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Formulation and Characterisation of a Hibiscus–Baobab-Based Functional Drink with Enhanced Nutritional and Antioxidant Properties

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Abstract
The purpose of this article is to develop a functional plant-based beverage that harnesses the nutritional and bioactive properties of baobab powder and hibiscus flower extract. A completely randomised design was used in the study, with baobab levels of 1 per cent, 2 per cent, and 3 per cent and hibiscus extract concentrations of 6.25 per cent, 12.5 per cent, and 25 per cent. A total of nine variants were evaluated for sensory, physicochemical, phytochemical, antioxidant activity, and nutritional attributes. Sensory evaluation was conducted by 25 untrained panellists familiar with ready-to-drink beverages using a 5-point hedonic scale. Analysis of variance (ANOVA) was conducted at a significance level of $p \leq 0.05$. The hibiscus ratio of 12.5 per cent:1 per cent (HLB) recorded the highest sensory rating, particularly for overall acceptability (1.72). Subsequent analyses compared HLB with controls comprising a 2 per cent baobab drink and a 12.5 per cent hibiscus drink. The HLB formulation had a colour intensity of 136 Pfund and vitamin C content of 0.82 mg/g, while fructose levels did not differ significantly among the samples. No microbial growth was observed after culturing the drink. HLB contained the highest total phenolic content (47.51 mg GAE/100 g) and total flavonoid content (296.27 mg QE/100 g), alongside strong antioxidant activity, as reflected by the lowest DPPH IC50 value (10.32 mg/mL). Therefore, the 12.5 per cent:1 per cent formulation demonstrated favourable sensory acceptance, nutritional and antioxidant potential, and microbiological stability, highlighting its potential as a functional plant-based beverage.

Keywords: Antioxidant activity, baobab, functional beverage, *Hibiscus sabdariffa,* phytochemicals.

INTRODUCTION

Rising consumer interest in healthier, plant-based functional foods has heightened the demand for drinks that offer natural bioactive compounds in addition to nutritional advantages (Fehér et al., 2020). This has opened avenues for creating functional drinks using native African plant resources, especially those possessing complementary nutritional and phytochemical characteristics. *Hibiscus sabdariffa* and *Adansonia digitata* (baobab) are encouraging components for these drinks as they provide complementary functional qualities. Hibiscus contains significant levels of anthocyanins, phenolic compounds, and organic acids that give it its distinctive red hue, tartness, and antioxidant properties, whereas baobab fruit pulp provides vitamin C, dietary fibre, minerals, phenolic compounds, and additional bioactive elements (Chadare et al., 2008; Reyes-Jurado et al., 2023). The combination of hibiscus and baobab creates a chance to produce a plant-based functional drink that offers improved nutritional and phytochemical benefits while fostering the use and added value of native plant resources.

Among the promising indigenous plant-based ingredients, hibiscus and baobab possess substantial nutritional and functional potential. For instance, *Hibiscus calyces* are widely consumed in beverages due to their characteristic red pigmentation, refreshing acidic taste, and high content of anthocyanins, flavonoids, phenolic acids, and organic acids (Da-Costa-Rocha et al., 2014). Recent studies have demonstrated that hibiscus beverages contain substantial levels of bioactive compounds associated with antioxidant, anti-inflammatory, antihypertensive, and metabolic health benefits (Riaz & Chopra, 2018; Izquierdo-Vega et al., 2020). The antioxidant activity of hibiscus is mainly attributed to compounds such as delphinidin-3-sambubioside, cyanidin derivatives, chlorogenic acid, and protocatechuic acid, which contribute to free radical scavenging, hence the reduction of oxidative stress (Da-Costa-Rocha et al., 2014).

Similarly, baobab fruit pulp has equally attracted increasing scientific and commercial interest because of its rich nutritional composition, particularly vitamin C, dietary fibre, minerals, amino acids, and polyphenolic compounds (Braca et al., 2018). Baobab has traditionally been used in African communities as a refreshing drink ingredient and medicinal food due to its pleasant acidic flavour and nutritional value (Chadare et al., 2008; Braca et al., 2018). In addition, baobab contributes desirable sensory and physicochemical properties, including natural acidity, flavour enhancement, and soluble solids, which are crucial for beverage stability and consumer acceptability (Muhammad et al., 2025).

Despite the nutritional and functional potential of hibiscus and baobab, formulating acceptable plant-based beverages remains challenging because incorporating bioactive-rich plant materials can affect acidity, flavour balance, mouthfeel, colour intensity, and overall sensory perception. Elevated levels of phenolic compounds and organic acids may result in pronounced sour, astringent, or bitter tastes, which can negatively affect consumer acceptability (Cömert & Gökmen, 2018). Furthermore, interactions between phytochemicals and other food components may alter physicochemical stability, antioxidant activity, and nutritional quality of the final beverage (Jakobek, 2015). There have been no prior baobab-hibiscus mix products developed in order to harness their nutrient-rich and health-promoting attributes. It is unclear how a combination of these ingredients would interact to achieve an acceptable shelf-stable product.

Therefore, the aim of this study was to develop and characterise a functional plant-based beverage formulated from hibiscus and baobab powder, with emphasis on sensory attributes, physicochemical properties, phytochemical composition, antioxidant activity, mineral content, and amino acid profile. The findings of this study will provide scientific insights into the potential benefits of combining hibiscus and baobab as complementary ingredients for the development of a nutrient- and antioxidant-rich beverage.

METHODOLOGY

Chemicals

Analytical-grade reagents were used throughout the study unless otherwise stated and were procured from Merck KGaA (64271 Darmstadt, Germany). Sodium hydroxide (NaOH), 2,2-diphenyl-1-picrylhydrazyl (DPPH), amino acid standard-18 (AA-S-18), nutrient agar, liquid chromatography-mass spectrometry (LC-MS)-grade water, LC-MS-grade acetonitrile, fructose, sucrose, glucose, ascorbic acid, $AlCl_3$, methanol, H_3PO_4, quercetin, Folin-Ciocalteu reagent, sodium carbonate, gallic acid, H_2SO_4, linalool, HCl, formic acid, and mixed element standard.

Product Formulation

Table 1 presents the different combinations of baobab and hibiscus, together with their respective controls. The study adopted a completely randomised design, with

baobab incorporated at levels of 1 per cent, 2 per cent, and 3 per cent, while hibiscus extract was used at concentrations of 6.25 per cent, 12.5 per cent, and 25 per cent, respectively. A total of nine different variations were produced for sensory, physicochemical, phytochemical, antioxidant activity, and nutritional attributes.

Table 1: Product Formulation

Boabab/Hibiscus	6.25%	12.5%	25%
F1 (1% powder)	1:6.25	1:12.5	1:25
F2 (2% powder)	2:6.25	2:12.5	2:25
F3 (3% powder)	3:6.25	3:12.5	3:25
(F4 (Boabab powder- 2%) Control 1			
F5 (Hibiscus 12.5%) Control 2			

Sensory Attributes

The formulated products were subjected to sensory evaluation using a five-point hedonic scale as described by Micene et al. (2020) with minor modifications, where 1 represented "liked extremely" and 5 represented "disliked extremely." Samples were assigned random codes to minimise bias during evaluation. The sensory attributes assessed included colour, flavour, taste, mouthfeel, and overall acceptability. The panellists were selected on a voluntary basis and were requested to sign a consent form to approve their participation in the study. The best formulation was selected for further analyses.

Microbial Growth

The formulated samples were examined for microbiological quality using the total mesophilic aerobic plate count method. Briefly, 1 mL of each sample was aseptically transferred into sterile diluent and serially diluted ten-fold to obtain dilutions of 10^{-1}, 10^{-2}, and 10^{-3}. From each dilution, 1 mL was aseptically inoculated onto sterile Petri plates containing 25 mL of sterile nutrient agar. The inoculated plates were gently mixed and allowed to solidify before incubation at 37 °C for 18 h. Following incubation, visible colonies on the plates were enumerated, and plates with a suitable countable range were used to determine the microbial load, which was expressed as colony-forming units per millilitre (CFU/mL). The microbial count was calculated using the following formula:

CFU/mL = Number of colonies × Dilution factor / Volume of sample plated (mL).

Where plates from more than one dilution fell within the countable range, the dilution producing the most reliable count was used. Results were reported as CFU/mL, and where appropriate, microbial counts were converted to $\log_{10}$ CFU/mL for statistical analysis. All analyses were performed in triplicate.

Physicochemical Analyses

These were done following the Horwitz and Latimer (2005) protocols, with minor modifications where applicable.

Colour (Pfund; Mm)

Colour of the hibiscus/baobab formulations was determined using the Pfund scale method. Briefly, homogenised samples were placed in a clean cuvette and absorbance measured at 635 nm using a UV–Vis spectrophotometer against distilled water as the blank. The absorbance values were converted to Pfund values (mm) using the following equation:

where represents the absorbance measured at 635 nm. The resulting Pfund values were used to compare colour intensity among the different formulations.

pH and Free Acidity

A pH meter was utilised to determine the pH of 10 mL of the sample. Determination of free acidity was done by titrating the same sample solution with 0.1 M NaOH until pH 8.3.

Electrical Conductivity

A Jenway conductivity meter (Model 3540) was employed to determine the electrical conductivity of 10 mL of the sample. The meter was calibrated with a conductivity solution before taking the readings of samples.

Total Dissolved Solids (TDS)

The TDS was measured using a TDS conductivity meter. The probe was directly inserted into 10 mL of the

sample, and TDS values were recorded (ppt). The presence of ions from dissolved solids allows the sample to conduct electricity, and the resulting conductivity is measured using a standard conductivity or TDS meter.

Vitamin C

The sample was prepared as earlier described, with minor modifications (Ňorbová et al., 2023). Briefly, 8 g of the sample was mixed with 25 mL of the extraction agent (1% mercaptoethanol). This was followed by 15 minutes of ultrasonic-assisted extraction in an ultrasound bath. The extracted solution was thereafter passed through a 0.45 µm PVDF filter, and the resulting filtrate was transferred into clean glass vials prior to HPLC analysis.

Vitamin C concentration was determined using high-performance liquid chromatography (HPLC) coupled with diode-array detection (DAD). The external standard method and calibration curve were used for identification and quantification (ascorbic acid standard). A C18 column (dimensions 150 x 4.6 mm, with a particle diameter of 5 µm) was used for the separation. Mobile phase solutions consisted of methanol and 0.01% H_3PO_4 in ddH2O (v/v). The isocratic elution was as follows: 0-10 min (20% methanol and 80% acidified water). The analysis employed a flow rate of 0.8 mL/min with 10 µL of sample injected. The oven temperature was maintained at 30 °C, whereas the samples were kept at 8 °C within the autosampler compartment. The detection and quantification wavelength was set at 254 nm.

Phytochemical Contents

Total Flavonoids Content (TFC)

The total flavonoid content (TFC) of the samples was quantified by the aluminium chloride colourimetric assay following Mokaya et al. (2023). A 1 mL portion of the sample solution, prepared at 50 mg/mL in 50 per cent methanol, was mixed with 4 mL of 50 per cent methanol and 0.3 mL of 5 per cent $NaNO_2$ solution. Following 5 min of incubation, 0.3 mL of 10 per cent $AlCl_3$ solution was introduced, and the mixture was left to stand for 1 min. This was followed by the addition of 2 mL of 1 M NaOH and 2.4 mL of 50 per cent methanol. Absorbance was recorded at 510 nm using a Jenway 6850 UV/Vis spectrophotometer (Kobian), while a reagent blank comprising all reagents except the sample solution was used as the reference. Quercetin was employed as the standard for calibration, using concentrations ranging from 20 to 200 µg/mL, and TFC was reported as mg QE/100 g of sample.

Total Phenols Content (TPC)

Total phenolic content (TPC) was quantified using the Folin–Ciocalteu colourimetric method following the procedure of Mokaya et al. (2023). Briefly, 1 mL of the sample solution (50 mg/mL prepared in 50 per cent methanol) was combined with 5 mL of 0.2 N Folin–Ciocalteu reagent and allowed to react for 5 min. Subsequently, 4 mL of sodium carbonate solution (75 g/L) was added, and the mixture was incubated at room temperature for 2 h. The absorbance was then measured at 760 nm using a UV/Vis spectrophotometer against a reagent blank containing all reagents except the sample, which was replaced with 50 per cent methanol. Gallic acid was used as the reference standard to construct a calibration curve over the range of 0–250 µg/mL. The results were expressed as milligrams of gallic acid equivalents per 100 g of sample (mg GAE/100 g)

Total Terpenoid Content (TTC)

Total terpenoid content (TTC) was determined using a colourimetric method adapted from Malik (2017) with slight modifications. Briefly, 100 µL of the sample solution (50 mg/mL in 50% methanol) was mixed with 1.5 mL of chloroform and vortexed at 3,000 rpm for 3 min. Thereafter, 100 µL of concentrated H_2SO_4 was added, and the reaction mixture was incubated in the dark for 1 h 30 min without disturbance. Following incubation, the supernatant was carefully decanted, leaving the reddish-brown precipitate intact. The precipitate was then dissolved in 1.5 mL of methanol followed by vortex mixing. The same procedure was performed for linalool standard solutions prepared at concentrations ranging from 10–500 mg/mL to generate the calibration curve. Absorbance was measured at 538 nm using a UV/Vis spectrophotometer against a reagent blank containing all reagents except the sample solution, which was replaced with 50 per cent methanol. Total terpenoid content was expressed as milligrams linalool equivalents per 100 g of sample (mg LE/100 g).

In-Vitro Antioxidant Activity

2,2-Diphenyl-1-Picrylhydrazyl (DPPH) Assay

The DPPH radical scavenging activity of the samples was evaluated according to the method described by Mokaya et al. (2024) with slight adjustments. The reaction mixture consisted of 5.4 mL of sample solutions prepared at different concentrations in 50 per cent methanol, and 0.6 mL of 0.8 mM DPPH solution prepared in 95 per cent methanol. The mixtures were kept in the dark at room temperature for 30 min, followed by absorbance measurement at 517 nm using a UV/Vis spectrophotometer. A control solution containing

all reagents except the sample extract, which was replaced with 50 per cent methanol, was prepared under the same conditions. The percentage DPPH radical scavenging activity was calculated using the following equation:

$$Scavenging\ activity\ (\%) = \frac{(Acontrol - Asample)}{Acontrol} x100$$

where $A_{control}$ is the absorbance of the control, and A_{sample} is the absorbance of the sample. The sample concentration providing 50 per cent inhibition (IC_{50}) was calculated using the graph by plotting the percentage scavenging activity against the sample concentration.

Sugars Profile

Glucose, fructose, and sucrose contents were analysed using High-Performance Liquid Chromatography (HPLC) following the method described by Mokaya et al. (2020). The mobile phase consisted of water and acetonitrile at a 25:75 (v/v) ratio and was delivered at a flow rate of 1 mL/min. Sugar separation was achieved using a 5 µm LC-NH_2 column (250 mm × 4.6 mm; Supelco, Bellefonte, PA, USA). The HPLC system (Agilent Technologies) was equipped with a binary pump, an autosampler, and a refractive index detector. Quantification was based on external calibration curves prepared using standard sugar solutions, with the results presented as grams per 100 g of sample or per cent.

Statistical Analysis

Data analysis was performed using RStudio version 2.0–5, GraphPad Prism version 8, and PAST software version 4.06b. Statistical differences among samples were determined using one-way analysis of variance (ANOVA), followed by Tukey's test for mean separation. All results were presented as mean ± standard deviation (SD) based on three independent replicates, with statistical significance set at $p \leq 0.05$.

FINDINGS AND DISCUSSION

Sensory Attributes

The sensory evaluation revealed variation among the hibiscus/baobab powder formulations, with lower scores indicating greater consumer preference (Figure 1). For instance, acceptability improved as the formulations approached balanced hibiscus: baobab ratios, with the 12.5:1 formulation recording the lowest score (1.8), indicating the highest overall preference. In contrast, formulations with high hibiscus proportions such as 25:1 and 25:2 had the highest overall acceptability scores (>3.2), suggesting lower consumer acceptance. Flavour and taste followed a similar pattern, where the 12.5:1 formulation achieved the best flavour and taste scores (1.7–1.8), demonstrating superior palatability. Meanwhile, the 25:3 formulation showed relatively poor taste perception (3.1), while flavour scores remained high in 25:1 and 25:2 (>3.0), likely due to excessive tartness or astringency associated with hibiscus dominance.

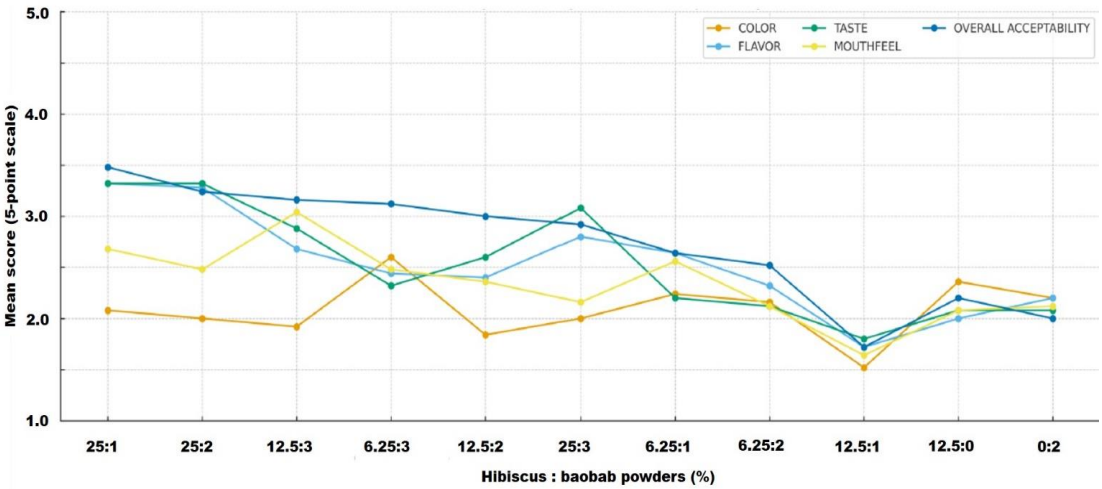

Figure 1: Sensory Attributes (Colour, Flavour, Taste, Mouthfeel and Overall Acceptability) of the Different Combinations of Baobab and Hibiscus

The hibiscus–baobab formulations' sensory attributes are affected by the blend of volatile and non-volatile compounds from both plant sources. Beverages derived from plants include volatile substances like acids, alcohols, aldehydes, ketones, esters, and aromatic compounds that enhance aroma and flavour (Vaikma et al., 2021; Di Renzo et al., 2025). In the current research, the higher flavour and taste ratings of the 12.5:1

formulation could indicate a better equilibrium between the distinct acidity and flavour of hibiscus alongside the sensory input of baobab. Conversely, the reduced acceptance of high-hibiscus formulations, especially 25:1 and 25:2, could be linked to a more pronounced tartness or astringency.

Prior studies suggest that merging plant materials can alter and enhance their distinct aroma and flavour traits through interactions between their individual compounds (da Rocha Esperança et al., 2022). This aligns with the current results, suggesting that the addition of baobab may have tempered the prominent sensory attributes of hibiscus and created a more even flavour profile. Nonetheless, since volatile compounds were not chemically identified in this research, their exact role in the detected sensory variations remains unverified. In general, the 12.5:1 formulation offered the best sensory balance and was consequently chosen as the HLB formulation for additional evaluations.

Microbial Analysis

No detectable microbial growth was observed in the HLB formulation during the microbiological analysis, suggesting excellent microbiological stability throughout the evaluation period. This result can be ascribed to the joint influences of pasteurisation, low pH, elevated free acidity, and the incorporation of sodium metabisulfite. Pasteurisation would have decreased the starting microbial level, while the beverage's acidic environment would have established unfavourable conditions for the growth and spread of numerous microorganisms. The low pH and comparatively high free acidity of the HLB formulation (16.66 meq/kg) suggest an acidic setting that limits the growth of various bacterial species. Recent research has shown that the inherent characteristics of fruit and plant-derived drinks, especially pH and organic acid levels, can significantly affect microbial growth and stability (Sourri et al., 2022; Redding et al., 2023).

The presence of sodium metabisulfite might have created an extra antimicrobial challenge. Sulfites are commonly utilised as preservatives in food due to their antimicrobial properties and their role in enhancing the microbiological stability and longevity of products (EFSA, 2022). Moreover, the HLB formulation's comparatively high levels of phenolics and flavonoids may have offered an extra inhibitory effect, since many plant phenolic compounds have antimicrobial characteristics. Nonetheless, in this study, the impact of these phytochemicals cannot be separated from the influences of pasteurisation, acidity, and sodium metabisulfite. Consequently, the lack of identifiable culturable microorganisms should be seen as a probable result of the synergistic preservation challenges posed by heat treatment, acidity, sodium metabisulfite, and possibly bioactive phytochemicals.

The noted microbiological stability aligns with the known connection between beverage acidity and microbial proliferation, as lower pH typically offers enhanced suppression of numerous spoilage and pathogenic microorganisms in acidic plant-based drinks (Sourri et al., 2022; Redding et al., 2023).

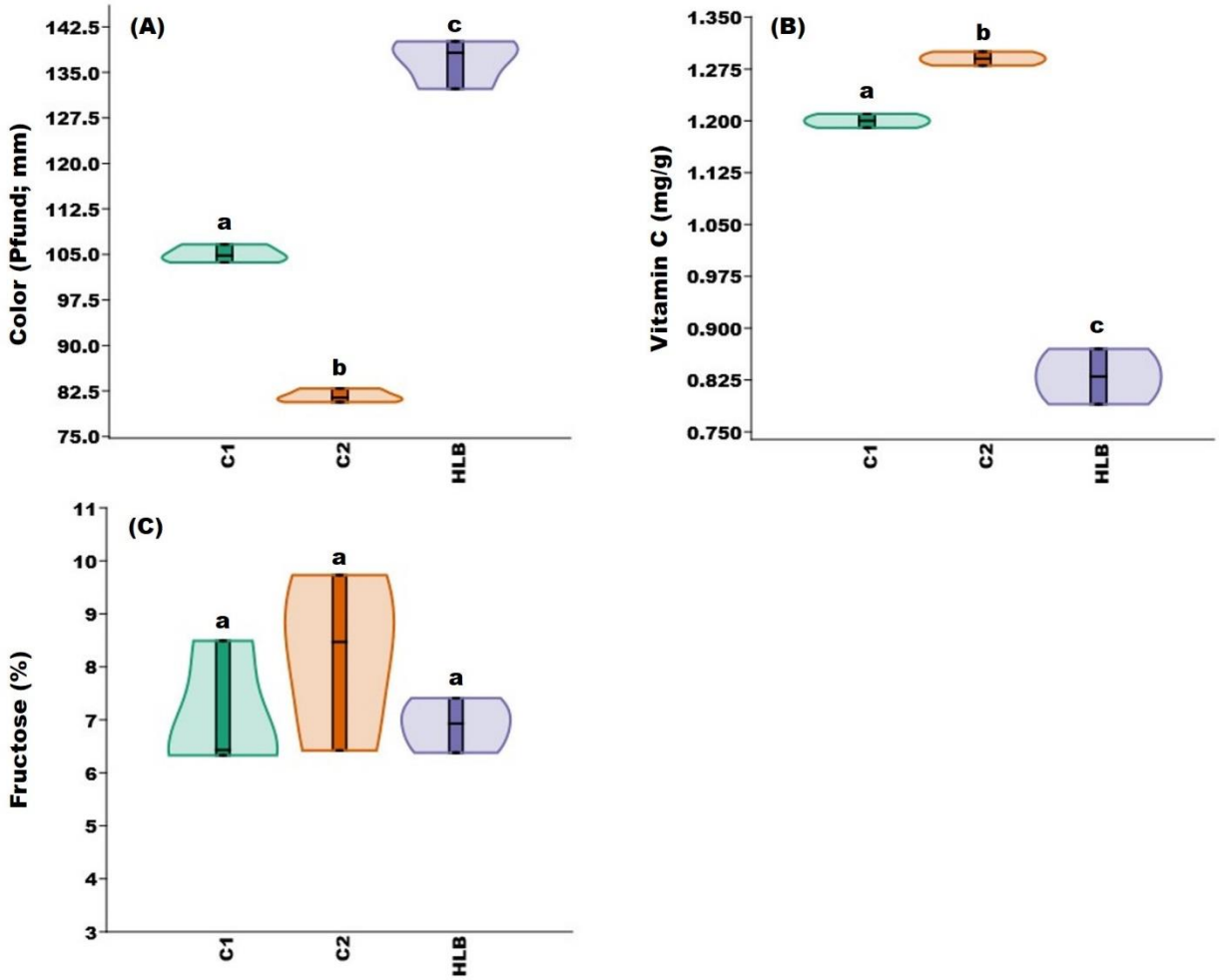

Figure 2: Colour (A), Vitamin C (B), and Fructose (C) Content of the Raw Materials (C1=Baobab and C2=Hibiscus Solutions) and the Formulation (Hlb=12.5% Hibiscus and 1% Baobab Powder)

Physicochemical Parameters

The colour intensity (Figure 2A) varied significantly between the studied samples. For instance, HLB recorded the highest value (136 Pfund, mm), significantly higher than C1 (105 Pfund, mm) and C2 (82 Pfund, mm). This suggests that the HLB formulation possessed a darker or more intense colouration, whereas C2 exhibited the lightest appearance. It has been reported that combining different plant materials seems not only to have a positive impact on sensory attributes, but also on the colour of the final product. For example, a study by Felberg et al. (2009) on a drink with a soy and Brazil nut blend found that this mixture contributed to a change in the product's colour (decreasing the yellow colour and increasing the white colour) and improved the acceptance of the product, corroborating the findings of the current study.

In regard to vitamin C content (Figure 2B), it also varied significantly among samples, where C2 had the highest vitamin C concentration (1.28 mg/g), followed by C1 (1.20 mg/g), while HLB had the lowest value (0.82 mg/g). Both baobab and hibiscus are known natural sources of vitamin C (Ilodibia eta l., 2019; Muhammad et al., 2025). The antioxidant properties of vitamin C help protect cells from oxidative damage caused by free radicals and other reactive oxygen species, thereby contributing to improved nutritional health (Tembo et al., 2017). In contrast, fructose content (Figure 2C) did not differ significantly among the samples ($p > 0.05$). It is important to note that glucose and sucrose were below detectable limits. In a way, the combination of C1 and C2 did not contribute to the vitamin C and sugar improvement of the formulation, which is in agreement with the findings of a previous study (Felberg et al., 2009).

The sample C2 recorded the highest pH (4.17), significantly higher than C1 and HLB, which had comparable pH values of almost 3.4 (Figure 3A). This

suggests that C2 was less acidic, whereas C1 and HLB maintained a more acidic nature. These values are in the 2.5–4.0 range, considered satisfactory limits for acidified beverage preservation, as described by Woodroof and Phillips (Woodroof & Phillips, 1978), and are also comparable to those reported in the literature (Tembo et al., 2017; Muhammad et al., 2025). Meanwhile, free acidity followed the opposite trend, with HLB showing the highest value (16.66 meq/kg), followed by C1 (12.33 meq/kg), while C2 exhibited the lowest acidity (7.33 meq/kg) (Figure 3B). The elevated free acidity in HLB may be associated with higher organic acid content (such as acetic, citric, or lactic acid), which acts as a powerful preservative and could contribute to flavour intensity. The high free acidity of the HLB formulation may be attributed to the high concentration of organic acid present (Tembo et al., 2017), including ascorbic acid, as shown in Figure 2B.

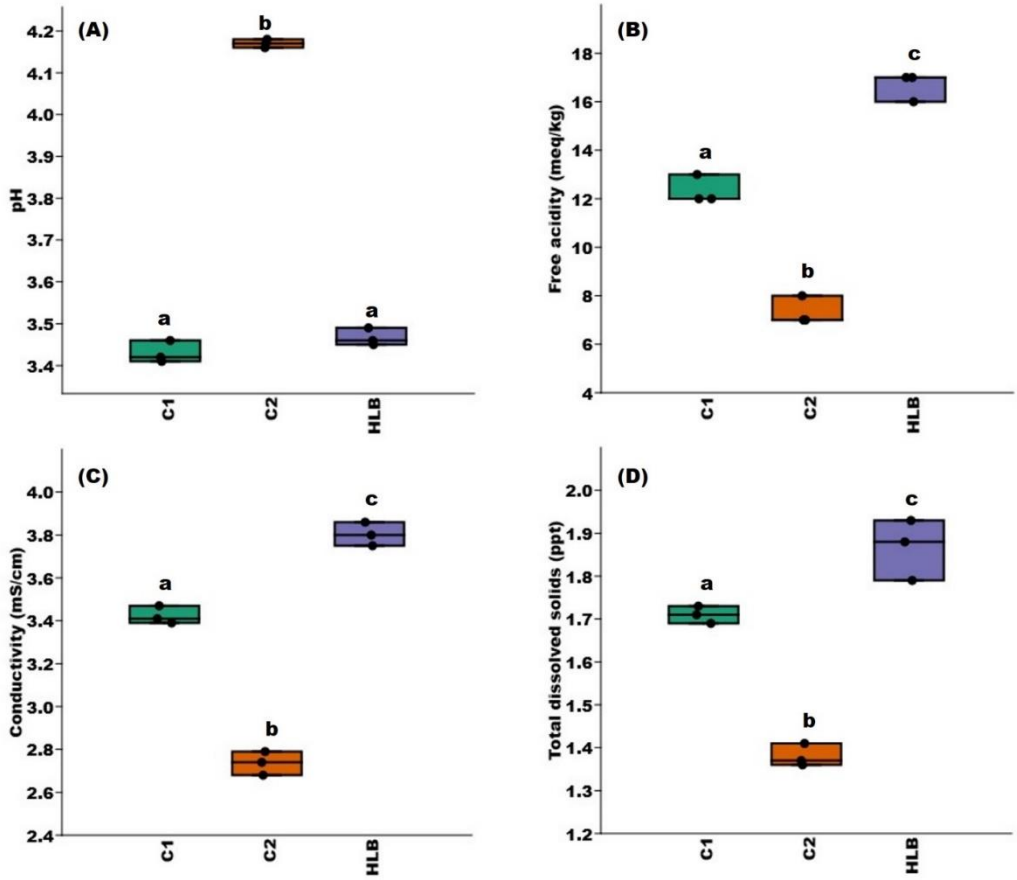

Figure 3: Physical-Chemical Properties of the Raw Materials (C1=Baobab and C2=Hibiscus Solutions) and the Formulation (Hlb=12.5% Hibiscus and 1% Baobab Powder)

Electrical conductivity and total dissolved solids (TDS) were highest in HLB, with values of 3.81 mS/cm and 1.87 ppt, respectively (Figure 3C & D). In contrast, C2 showed the lowest conductivity (2.74 mS/cm) and TDS (1.38 ppt). Higher conductivity and TDS values in HLB indicate greater concentrations of dissolved ions and soluble solids, reflecting its richer mineral composition, which is in agreement with the data in Table 1. Both conductivity and TDS are directly related to the concentration of dissolved ionised solids in the sample (all inorganic and organic matter). Ions from the dissolved solids create the ability to conduct an electric current, which can then be measured (Islam et al., 2017). Additionally, the two parameters have a direct correlation with the mineral content of the sample, which is in agreement with the data in Table 1, where HLB showed a substantial elemental profile (Jakhrani et al., 2019).

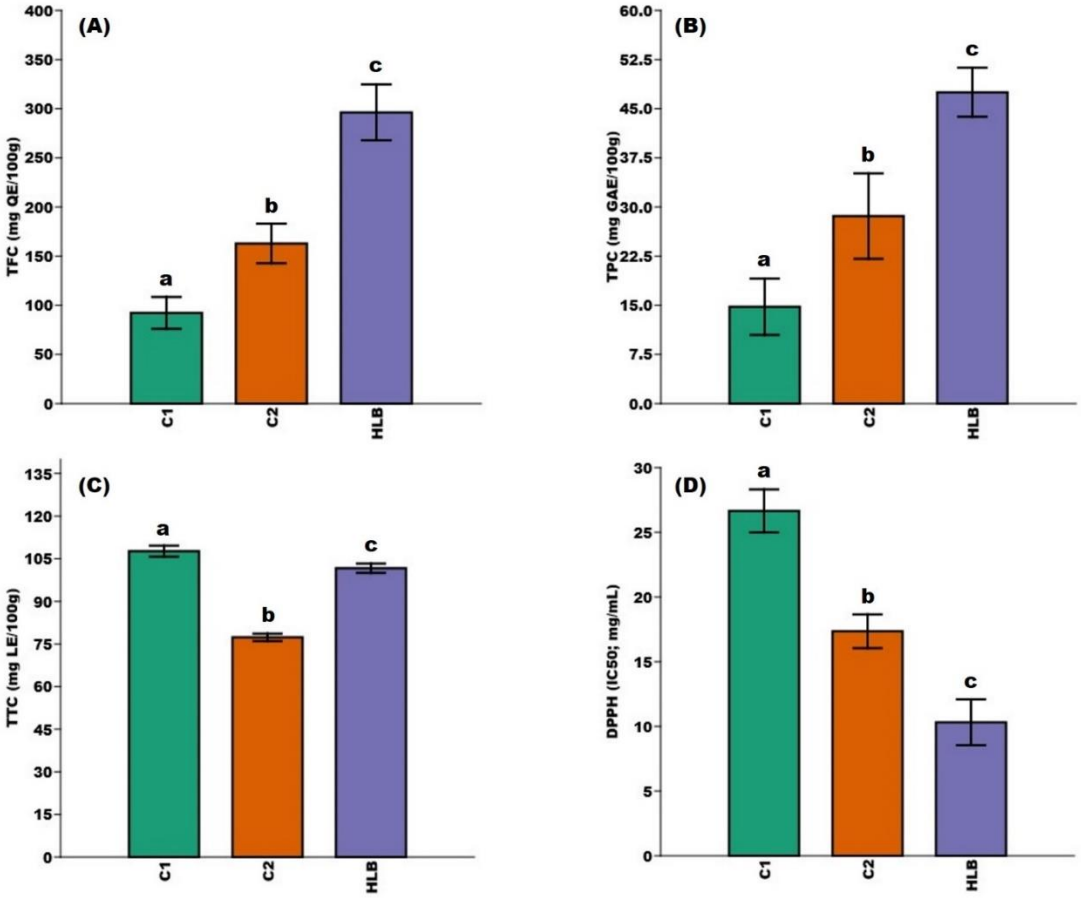

Figure 4: Phytochemical Contents and DPPH Scavenging Activity of the Raw Materials (C1=Baobab and C2=Hibiscus Solutions) and the Formulation (Hlb=12.5% Hibiscus and 1% Baobab Powders)

Phytochemical Content and Antioxidant Activity

The phytochemical and antioxidant properties differed significantly among the formulations ($p < 0.05$) (Figure 4). HLB consistently exhibited the highest total phenolic content (47.51 mg GAE/100 g) and total flavonoid content (296.27 mg QE/100 g), as shown in Figure 4A and B. In contrast, C1 recorded the lowest phenolic and flavonoid levels. Total terpenoid content showed a different trend, with C1 having the highest value (107.68 mg LE/100 g), followed closely by HLB, while C2 contained the lowest terpenoid content (Figure 4C). This suggests that TTC accumulation varied independently from total phenolics and flavonoids. Previous studies have shown that both baobab and hibiscus are rich in phytochemicals (Debel et al., 2023; Asare et al., 2025). The results therefore demonstrated that despite being processed into a beverage, baobab pulp and hibiscus powders still retain significant bioactive compounds, highlighting their potential utility in functional beverages. These findings are consistent with those reported in previous studies on plant-based beverages (Taesuk et al., 2025; Yildizozu et al., 2025). The phytochemicals play a significant role in enhancing the nutritional and functional quality of plant-based beverages, including colour, flavour, aroma, stability, and health-promoting properties (Chandrasekara & Shahidi, 2018).

Antioxidant activity, measured by DPPH IC_{50}, was strongest in HLB, which recorded the lowest IC_{50} value (10.32 mg/mL), indicating superior free radical scavenging capacity (Figure 4D). The high amounts of phytochemicals in HLB could be the main contributor, as their major biological role is antioxidant activity. These compounds help eliminate free radicals and reduce oxidative stress, which contribute to the development of chronic conditions such as cardiovascular disease, diabetes, cancer, and neurodegenerative disorders (Marafon et al., 2025). Phenolic compounds and flavonoids are particularly important because of their strong antioxidant potential and ability to protect cells from oxidative damage (Ekalu & Habila, 2020). Therefore, the results demonstrate that the HLB

formulation possessed the most favourable phytochemical profile and antioxidant potential.

Correlation Between the Assayed Parameters

The Spearman correlation analysis revealed strong relationships among physicochemical properties, phytochemical compounds, and antioxidant activity, as shown in Figure 5. Free acidity showed strong positive correlations with conductivity (r = 0.94), TDS (r = 0.94), and colour (r = 0.89), indicating that increased acidity was associated with higher dissolved solids, ionic content, and darker colouration. Similarly, conductivity was highly correlated with TDS (r = 0.98) and colour (r = 0.93), suggesting that mineral-rich formulations also tended to exhibit greater colour intensity.

Total phenolic content (TPC) was strongly and positively associated with vitamin C (r = 0.87), while both TPC and vitamin C showed strong negative correlations with DPPH IC_{50} values (r = −0.87 and −0.92, respectively). Since lower IC_{50} values indicate stronger antioxidant activity, these findings confirm that phenolics and vitamin C were major contributors to antioxidant activity. The colour also exhibited a strong negative correlation with vitamin C (r = −0.93), suggesting that darker formulations tended to contain lower vitamin C concentrations.

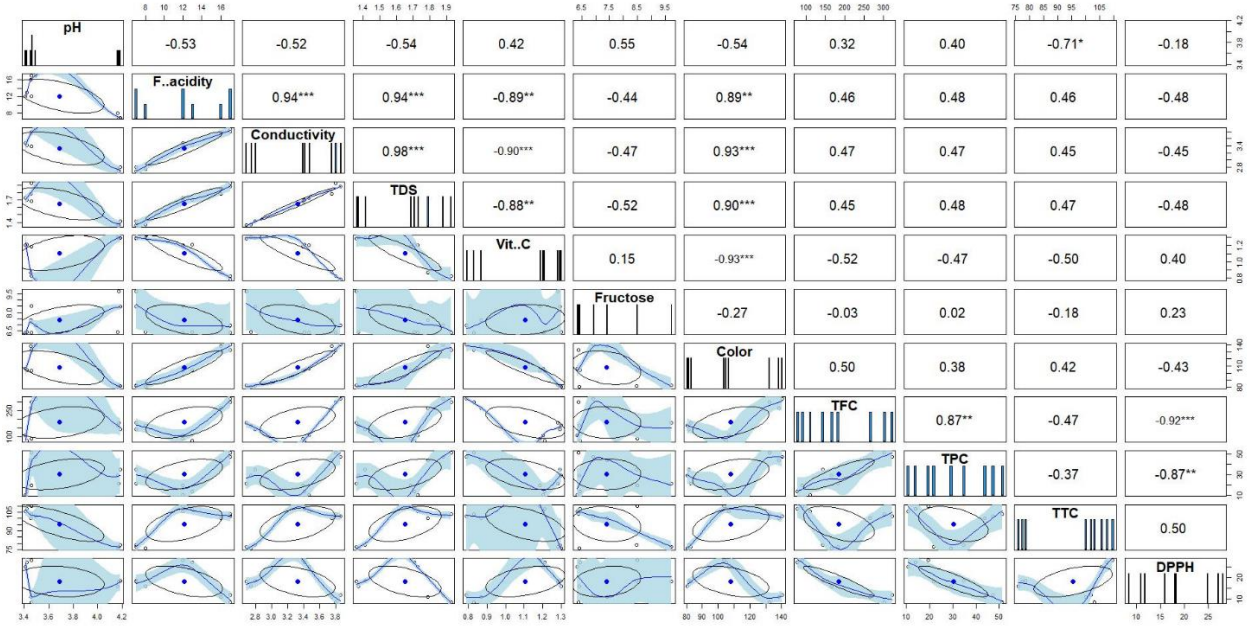

Figure 5: Spearman Rank Correlation Between the Assayed Physico-Chemical, Phytochemical Contents and DPPH Scavenging Activity of the Raw Materials (C1 = Baobab and C2 = Hibiscus) and the Product (HLB = 12.5% Hibiscus and 1% Baobab Powders).

Among sensory-related physicochemical traits, pH showed a strong negative correlation with TTC (r = −0.71), indicating that increased terpenoid levels were associated with greater acidity. Fructose demonstrated weak correlations with most parameters, implying limited influence on the overall physicochemical and antioxidant characteristics. From these correlations, it could be deduced that acidity, phenolic compounds, and vitamin C were the primary factors influencing antioxidant potential and the physicochemical quality of the assayed samples, corroborating the earlier reports (Tembo et al., 2017; Mokaya et al., 2020).

CONCLUSION AND RECOMMENDATIONS

Conclusion: The present study demonstrated that incorporation of baobab into hibiscus-based formulations significantly influenced sensory quality, physicochemical characteristics, phytochemical composition, antioxidant activity, and nutritional value. Among the tested formulations, the 12.5:1 (hibiscus: baobab) showed the most desirable balance of consumer acceptability and functional properties. The formulation exhibited enhanced phenolic and flavonoid contents, strong antioxidant activity, and improved mineral composition compared to the individual raw material solutions. In addition, the absence of culturable microbes confirmed its relative safety and microbiological stability for

consumption, which may be associated with its low pH, high acidity, and elevated bioactive compound content. These findings suggest that the 12.5:1 formulation has strong potential as a nutritious functional plant-based beverage that may contribute to improved dietary quality and natural antioxidant intake.

Recommendations: Future studies should focus on storage stability, large-scale consumer evaluation, bioavailability assessment, and optimisation of processing conditions to support commercialisation and wider application of the beverage.

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