± 0.01 ^a	5.34 ± 0.04 ^a
J	10.00	18.20	35.30	36.40	5.30 ± 0.16 ^{ab}	13.33 ± 0.71 ^{cde}	5.80 ± 0.01 ^b	0.34 ± 0.01 ^{ab}	1.06 ± 0.01 ^a	30.00 ± 0.01 ^b	5.18 ± 0.01 ^b
K	10.00	20.00	40.00	30.00	4.80 ± 0.09 ^{cde}	11.50 ± 0.31 ^{efg}	6.00 ± 0.01 ^a	0.30 ± 0.01 ^{cde}	1.01 ± 0.01 ^{cd}	20.00 ± 0.01 ^c	4.93 ± 0.03 ^{fg}
L	13.20	16.80	30.00	40.00	4.89 ± 0.09 ^{cd}	14.30 ± 0.55 ^{bcd}	5.33 ± 0.07 ^f	0.26 ± 0.01 ^{fgh}	1.03 ± 0.01 ^{abc}	10.00 ± 0.01 ^d	4.76 ± 0.05 ^{hi}

Means in the same column bearing different superscripts are significantly different at (p<0.05).

Key: TS = Total solid; TSS = Total soluble solid; TTA = Titratable acidity; SG = Specific gravity; FC = Foam capacity

Table 3. Summary of the ANOVA for the physicochemical properties of ‘pyer-kushu’ drink

Dependent variables	Model level of significance	Model terms	F-value	p-value	R ² – value
pH	Reduced Special Cubic model	Linear Mixture, AB, AC, AD, BD, CD, ABD, ACD	14.33	0.20	0.9931
TS	Linear model	Linear Mixture	0.54	0.67	0.1673
TSS	Linear model	Linear Mixture	2.70	0.12	0.5034
TTA	Quadratic model	Linear Mixture, AB, AC, AD, BC, BD, CD	0.32	0.91	0.5891
SG	Reduced Special Quartic model	Linear Mixture, BC, BD, CD, B ² CD	1.39	0.40	0.7082
FC	Reduced Special Cubic model	Linear Mixture, AD, BC, BD, CD, BCD	3.54	0.16	0.9043
VC	Reduced Special Cubic model	Linear Mixture, AB, AD, BC, BD, CD, ABD, BCD	19.86	0.17	0.9950

Key: TS = Total solid; TSS = Total soluble solid; TTA = Titratable acidity; SG = Specific gravity; FC = Foam capacity; VC = Viscosity.

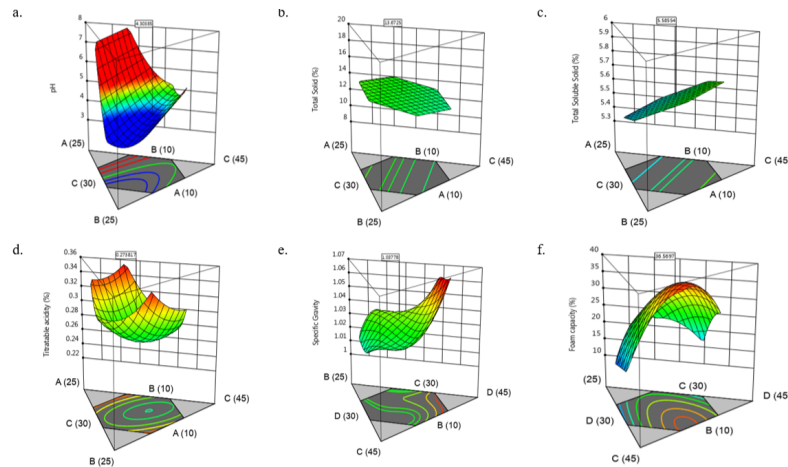


Figure 3. Surface plot showing the effect of MRS (A), MWS (B), URS (C) and UWS (D) on the physicochemical properties of ‘pyer-kushu’ drink.

malted red sorghum (MRS), B represents malted white sorghum (MWS), C represents unmalted red sorghum (URS), and D represents unmalted white sorghum (UWS). Terms with a single letter state linear effects, while two letters indicate interaction effects. The ANOVA gave reduced special quartic and cubic models with significant ($p < 0.05$) effects on the pH, foaming capacity, and viscosity of the ‘pyer-kushu’ drink. A linear model was obtained for total solids and total soluble solids, while quadratic and reduced quartic models were obtained for titratable acidity and specific gravity, respectively. However, low R² values (≤ 0.7082) obtained for total solids, total soluble solids, titratable acidity, and specific gravity indicate less reliability of the selected models

for these qualities. Hussein *et al.* (2022) noted that the closer R² is to 1.00, the better. This suggests that the predicted model based on these equations with high R² is highly reliable in explaining the variability of the test qualities of the ‘pyer-kushu’ drink. Therefore, it can be used effectively in the optimisation process to achieve a product with optimal characteristics and improve customer satisfaction.

$$\begin{aligned}
 \text{pH} = & 34.96x_1 - 5.41x_2 + 8.11x_3 + 8.01x_4 \\
 & - 0.08x_1x_2 - 1.00x_1x_3 - 1.02x_1x_4 \\
 & + 0.03x_2x_3 - 0.34x_3x_4 \\
 & + 0.00041x_1x_2x_4 + 0.03x_1x_3x_4
 \end{aligned}
 \quad (3)$$

$$\text{Total solid (\%)} = 0.19x_1 + 1.00x_2 - 0.03x_3 + 0.29x_4 \quad (4)$$

$$\begin{aligned} \text{Total soluble solid (°Brix)} &= 0.05x_1 + 0.07x_2 \\ &+ 0.08x_3 + 0.03x_4 \end{aligned} \quad (5)$$

$$\begin{aligned} \text{Titrateable acidity (\%)} &= 0.13x_1 + 0.06x_2 \\ &+ 0.00229x_3 - 0.07x_4 \\ &- 0.00329x_1x_2 \\ &- 0.00239x_1x_3 \\ &+ 0.00030x_1x_4 \\ &- 0.00124x_2x_3 \\ &+ 0.00112x_3x_4 \\ &+ 0.00150x_2x_4 \end{aligned} \quad (6)$$

$$\begin{aligned} \text{Specific gravity} &= 1.00x_1 + 1.07x_2 + 1.07x_3 \\ &+ 1.21x_4 - 0.26x_2x_3 \\ &- 0.55x_2x_4 - 0.43x_3x_4 \\ &+ 5.83x_2^2x_4 \end{aligned} \quad (7)$$

$$\begin{aligned} \text{Foaming capacity (\%)} &= -19.67x_1 + 28.90x_2 \\ &+ 1.47x_3 - 17.02x_4 \\ &+ 0.87x_1x_2 - 1.09x_2x_3 \\ &- 0.72x_2x_4 + 0.21x_3x_4 \\ &+ 0.04x_2x_3x_4 \end{aligned} \quad (8)$$

$$\begin{aligned} \text{Viscosity (m}^2\text{/s)} &= 1016x_1 - 118.39x_2 - 36.19x_3 \\ &- 53.49x_4 + 0.68x_1x_2 \\ &+ 0.58x_1x_3 + 3.55x_2x_3 \\ &+ 4.50x_2x_4 + 188x_3x_4 \\ &- 0.03x_1x_2x_4 - 0.11x_2x_3x_4 \end{aligned} \quad (9)$$

Optimization of Mixture Combinations

The optimum mixture combinations of 20% MRS, 12.91% MWS, 30% URS, and 37.09% UWS gave an optimum pH value of 5.63 at a desirability level of 1. It was found that the best

total solid was 11.48% at a desirability level of 0.741 when the mixtures of 10% MRS, 20% MWS, 40% URS, and 30% UWS were mixed together. A mixture combination of 10% MRS, 20% MWS, 40% URS, and 30% UWS was achieved to obtain an optimum total soluble solid of 5.89% at a desirability level of 0.841. The best mixture was found to be 15.40% MRS, 15.13% MWS, 39.47% URS, and 30.00% UWS, which led to an optimal titrateable acidity of 0.22% at a desirability level of 1. A mix of 10% MRS, 18.22% MWS, 35.34% URS, and 36.44% UWS was found to have the best specific gravity of 1.06 at a level of desirability 1.

The best mix of ingredients for getting a foaming capacity of 9.25% was found to be 13.21% MRS, 16.79% MWS, 30% URS, and 30% UWS at a desirability level of 1. The best mix for getting a viscosity of 3.51 m²/s at a desirability level of 1 was found to be 10.64% MRS, 19.02% MWS, 39.02% URS, and 31.33% UWS. These results suggest that the combination of MRS, MWS, URS, and UWS in the specified proportions can achieve the desired level of the test qualities. That is, the chosen mixture combinations resulted in the desired levels of the 'pyer-kushu' drink qualities with high desirability.

The mineral composition of 'pyer-kushu' drink

The results obtained from mineral analysis of 'pyer-kushu' drink are presented in Table 4. The results showed significant differences ($p < 0.05$) among all the samples. The sodium content of the 'pyer-kushu' drink varied from 21.00 to 23.66 mg/100g, with sample C having the lowest value of 21.00 mg/100g, while sample G had the highest value of 23.66 mg/100g. Sodium is an essential mineral that helps to control body water and regulate thirst. Sodium is both an electrolyte and mineral; it helps keep the water (the amount of fluid inside and outside the body's cells) and electrolyte balance. Sodium is also essential for how nerves and muscles work. In addition to its role in controlling body water and regulating thirst, sodium is crucial for the proper functioning of nerves and muscles (Stanhewicz & Larry Kenney 2015). The significant differences in sodium content among the samples indicate that the 'pyer-kushu'

Table 4. Mineral compositions of ‘pyer-kushu’ drink (mg/100g)

S/N	Experimental mixtures					Response			
	MRS	MWS	URS	UWS	Sodium	Calcium	Manganese	Iron	Phosphorus
A	20.00	12.90	30.00	37.10	21.83 ± 0.64 ^{bcd}	6.10 ± 0.06 ^a	39.26 ± 0.22 ^{ab}	7.26 ± 0.09 ^c	2.60 ± 0.17 ^d
B	13.70	13.40	39.20	33.70	21.40 ± 0.15 ^d	5.63 ± 0.03 ^a	34.33 ± 0.62 ^h	9.13 ± 0.09 ^a	2.06 ± 0.03 ^e
C	16.20	10.00	35.30	38.50	21.00 ± 0.01 ^d	3.60 ± 0.15 ^{cd}	40.00 ± 0.12 ^a	8.00 ± 0.06 ^b	3.16 ± 0.12 ^c
D	10.00	10.00	40.00	40.00	21.66 ± 0.41 ^{cd}	4.66 ± 0.28 ^b	28.66 ± 0.62 ^j	6.86 ± 0.20 ^{cd}	3.66 ± 0.28 ^b
E	20.00	10.00	40.00	30.00	21.76 ± 0.42 ^{bcd}	5.70 ± 0.06 ^a	37.36 ± 0.50 ^{cdef}	6.73 ± 0.12 ^{cd}	4.26 ± 0.09 ^a
F	13.70	13.40	39.20	33.70	22.60 ± 0.36 ^{abc}	5.66 ± 0.28 ^a	31.30 ± 0.65 ⁱ	6.70 ± 0.23 ^{cd}	2.00 ± 0.06 ^e
G	18.50	16.20	35.30	30.00	23.66 ± 0.52 ^a	4.10 ± 0.40 ^{bc}	35.80 ± 0.90 ^g	6.13 ± 0.15 ^e	3.00 ± 0.06 ^c
H	17.00	20.00	30.00	33.00	21.56 ± 0.27 ^{cd}	4.13 ± 0.09 ^{bc}	35.63 ± 0.12 ^g	5.93 ± 0.03 ^e	3.60 ± 0.12 ^b
I	15.30	15.50	33.70	35.60	23.40 ± 0.25 ^a	5.86 ± 0.09 ^a	38.26 ± 0.24 ^{bc}	6.83 ± 0.07 ^{cd}	3.06 ± 0.03 ^c
J	10.00	18.20	35.30	36.40	21.76 ± 0.09 ^{bcd}	5.73 ± 0.07 ^a	36.43 ± 0.13 ^{efg}	6.13 ± 0.03 ^e	2.96 ± 0.12 ^c
K	10.00	20.00	40.00	30.00	22.80 ± 0.10 ^{ab}	5.76 ± 0.07 ^a	36.10 ± 0.25 ^{fg}	5.93 ± 0.33 ^e	3.00 ± 0.06 ^c
L	13.20	16.80	30.00	40.00	23.43 ± 0.27 ^a	4.43 ± 0.27 ^b	37.93 ± 0.18 ^{cd}	7.03 ± 0.07 ^{bc}	3.06 ± 0.03 ^c

Means in the same column bearing different superscript are significantly different at ($p < 0.05$).

Key: MRS = Malted Koyanga Red Sorghum; MWS = Malted Moskwa White Sorghum;

URS = Unmalted Koyanga Red Sorghum; UWS = Unmalted Moskwa White Sorghum.

drink can vary in its potential impact on these bodily functions.

Mineral composition of ‘pyer-kushu’ drink

The calcium content of ‘pyer-kushu’ drink ranges from 3.60 to 6.10 mg/100g; sample A recorded the highest value of 6.10 mg/100g, and sample C had the lowest value of 3.60 mg/100g. The mineral content in ‘pyer-kushu’ drink plays a vital role in many biological functions such as reproduction, diabetes control, stress level, immune resistance, smell, taste, physical growth, appetite, and digestion. Calcium is an essential mineral for maintaining strong bones and teeth, as well as aiding in muscle function and nerve transmission.

Additionally, it is important for blood clotting and regulating blood pressure (Soetan *et al.* 2010, Chaudhari & Dadheech 2023). It has a natural calming and tranquillizing effect and is necessary for maintaining a regular heartbeat and the transmission of nerve impulses. Furthermore, calcium is involved in the release of certain hormones and enzymes that are crucial for various bodily processes. It also helps in maintaining proper pH levels in the body and supports the function of other minerals like magnesium and potassium (Ali 2023). Overall, the presence of calcium in ‘pyer-kushu’ drink contributes to overall health and well-being by supporting multiple physiological functions.

The manganese content of the ‘pyer-kushu’ drink ranged from 28.66 to 40.00 mg/100g, with sample C having the highest value of 40.00 mg/100 ml, while sample D had the lowest value of 28.66 mg/100g. These findings indicate that the ‘pyer-kushu’ drink is a good source of manganese, as it exceeds the recommended daily intake for this mineral. The variation in manganese content among the samples suggests potential differences in the production process or ingredient composition.

Manganese is a powerful antioxidant that searches for free radicals in the human body, neutralises these damaging particles, and prevents any potential danger they may cause. In addition to its role as an antioxidant, manganese also plays a crucial role in the metabolism of carbohydrates, amino acids, and cholesterol.

It is involved in the production of enzymes that are essential for proper digestion and nutrient absorption (Rondanelli *et al.* 2021). Therefore, maintaining adequate levels of manganese is vital for overall health and well-being. The iron content of ‘pyer-kushu’ drinks ranged from 5.93 to 9.13 mg/100g, with samples H and K having the lowest value of 5.93 mg/100g each, while sample B had the highest value of 9.13 mg/100g. These findings suggest that the iron content in ‘pyer-kushu’ drinks can vary

significantly. It is important to consider these variations when assessing the nutritional value of different samples. Iron is crucial for the proper functioning of the body, as it is involved in various biological processes. It acts as an oxygen carrier and can also function as a protein-bound redox element, according to East *et al.* (2021). Therefore, understanding the variations in iron content in 'pyer-kushu' drinks is important for assessing their nutritional value and potential health benefits.

Phosphorus is an essential mineral that is involved in various physiological processes, such as energy production, DNA synthesis, and bone mineralization. It is found in high amounts in foods like dairy products, meat, and whole grains. Additionally, phosphorus works closely with calcium to maintain strong and healthy bones and teeth (Serna & Bergwitz 2020). In addition to its role in bone and tooth formation, phosphorus is also essential for maintaining a healthy pH balance in the body. It helps regulate the acidity of bodily fluids, ensuring the proper functioning of enzymes and other biochemical processes. The phosphorus of the 'pyer-kushu' drink produced ranged from 2.00 to 3.66 mg/100g, with sample F having the lower value of 2.00 mg/100g, while sample D had the highest value of 3.66 mg/100g. These findings suggest that the 'pyer-kushu' drink can be a good source of phosphorus, contributing to overall bone health and pH balance in the body. It is important to consume a balanced diet that includes foods rich in phosphorus to ensure optimal bodily functions. The nutritional quantity and quality of these locally made drinks make them a better option than conventional soft drinks for those who prioritise health and wellness.

The ANOVA table (Table 5) gave a reduced cubic model with the model term (linear mixture, BD, CD, BD(B-D)) for sodium contents and a reduced special quartic model with the model term (linear mixture, AC, AD, CD, AC²D) for iron contents. These models significantly ($p < 0.05$) affected the sodium and iron contents of the 'pyer-kushu' drink. A quadratic model with the model terms: linear mixture, AB, AC, AD, BC, BD, CD; linear mixture, AB, AC, AD, BC,

BD, CD; and linear mixture, AB, AC, AD, BC, BD, CD, were obtained for calcium, manganese, and phosphorus contents, respectively. These models also significantly ($p < 0.05$) affected the calcium, manganese, and phosphorus contents of the 'pyer-kushu' drink.

The mixture D optimal design based on the value of the mineral composition of 'pyer-kushu' drink gave a predicted model, Equations 10, 11, 12, 13, and 14, respectively, for sodium, calcium, manganese, iron, and phosphorus contents. These equations had a significant effect on the mineral qualities evaluated, so the value of these responses may be used for the optimisation process to get a product with optimum characteristics.

The high coefficient of determination ($R^2 \geq 0.8846$) obtained for calcium, manganese, and phosphorus contents indicates a good explanation of the variability of the selected model for these mineral qualities of the 'pyer-kushu' drink.

$$\begin{aligned} \text{Na} = & 24.42x_1 + 26.64x_2 + 18.82x_3 + 13.44x_4 \\ & + 6.09x_2x_4 + 22.25x_3x_4 \\ & - 100.00x_2x_4(x_2 - x_4) \end{aligned} \quad (10)$$

$$\begin{aligned} \text{Ca} = & 2.46x_1 - 2.70x_2 + 0.77x_3 - 1.53x_4 \\ & - 0.02x_1x_2 - 0.01x_1x_3 + 0.01x_1x_4 \\ & + 0.01x_2x_3 + 0.08x_3x_4 + 0.01x_3x_4 \end{aligned} \quad (11)$$

$$\begin{aligned} \text{Mg} = & -2.67x_1 + 4.51x_2 - 3.16x_3 + 0.78x_4 \\ & - 0.14x_1x_2 + 0.14x_1x_4 + 0.01x_1x_4 \\ & + 0.01x_2x_3 + 0.08x_2x_4 + 0.01x_3x_4 \end{aligned} \quad (12)$$

$$\begin{aligned} \text{Fe} = & 10.00x_1 + 2.90x_2 + 9.25x_3 + 10.90x_4 \\ & - 11.67x_1x_3 - 12.01x_1x_4 - 12.71x_3x_4 \\ & + 226.42x_1x_3^2x_4 \end{aligned} \quad (13)$$

Table 5. The summary of the ANOVA for the mineral compositions of ‘pyer-kushu’ drink

Dependent variables	Model level of significance	Model terms	F-value	p-value	R ² value
Sodium contents	Reduced Cubic model	Linear Mixture, BD, CD, BD(B-D)	3.08	0.12	0.7870
Calcium contents	Quadratic model	Linear Mixture, AB, AC, AD, BC, BD, CD	1.78	0.41	0.8890
Manganese contents	Quadratic model	Linear Mixture, AB, AC, AD, BC, BD, CD	4.04	0.21	0.9478
Iron contents	Reduced Special Quartic model	Linear Mixture, AC, AD, CD, AC ² D	1.11	0.49	0.6611
Phosphorus contents	Quadratic model	Linear Mixture, AB, AC, AD, BC, BD, CD	1.70	0.42	0.8846

$$\begin{aligned}
 P = & 1.15x_1 + 2.83x_2 - 0.09x_3 + 0.65x_4 \\
 & - 0.04x_1x_2 + 0.00162x_1x_3 - 0.03x_1x_4 \\
 & - 0.04x_2x_3 - 0.05x_2x_4 - 0.01x_3x_4
 \end{aligned}
 \quad (14)$$

The low R² values of 0.7870 and 0.6611 for the sodium and iron contents, on the other hand, shows that the chosen model is less reliable for these mineral qualities of the ‘pyer-kushu’ drink. Hussein *et al.* (2022) reported that the closer the R² was to 1.00, the better. However, according to Chauhan & Gupta (2004), an R² of more than 0.75 may also be appropriate when fitting a model. This suggests that the predicted model based on these equations with high R² is highly reliable in explaining the variability of the mineral qualities of the ‘pyer-kushu’ drink. Therefore, it can be used effectively in the optimisation process to achieve a product with optimal characteristics and improve customer satisfaction. The use of this model can lead to a more consistent and desirable mineral composition in the ‘pyer-kushu’ drink.

Conversely, the model’s F-value and p-value indicate that the model lacks significance. Nevertheless, the analysis of the surface plot (Fig. 4) demonstrated that the increase in the proportion of MRS had the most significant effect on raising the manganese content. On the other hand, the increase in URS had the greatest impact on elevating the calcium content. Additionally, the increase in UWS had the highest contribution to enhancing the sodium, iron, and phosphorus contents of the ‘pyer-

kushu’ drink. According to Rambali *et al.* (2003), model terms are considered significant when the p-values are less than 0.05, signaling statistical importance. Conversely, p-values exceeding 0.10 suggest that the model terms lack significance and should be considered non-significant. The optimum mixture combination of 11.45% MRS, 13.36% MWS, 35.19% URS, and 40% UWS gave an optimum sodium content of 24.03 mg/100g at a desirability level of 1. A mixture combination of 10.49% MRS, 15.84% MWS, 39.91% URS, and 33.75% UWS was achieved to obtain an optimum calcium content of 6.99 mg/100g at a desirability level of 1.

The best mixture was found to be 20% MRS, 10% MWS, 34.15% URS, and 34.85% UWS, which led to a manganese content of 42.32 mg/100g at a desirability level of 1.

A mix of 14.95% MRS, 10% MWS, 40% URS, and 35.05% UWS was found to have the best iron contents of 9.95 mg/100g at a desirability level of 1. The best mix of ingredients for getting phosphorus contents of 4.29 mg/100g was found to be 20% MRS, 20% MWS, 30% URS, and 30% UWS at a desirability level of 1.

These results suggest that the combination of MRS, MWS, URS, and UWS in the specified proportions can achieve the desired level of mineral qualities. That is, the chosen mixture combinations resulted in the desired levels of the “pyer-kushu” drink qualities with high desirability. However, it is important to note that

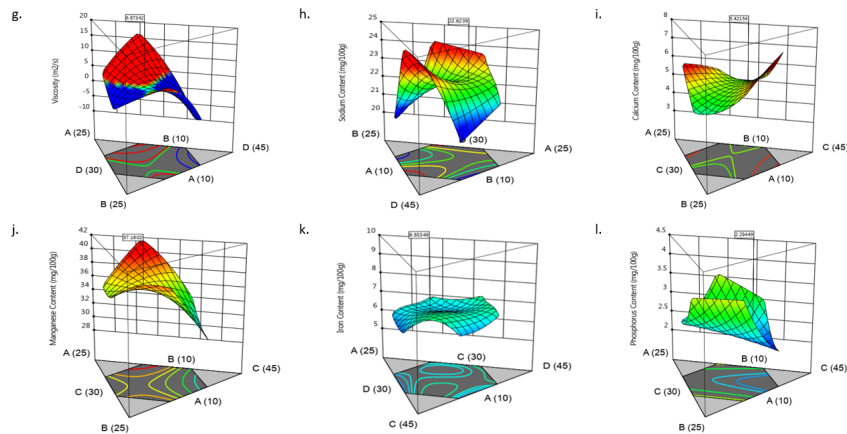


Figure 4. Surface plot showing the effect of MRS (A), MWS (B), URS (C) and UWS (D) on the mineral compositions of ‘pyer-kushu’ drink.

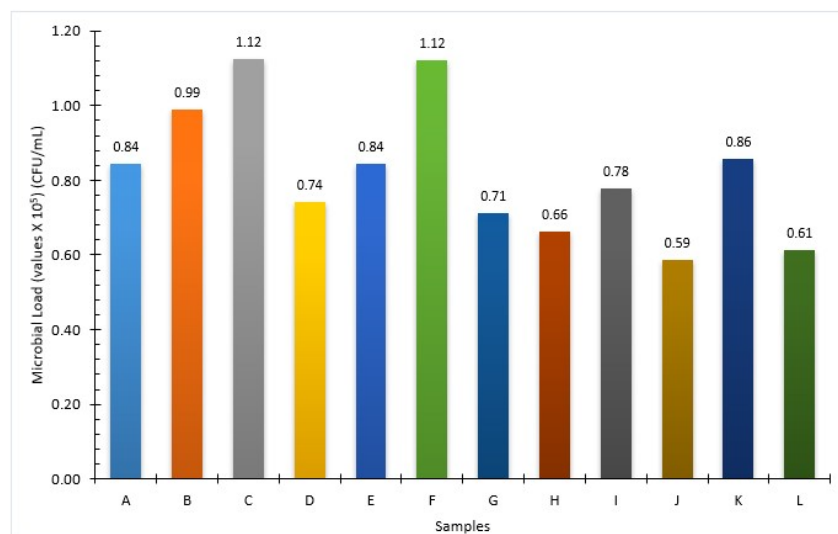


Figure 5. Microbial load of ‘pyer-kushu’ drinks.

Table 6. Sensory qualities of “pyer-kushu” drinks

S/N	Experimental mixtures				Sensory Qualities					
	MRS	MWS	URS	UWS	Appearance	Flavour	Mouthfeel	Sourness	Bitterness	Overall acceptance
A	20.00	12.90	30.00	37.10	6.80 ± 0.23 ^a	6.50 ± 0.17 ^a	6.60 ± 0.22 ^a	6.15 ± 0.28 ^{ab}	6.60 ± 0.21 ^a	6.54 ± 0.08 ^{ab}
B	13.70	13.40	39.20	33.70	6.40 ± 0.22 ^a	6.30 ± 0.23 ^a	6.35 ± 0.23 ^{ab}	5.55 ± 0.37 ^b	4.90 ± 0.38 ^b	6.03 ± 0.14 ^c
C	16.20	10.00	35.30	38.50	6.65 ± 0.17 ^a	6.90 ± 0.26 ^a	6.75 ± 0.22 ^a	6.35 ± 0.22 ^{ab}	5.95 ± 0.30 ^a	6.56 ± 0.11 ^{ab}
D	10.00	10.00	40.00	40.00	6.85 ± 0.17 ^a	6.40 ± 0.20 ^a	6.60 ± 0.25 ^a	6.50 ± 0.29 ^{ab}	6.00 ± 0.35 ^a	6.53 ± 0.09 ^{ab}
E	20.00	10.00	40.00	30.00	6.65 ± 0.29 ^a	6.30 ± 0.26 ^a	6.10 ± 0.41 ^{ab}	6.15 ± 0.39 ^{ab}	6.05 ± 0.32 ^a	6.25 ± 0.16 ^{bc}
F	13.70	13.40	39.20	33.70	6.75 ± 0.20 ^a	6.70 ± 0.27 ^a	6.85 ± 0.21 ^a	6.35 ± 0.20 ^{ab}	6.60 ± 0.27 ^a	6.71 ± 0.08 ^a
G	18.50	16.20	35.30	30.00	6.95 ± 0.17 ^a	6.50 ± 0.14 ^a	6.35 ± 0.21 ^{ab}	6.20 ± 0.17 ^{ab}	6.40 ± 0.20 ^a	6.54 ± 0.08 ^{ab}
H	17.00	20.00	30.00	33.00	6.90 ± 0.16 ^a	6.70 ± 0.22 ^a	6.60 ± 0.20 ^a	6.25 ± 0.22 ^{ab}	5.90 ± 0.30 ^a	6.50 ± 0.08 ^{ab}
I	15.30	15.50	33.70	35.60	6.70 ± 0.19 ^a	6.93 ± 0.21 ^a	6.45 ± 0.20 ^{ab}	6.70 ± 0.18 ^a	6.55 ± 0.23 ^a	6.69 ± 0.85 ^a
J	10.00	18.20	35.30	36.40	6.85 ± 0.22 ^a	6.65 ± 0.17 ^a	6.65 ± 0.17 ^a	6.60 ± 0.20 ^a	6.60 ± 0.33 ^a	6.71 ± 0.87 ^a
K	10.00	20.00	40.00	30.00	6.70 ± 0.19 ^a	6.60 ± 0.25 ^a	6.50 ± 0.27 ^a	5.95 ± 0.21 ^{ab}	6.70 ± 0.22 ^a	6.53 ± 0.78 ^{ab}
L	13.20	16.80	30.00	40.00	6.70 ± 0.16 ^a	6.75 ± 0.23 ^a	6.30 ± 0.28 ^{ab}	6.30 ± 0.28 ^{ab}	6.35 ± 0.25 ^a	6.45 ± 0.70 ^{ab}

Means in the same column bearing different superscripts are significantly different at ($p < 0.05$).

Key: MRS = Malted Red Sorghum (“Koyanga”); MWS = Malted White Sorghum (“Moskwa”); URS = Unmalted Red Sorghum; UWS = Unmalted White Sorghum.

further experiments and analysis may be needed to validate these findings and ensure consistent product performance in different conditions or variations.

Microbial load analysis of “pyer-kushu” drink

The microbial load analysis helps in determining the safety and quality of the product. It also helps identify any potential harmful microorganisms that may be present, ensuring that the malt drink meets the necessary regulatory standards for consumption. The results of the bacterial load count of the “pyer-kushu” drink samples are depicted in Fig. 5. The colony-forming units (CFU/mL) of the “pyer-kushu” drink ranged from 5.9×10^4 to 1.12×10^5 CFU/mL. Samples C and F had the highest bacterial load count of 1.12×10^5 CFU/mL, while sample J had the lowest value of 5.9×10^4 CFU/mL.

This indicates that the bacterial contamination levels varied among the different samples of the “pyer-kushu” drink. Notwithstanding, the results obtained in this research were within the tolerable limits of less than 10^6 CFU/mL for microorganisms in ready-to-eat foods (Aboagye *et al.*, 2020). Thus, the microbial analysis of the “pyer-kushu” drink reveals that all the drinks are safe for consumption. The microbial analysis also showed the absence of harmful pathogens or contaminants. Therefore, consumers can enjoy the “pyer-kushu” drink without any concerns for their health. However, it is important to note that regular monitoring and quality control measures should be implemented to maintain the microbial safety of the product.

Sensory evaluation of “pyer-kushu” drinks

The results obtained from the sensory evaluation of “pyer-kushu” drink are presented in Table 6. The sensory scores ranged from 6.40 to 6.95 for appearance, 6.30 to 6.93 for flavour, 6.10 to 6.85 for mouthfeel, 5.55 to 6.70 for sourness, 4.90 to 6.70 for bitterness, and 6.03 to 6.71 for overall acceptability. The result shows no significant difference ($p > 0.05$) in the “pyer-kushu” drinks in terms of their appearance, sweetness, and flavour. On the other hand, there was a significant difference ($p < 0.05$) in terms of mouthfeel, sourness, bitterness, and overall

acceptability. The sensory evaluation of the “pyer-kushu” drink revealed that the appearance, flavour, mouthfeel, sourness, bitterness, and overall acceptability all fell within a preferred range of scores. This suggests that the drink consistently delivered a satisfactory sensory experience across these attributes.

Also, the sensory evaluation results indicate that the “pyer-kushu” drinks were well-received by the panellists, as they preferred them based on the scores obtained. However, there was a slight difference in terms of overall acceptability among the drinks. This difference in overall acceptability may be attributed to variations in the intensity of certain attributes such as sweetness or bitterness. Further analysis could help identify the specific factors that contributed to this variation and potentially improve the overall acceptability of the “pyer-kushu” drinks.

CONCLUSION

This study successfully developed and optimised a traditional nonalcoholic malted beverage, “pyer-kushu,” using locally sourced red (Koyanga) and white (Moskwa) sorghum varieties in both malted and unmalted forms. The application of a D-optimal mixture design provided an efficient and statistically robust framework for evaluating the impact of sorghum blend ratios on the drink’s physicochemical and mineral properties. The results of the study have provided insights into the nutritive value of “pyer-kushu” drink.

The best formulation, 20.00% MKRS, 12.90% MMWS, 30.00% UKRS, and 37.10% UMWS, achieved high sensory acceptability, microbial safety, and nutritional quality, with a desirability value of 1.0, indicating a well-balanced product. Based on these findings, it is recommended that this optimum blend be adopted for local-scale and possibly industrial-scale production of “pyer-kushu,” with standardised processing methods to ensure quality consistency. Government and development agencies can support smallholder farmers and local brewers to scale up sorghum-based beverage production as a strategy for nutritional security and economic empowerment in rural communities.

It is believed that moderate consumption of the “pyer-kushu” beverage across diverse demographics will undoubtedly enhance the overall health and well-being of the population. Additionally, there is a conviction that the production and distribution of these indigenous beverages have the potential to foster economic prosperity, particularly benefiting sorghum farmers and unemployed youths. Furthermore, the promotion of these local beverages can also help preserve cultural traditions and heritage.

For future studies, it is recommended to examine the shelf stability of the optimised “pyer-kushu” drink under different storage conditions, assess consumer preferences across diverse demographics, and explore the addition of functional ingredients (e.g., probiotics or plant extracts) to enhance its health benefits. Additionally, a comparative economic analysis with commercial malt drinks would offer insight into its market potential and commercial viability.

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