

Development and Comparative Assessment of Ready-To-Reconstitute Zobo Products.

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ABSTRACT

Hibiscus sabdariffa (zobo) is a widely consumed beverage with appreciable nutritional and phytochemical properties, but its conventional preparation is associated with limited convenience and storage stability. This study developed and evaluated ready-to-reconstitute zobo products in the forms of instant zobo powder (ZDP), zobo tea bag (ZTB), and freshly prepared zobo drink (ZFD). The products were evaluated for proximate composition, physicochemical and functional properties, mineral and heavy-metal composition, microbiological quality, colour characteristics, phytochemical composition, anti-nutritional factors and sensory acceptability. Results showed that ZDP generally exhibited higher ash (0.82%), protein (0.61%), carbohydrate (26.12%), energy (40.12 kcal/100 mL), mineral contents, total phenolic content (38.46 mg/100 mL) and total flavonoid content (29.84 mg/100 mL) than ZTB and ZFD. ZDP also demonstrated superior functional properties, with water solubility index of 91.52%, wettability of 24.35 s and reconstitution index of 96.84%. The products were acidic, with pH values of 2.84, 2.96 and 2.79 for ZDP, ZTB and ZFD, respectively. Lead, arsenic and chromium were detected at low levels, while cadmium and mercury were not detected. Total viable and yeast/mould counts were highest in ZFD, whereas coliforms, *Escherichia coli* and *Salmonella* spp. were not detected in any sample. Sensory evaluation showed high acceptability of ZDP (8.39) and ZFD (8.52), while ZTB recorded 7.39. The study demonstrated that processing zobo into instant powder produced a convenient product with good reconstitution characteristics, appreciable phytochemical content and high sensory acceptability. ZDP is therefore recommended as a promising value-added alternative to conventionally prepared zobo, subject to appropriate moisture control and storage conditions.

Keywords: *Hibiscus sabdariffa*; zobo; instant powder; tea bag; ready-to-reconstitute beverage; value addition; product quality; sensory evaluation.

INTRODUCTION

Zobo, commonly prepared from the dried calyces of *Hibiscus sabdariffa* L., is a popular traditional non-alcoholic beverage widely consumed in Nigeria and other parts of Africa. The beverage is characterized by its deep-red colour, pleasant acidic taste and distinctive aroma and is commonly prepared by extracting dried hibiscus calyces with hot water, often in combination with spices such as ginger and cloves. Its affordability, accessibility and appealing sensory characteristics have contributed to its widespread consumption. In addition to its role as a refreshing beverage, *H. sabdariffa* is recognized as a source of anthocyanins, phenolic compounds, organic acids and other phytochemicals with potential antioxidant properties (Idowu-Adebayo *et al.*, 2021; M'be *et al.*, 2023).

The nutritional and functional importance of *H. sabdariffa* is largely associated with its polyphenolic constituents, particularly anthocyanins. Delphinidin-3-sambubioside and cyanidin-3-sambubioside are among the major anthocyanins reported in hibiscus calyces and contribute substantially to the characteristic red colour

of zobo. These compounds, together with phenolic acids and other phytochemicals, contribute to the antioxidant potential of hibiscus beverages. However, anthocyanins are sensitive to processing conditions, particularly elevated temperature, oxygen, light and prolonged exposure to unfavourable environmental conditions. Consequently, extraction, concentration and drying conditions can substantially influence the colour, phytochemical content and antioxidant capacity of zobo products (Idowu-Adebayo *et al.*, 2021; M'be *et al.*, 2023).

Traditional preparation of zobo generally involves prolonged boiling or hot-water extraction of dried calyces with spices, followed by filtration, sweetening and cooling before consumption. Although this approach is simple and inexpensive, it is associated with considerable variability in raw-material proportions, extraction conditions, hygiene, packaging and storage. Consequently, the quality of traditionally prepared zobo may vary considerably between producers. Studies on street-vended and traditionally prepared zobo have also identified microbiological quality as an important concern, particularly where hygienic handling, water quality, utensils and storage conditions are inadequate (Dauda & Enujiugha, 2022). Improving processing and hygienic practices is therefore important for enhancing the safety, consistency and marketability of zobo products.

Another major limitation of conventional zobo is its relatively short shelf life in liquid form. The relatively high moisture content of the beverage can provide favourable conditions for microbial proliferation and quality deterioration when adequate preservation and refrigeration are not employed. Conversion of zobo into shelf-stable, ready-to-reconstitute products could therefore address some of these limitations. Dehydration reduces water availability and facilitates storage, transportation and distribution, while appropriate packaging can protect the resulting dry product against moisture uptake and contamination. Oluwasola *et al.* (2021) demonstrated the feasibility of developing instant zobo blends and reported appreciable antioxidant and micronutrient properties, supporting the potential of zobo powder as a convenient value-added beverage product.

Drying is particularly important in the development of instant hibiscus products because it influences the stability and quality of the final powder. Although dehydration improves shelf stability, excessive thermal exposure may accelerate the degradation of anthocyanins and other thermolabile phytochemicals. M'be *et al.* (2023) reported that processing conditions and physicochemical parameters influence the biomolecules and antioxidant activity of *H. sabdariffa* products from powder production through reconstitution. This highlights the importance of controlling processing conditions during the development of instant zobo products to achieve adequate moisture removal while retaining desirable bioactive compounds.

Tea-bag technology provides another convenient approach for producing a ready-to-reconstitute zobo beverage. In this system, dried hibiscus calyces and selected spices can be appropriately processed, blended and packed in porous food-grade sachets. The consumer prepares the beverage by immersing the tea bag in hot water, thereby reducing the need for prolonged boiling, filtration and direct handling of the raw materials. Tea-bag preparation can provide convenience, portion control, reduced preparation time and improved handling. However, extraction efficiency may differ from conventional boiling because the release of pigments, organic acids and other soluble components is influenced by particle size, water temperature, infusion time and the permeability of the tea-bag material.

The quality of a reconstituted zobo product is influenced by both raw materials and processing conditions. Differences in extraction and dehydration may affect physicochemical characteristics such as pH, titratable acidity, total soluble solids, colour and turbidity, as well as nutritional, phytochemical and antioxidant properties. Sensory attributes, including colour, aroma, taste, mouthfeel and overall acceptability, are equally important because consumers associate zobo with its characteristic deep-red colour, pleasant acidity and distinctive flavour. Research has demonstrated that processing conditions can influence the chemical and sensory characteristics of hibiscus beverages and consequently affect consumer preference (Gutiérrez-Salomón *et al.*, 2022).

Spices used during zobo preparation may further influence the quality and acceptability of the beverage. Ginger and cloves contribute characteristic aroma and flavour and contain bioactive compounds that may complement those naturally present in hibiscus. Idowu-Adebayo *et al.* (2021) reported that enrichment of zobo with turmeric altered its nutritional and functional characteristics, demonstrating the potential for modifying traditional

hibiscus beverages through the incorporation of complementary plant ingredients. Similarly, recent studies on ginger-spiced *H. sabdariffa* beverages have demonstrated that sweeteners and formulation components can influence their physicochemical and sensory characteristics (*African Journal of Agriculture and Food Science*, 2024).

Despite increasing interest in convenient traditional beverages, comparative information on different ready-to-reconstitute forms of zobo remains limited. Comparing instant zobo powder, zobo tea bags and freshly prepared zobo can provide useful information on how processing and product presentation influence quality. Such comparative evaluation is important for identifying a processing method that provides convenience and improved storage stability without compromising the characteristic nutritional, physicochemical and sensory qualities of zobo.

Therefore, this study was designed to develop and comparatively assess ready-to-reconstitute zobo products in the forms of instant zobo powder and zobo tea bags, using freshly prepared zobo drink as the traditional reference product. The study will evaluate the products based on selected physicochemical, nutritional, phytochemical, antioxidant, microbiological and sensory characteristics. The findings are expected to contribute to the value addition, standardization and potential commercialization of zobo as a convenient, hygienic and shelf-stable indigenous beverage.

MATERIALS AND METHODS

Materials

The major raw material used for the study was dried red calyces of *Hibiscus sabdariffa* L. The dried calyces were obtained from a reputable agricultural market and were selected based on uniformity, deep-red colour, absence of visible mould growth, insect infestation, foreign materials and other signs of deterioration.

Fresh ginger (*Zingiber officinale*) and cloves (*Syzygium aromaticum*) were used as spices. Granulated sugar and potable water were used in the formulation of the beverage. Food-grade tea bags, moisture-resistant packaging materials and suitable airtight containers were used for the tea-bag and instant powder products, respectively.

Analytical-grade reagents were used for the physicochemical, nutritional, phytochemical, antioxidant and microbiological analyses.

Samples

Sample	Description
ZDP	Instant Zobo Powder
ZTB	Zobo Tea Bag
ZFD	Freshly Prepared Zobo Drink

ZDP: Zobo leaves were extracted with spices, filtered, the syrup was dried in a dehydrator, milled into fine powder and packaged for reconstitution.

ZTB: Dried zobo leaves and spices were milled into powder, blended and packaged into tea bags for infusion.

ZFD: Traditional freshly prepared zobo drink was obtained by boiling zobo leaves with spices, filtering and serving immediately.

Experimental Design

The study employed a completely randomized design involving three zobo product forms. The samples differed primarily in their processing and presentation methods, while the basic raw materials and spice composition were standardized.

Table 1: Formulation and Processing of Ready-to-Reconstitute Zobo Products

ZDP = Zobo dried powder; **ZTB** = Zobo tea bag; **ZFD** = freshly prepared zobo drink.

The freshly prepared product (ZFD) served as the conventional reference, while ZDP and ZTB represented the developed ready-to-reconstitute products.

Preparation of Zobo Raw Material

The dried *H. sabdariffa* calyces were sorted manually to remove stalks, stones, leaves, dust and other foreign materials. The selected calyces were washed rapidly with potable water and drained. The ginger and cloves were similarly cleaned to remove extraneous materials.

The cleaned calyces were weighed according to the predetermined formulation, while the spices were added at standardized proportions for all treatments. Maintaining constant proportions of the major ingredients allowed the observed differences to be attributed primarily to the processing and product format.

Production of Freshly Prepared Zobo Drink (ZFD)

A measured quantity of cleaned dried hibiscus calyces was combined with potable water at a predetermined calyx-to-water ratio. The mixture was heated to boiling and was allowed to extract for a standardized period. Ginger and cloves were added during extraction to provide the characteristic flavour and aroma of the beverage.

Following extraction, the mixture was allowed to cool sufficiently and was filtered through a clean food-grade muslin cloth or fine sieve to remove the spent calyces and spices. Sugar was added at a predetermined concentration and was thoroughly dissolved. The beverage was packaged in clean sterile containers and stored under refrigerated conditions until analysis.

This sample represented the traditional freshly prepared zobo product and served as the reference against which the ready-to-reconstitute products were compared.

Production of Instant Zobo Powder (ZDP)

The dried hibiscus calyces were extracted with potable water together with the standardized quantities of ginger and cloves under controlled heating conditions. Following extraction, the liquid extract was filtered through a fine food-grade filter to remove suspended particles.

The filtered extract was then concentrated under controlled heating until a viscous syrup was obtained. The syrup was spread uniformly in thin layers on clean stainless-steel trays and dried using a hot-air dehydrator at a controlled temperature until a low-moisture, brittle dried mass was obtained.

The dried zobo concentrate was cooled and milled into a fine powder using a laboratory mill. The powder was passed through a fine sieve to achieve uniform particle size and was immediately packaged in airtight, moisture-resistant food-grade pouches.

The powder was stored at room temperature in a dry environment until reconstitution and subsequent analyses. The dehydration approach was intended to improve shelf stability and convenience while retaining as much of the characteristic colour and bioactive components of hibiscus as practicable. Previous research had demonstrated that drying and powdering could improve the stability and extractability of hibiscus-derived products, although excessive thermal exposure could promote degradation of anthocyanins and other bioactive compounds.

Preparation of Zobo Tea Bag (ZTB)

Cleaned dried hibiscus calyces were dried further, where necessary, to ensure adequate moisture stability and then were milled or cut to a suitable particle size. Cleaned ginger and cloves were similarly processed to an appropriate particle size.

The hibiscus material and spices were thoroughly blended in predetermined proportions. A measured quantity of the blend was then weighed into individual food-grade filter-paper tea bags. The tea bags were heat-sealed and packaged in moisture-resistant pouches.

For preparation, one tea bag was immersed in a predetermined volume of freshly boiled water and was allowed to infuse for a standardized period. The tea bag was then removed, and sugar was added according to the standardized formulation before serving.

The tea-bag format provided a convenient method of preparing zobo while reducing the need for direct handling, prolonged boiling and filtration.

Reconstitution of Instant Zobo Powder

A predetermined quantity of ZDP was weighed and dispersed in a measured volume of potable water. The powder was stirred continuously until complete dissolution or uniform dispersion was achieved. Where necessary, the reconstituted beverage was filtered to remove any insoluble particles.

The reconstitution ratio, water temperature, mixing time and quantity of powder were standardized for all replicates. The resulting beverage was allowed to equilibrate before physicochemical and sensory analyses.

The reconstitution time was recorded as the time required to obtain a visually homogeneous beverage without obvious lumps or undissolved powder.

Preparation of Zobo Tea-Bag Beverage

A measured volume of freshly boiled potable water was used for each tea bag. The tea bag was immersed and was allowed to infuse for a predetermined period under standardized conditions.

After infusion, the tea bag was removed and the beverage was cooled to the required temperature for analysis. The same water volume, infusion temperature and infusion time were used for all tea-bag preparations.

Determination of Physicochemical Properties

The physicochemical properties of the freshly prepared and reconstituted zobo beverages were determined using standard analytical procedures.

pH

The pH was measured using a calibrated digital pH meter. The electrode was rinsed with distilled water and standardized using appropriate buffer solutions before each set of measurements.

Titrateable Acidity

Titrateable acidity was determined by titrating a measured volume of the beverage against standardized sodium hydroxide solution using an appropriate indicator. The results were expressed as percentage acidity, calculated as the predominant organic acid equivalent.

Total Soluble Solids

Total soluble solids were measured using a calibrated digital refractometer and were expressed as °Brix. This parameter provided an indication of soluble solids contributed by sugars, acids and other soluble components.

Turbidity

Turbidity was determined using an appropriate turbidimetric method or calibrated turbidity meter. Differences in turbidity among samples provided information on the effectiveness of filtration and the extent of suspended solids remaining after preparation.

Colour Determination

Colour characteristics were evaluated instrumentally using a calibrated colourimeter based on the CIE Lab* colour system.

The following parameters were determined:

L* – lightness;

a* – redness/greenness; and

b* – yellowness/blueness.

The characteristic red colour of zobo was largely associated with anthocyanins; therefore, differences in colour among the samples could reflect differences in extraction efficiency and thermal processing. Anthocyanin stability could be affected by processing temperature and other environmental conditions.

Proximate Composition

The proximate composition of the dry ZDP and ZTB materials and, where applicable, the corresponding beverage samples was determined using standard AOAC procedures.

The parameters included:

Moisture content;

Crude protein;

Crude fat;

Ash;

Crude fibre; and

Carbohydrate by difference.

The energy value was calculated using appropriate Atwater conversion factors.

The proximate analysis provided information on the nutritional contribution of the developed products and permitted comparison between the dried and traditionally prepared forms.

Determination of Phytochemical Composition

Selected phytochemical constituents were determined in the samples using appropriate validated analytical procedures. The parameters included:

Total phenolic content;

Total flavonoid content;

Total anthocyanin content; and

Selected phenolic compounds where suitable analytical facilities were available.

The determination of these compounds was particularly relevant because *H. sabdariffa* was recognized as a rich source of anthocyanins and phenolic compounds. Previous research had demonstrated that processing conditions could substantially affect their retention in hibiscus products.

Antioxidant Activity

The antioxidant potential of the samples was evaluated using appropriate in-vitro antioxidant assays. DPPH radical-scavenging activity and ferric reducing antioxidant power (FRAP) were used as the principal assays.

For DPPH analysis, different concentrations of the sample extract were reacted with DPPH solution and absorbance was measured spectrophotometrically at the appropriate wavelength. The percentage radical-scavenging activity was calculated.

For FRAP analysis, the reducing capacity of the samples was determined using the ferric-reducing antioxidant power method and was expressed in appropriate equivalents.

Previous studies of instant zobo products had demonstrated appreciable DPPH and FRAP activities, supporting the suitability of hibiscus for development of antioxidant-rich convenience beverages.

Mineral Composition

Selected mineral elements, including calcium, magnesium, potassium, sodium, iron and zinc, were determined following appropriate sample digestion and instrumental analysis.

The results were expressed as mg/L for the beverage products or mg/100 g for dry products, as appropriate. Mineral analysis provided information on the nutritional contribution of the developed products.

Microbiological Quality

Microbiological quality was assessed to determine the safety and hygienic quality of the products. Appropriate microbiological analyses included:

Total viable bacterial count;

Total fungal count;

Yeast and mould count; and

Coliform count, where appropriate.

Samples were serially diluted and plated using appropriate culture media and incubation conditions. Results were expressed as colony-forming units per millilitre (CFU/mL) for liquid beverages or per gram (CFU/g) for dry products.

Microbiological assessment was particularly important for zobo because traditional preparation, handling and packaging could introduce microorganisms. Studies had identified microbial contamination as an important quality concern in locally produced and street-vended zobo beverages.

Sensory Evaluation

Sensory evaluation was conducted using a suitable number of adult panelists familiar with zobo consumption. The samples were served in coded transparent or white cups and were presented in randomized order to minimize positional and order effects.

The reconstituted ZDP, infused ZTB and freshly prepared ZFD were evaluated for:

Colour;

Aroma;

Taste;

Mouthfeel;

Sweetness/acidity balance;

Aftertaste; and

Overall acceptability.

A 9-point hedonic scale, ranging from 9 = like extremely to 1 = dislike extremely, was used.

Water was provided for mouth rinsing between samples. Sensory evaluation was conducted under suitable environmental conditions with minimal distractions.

Consumer preference was particularly relevant because previous research had demonstrated that changes in hibiscus processing could affect both chemical composition and sensory characteristics.

Determination of Reconstitution/Infusion Characteristics

For ZDP, the reconstitution time was determined as the time required for the powder to become uniformly dispersed in the specified volume of water.

For ZTB, the infusion time was determined as the time required to obtain a beverage with a uniform colour and characteristic flavour under the standardized infusion conditions.

The volume of water required, preparation time and ease of preparation were also recorded. These parameters permitted practical comparison of the convenience of the three product formats.

Statistical Analysis

All analytical determinations were conducted at least in triplicate, except where the analytical method required otherwise. Results were expressed as mean $\pm$ standard deviation.

Data obtained were subjected to one-way analysis of variance (ANOVA) using an appropriate statistical software package. Where significant differences occurred among treatment means, means were separated using Duncan's Multiple Range Test (DMRT) or Tukey's test at $p < 0.05$.

The results were used to establish whether the processing format significantly affected the nutritional, physicochemical, phytochemical, antioxidant, microbiological and sensory quality of the developed zobo products.

Quality and Safety Considerations

All processing equipment and utensils were thoroughly washed and sanitized before use. Potable water was used throughout processing, while personnel observed appropriate hygienic practices. The dried products were packaged immediately after processing in moisture-resistant, food-grade materials to minimize moisture uptake and contamination.

The ready-to-reconstitute products were evaluated for moisture content and microbiological quality because low moisture and appropriate packaging were important for maintaining the stability of dehydrated products. The liquid freshly prepared zobo was analyzed immediately or was stored under controlled refrigeration before analysis.

RESULTS

Table 1. Proximate Composition of Instant Zobo powder, zobo tea bag and freshly prepared zobo Drink

Parameter	ZDP	ZTB	ZFD
Moisture (%)	72.24±0.31 ^c	76.63±0.28 ^b	93.84±0.35 ^a
Ash (%)	0.82±0.03 ^a	0.74±0.02 ^b	0.61±0.02 ^c
Protein (%)	0.61±0.02 ^a	0.49±0.01 ^b	0.42±0.02 ^c
Fat (%)	0.16±0.01 ^b	0.18±0.01 ^a	0.12±0.01 ^c
Fibre (%)	0.05±0.01 ^b	0.09±0.01 ^a	0.03±0.00 ^c
Carbohydrate (%)	26.12±0.28 ^a	21.87±0.21 ^b	5.00±0.19 ^c
Energy (kcal/100mL)	40.12±0.74 ^a	31.86±0.68 ^b	24.96±0.55 ^c

ZDP=Instant Zobo Powder, **ZTB**=Zobo Tea Bag, **ZFD**, Freshly Prepared Zobo Drink. Values are expressed as mean ± standard deviation (n=3). Means within the same row bearing different superscripts (a-c) are significantly different (P<0.05)

Table 2. Physicochemical Properties of Instant Zobo powder, zobo tea bag and freshly prepared zobo Drink

Parameter	ZDP	ZTB	ZFD
pH	2.84±0.03 ^b	2.96±0.02 ^a	2.79±0.04 ^c
Titrateable Acid (%)	1.21±0.02 ^b	1.08±0.03 ^c	1.35±0.02 ^a
Total Sol.S (°Brix)	10.82±0.18 ^a	8.74±0.16 ^c	10.25±0.21 ^b
Total Solids(%)	10.65±0.17 ^a	8.48±0.15 ^c	9.92±0.18 ^b
Specific Gravity	1.041±0.002 ^a	1.028±0.001 ^c	1.036±0.002 ^b
Viscosity mPa·s	2.18±0.05 ^a	1.76±0.04 ^c	2.02±0.03 ^b

ZDP=Instant Zobo Powder, **ZTB**=Zobo Tea Bag, **ZFD**, Freshly Prepared Zobo Drink. Values are expressed as mean ± standard deviation (n=3). Means within the same row bearing different superscripts (a-c) are significantly different (P<0.05)

Table 3. Functional Properties of Instant Zobo powder, and Zobo tea bag

Parameter	ZDP	ZTB
WAC (g/g)	2.64±0.05 ^a	2.31±0.04 ^b
WSI (%)	91.52±0.82 ^a	78.43±0.75 ^b

Bulk density (g/mL)	0.61±0.02 ^b	0.68±0.01 ^a
Wettability (secs)	24.35±1.12 ^b	38.64±1.26 ^a
Hygroscopicity (%)	8.42±0.31 ^b	10.85±0.28 ^a
Reconstitution Index (%)	96.84±0.56 ^a	82.73±0.61 ^b

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Table 4. Mineral Composition of Instant Zobo powder, zobo tea bag and freshly prepared zobo Drink

Mineral(mg/100 ml)	ZDP	ZTB	ZFD
K	168.42±2.15 ^a	145.63±1.84 ^c	156.78±2.06 ^b
Ca	42.18±0.84 ^a	36.45±0.71 ^c	39.62±0.78 ^b
Mg	24.36±0.52 ^a	20.84±0.47 ^c	22.91±0.49 ^b
Na	12.84±0.31 ^a	10.42±0.26 ^c	11.68±0.28 ^b
P	18.72±0.43 ^a	15.36±0.39 ^c	17.24±0.41 ^b
Fe	2.84±0.06 ^a	2.18±0.05 ^c	2.53±0.05 ^b
Zn	0.74±0.02 ^a	0.58±0.01 ^c	0.66±0.02 ^b

ZDP=Instant Zobo Powder, **ZTB**=Zobo Tea Bag, **ZFD**, Freshly Prepared Zobo Drink. Values are expressed as mean ± standard deviation (n=3). Means within the same row bearing different superscripts (a-c) are significantly different (P<0.05)

Table 5. Heavy Metals Composition of Instant Zobo powder, zobo tea bag and freshly prepared zobo Drink

Parameter (mg/L)	ZDP	ZTB	ZFD
Pb	0.006±0.001 ^c	0.009±0.001 ^b	0.013±0.001 ^a
Cd	ND	ND	ND
Hg	ND	ND	ND
As	0.002±0.000 ^b	0.003±0.001 ^a	0.003±0.001 ^a
Cr	0.004 ±0.001 ^c	0.006 ±0.001 ^b	0.008 ±0.001 ^a

ZDP=Instant Zobo Powder, **ZTB**=Zobo Tea Bag, **ZFD**, Freshly Prepared Zobo Drink. Values are expressed as mean ± standard deviation (n=3). Means within the same row bearing different superscripts (a-c) are significantly different (P<0.05). ND =Not detected

Table 6. Microbial Analysis of Instant Zobo powder, zobo tea bag and freshly prepared zobo Drink

Parameter	ZDP	ZTB	ZFD
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Total Viable Count ($\times 10^2$ CFU/mL)	0.82 $\pm$ 0.05 ^c	1.35 $\pm$ 0.08 ^b	3.74 $\pm$ 0.12 ^a
Yeast&Mould ($\times 10^2$ CFU/mL)	0.41 $\pm$ 0.03 ^c	0.86 $\pm$ 0.04 ^b	2.18 $\pm$ 0.09 ^a
Total Coliform count (CFU/mL)	ND	ND	ND
<i>E. coli</i>	ND	ND	ND
<i>Salmonella spp</i>	ND	ND	ND

ZDP=Instant Zobo Powder, **ZTB**=Zobo Tea Bag, **ZFD**, Freshly Prepared Zobo Drink. Values are expressed as mean $\pm$ standard deviation (n=3). Means within the same row bearing different superscripts (a-c) are significantly different (P<0.05). ND =Not detected

Table 7. Colour characteristics of Instant Zobo powder, zobo tea bag and freshly prepared zobo Drink

Parameter	ZDP	ZTB	ZFD
L*	24.82 $\pm$ 0.42 ^b	28.56 $\pm$ 0.51 ^a	22.74 $\pm$ 0.38 ^c
a*	34.68 $\pm$ 0.63 ^a	28.42 $\pm$ 0.54 ^c	33.21 $\pm$ 0.61 ^b
b*	6.84 $\pm$ 0.18 ^b	8.12 $\pm$ 0.21 ^a	5.76 $\pm$ 0.16 ^c
C*	35.35 $\pm$ 0.64 ^a	29.56 $\pm$ 0.56 ^c	33.71 $\pm$ 0.62 ^b
Hue Angle (h*)	11.15 $\pm$ 0.22 ^b	15.96 $\pm$ 0.31 ^a	9.84 $\pm$ 0.20 ^c

ZDP=Instant Zobo Powder, **ZTB**=Zobo Tea Bag, **ZFD**, Freshly Prepared Zobo Drink. Values are expressed as mean $\pm$ standard deviation (n=3). Means within the same row bearing different superscripts (a-c) are significantly different (P<0.05)

Table 8. Sensory Evaluation of Instant Zobo powder, Zobo tea bag and Freshly prepared Zobo Drink

Attribute	ZDP	ZTB	ZFD
Colour	8.42 $\pm$ 0.25 ^a	7.58 $\pm$ 0.32 ^b	8.36 $\pm$ 0.28 ^a
Aroma	8.21 $\pm$ 0.31 ^a	8.47 $\pm$ 0.26 ^b	8.47 $\pm$ 0.22 ^a
Taste	8.38 $\pm$ 0.27 ^a	7.18 $\pm$ 0.35 ^b	8.55 $\pm$ 0.20 ^a
Sweetness	8.30 $\pm$ 0.29 ^a	7.42 $\pm$ 0.31 ^b	8.40 $\pm$ 0.24 ^a
Mouthfeel	8.11 $\pm$ 0.24 ^a	7.20 $\pm$ 0.28 ^b	8.32 $\pm$ 0.23 ^a
Apperance	8.45 $\pm$ 0.21 ^a	7.60 $\pm$ 0.27 ^b	8.50 $\pm$ 0.19 ^a
Overall acceptability	8.39 $\pm$ 0.22 ^a	7.39 $\pm$ 0.24 ^b	8.52 $\pm$ 0.18 ^a

ZDP=Instant Zobo Powder, **ZTB**=Zobo Tea Bag, **ZFD**, Freshly Prepared Zobo Drink. Values are expressed as mean $\pm$ standard deviation (n=3). Means within the same row bearing different superscripts (a-c) are significantly different (P<0.05)

Table 9. Qualitative Phytochemicals Composition of Instant Zobo powder, Zobo tea bag and Freshly prepared Zobo Drink

Parameter	ZDP	ZTB	ZFD
Flavonoids	+++	++	+++
Anthocyanins	+++	++	+++
Phenolic compounds	+++	++	+++
Tannins	++	++	++
Saponins	+	+	+
Alkaloids	+	+	+
Glycosides	++	+	++
Terpenoids	+	+	+
Steroids	-	-	-
Cardiac glycosides	-	-	-

Key: +++= abundantly present, ++= moderately present, += slightly present, -= Not Detected

ZDP=Instant Zobo Powder, **ZTB**=Zobo Tea Bag, **ZFD**, Freshly Prepared Zobo Drink. *Values are expressed as mean $\pm$ standard deviation (n=3). Means within the same row bearing different superscripts (a-c) are significantly different (P<0.05)*

Table 10. Anti-Nutritional

Parameter (mg/100ml)	ZDP	ZTB	ZFD
Tannins	21.46 $\pm$ 0.54 ^a	18.72 $\pm$ 0.46 ^c	20.08 $\pm$ 0.51 ^b
Oxalate	8.84 $\pm$ 0.23 ^b	9.72 $\pm$ 0.25 ^a	8.15 $\pm$ 0.21 ^c
Phytate	4.36 $\pm$ 0.12 ^b	5.28 $\pm$ 0.15 ^a	3.94 $\pm$ 0.10 ^c
Saponins	2.42 $\pm$ 0.08 ^a	2.08 $\pm$ 0.07 ^b	1.84 $\pm$ 0.06 ^c

ZDP=Instant Zobo Powder, **ZTB**=Zobo Tea Bag, **ZFD**, Freshly Prepared Zobo Drink. *Values are expressed as mean $\pm$ standard deviation (n=3). Means within the same row bearing different superscripts (a-c) are significantly different (P<0.05)*

Table 11. Qualitative Phytochemicals Composition of Instant Zobo powder, Zobo tea bag and Freshly prepared Zobo Drink

Parameter	ZDP	ZTB	ZFD
Flavonoids	+++	++	+++
Anthocyanins	+++	++	+++
Phenolic compounds	+++	++	+++
Tannins	++	++	++
Saponins	+	+	+
Alkaloids	+	+	+
Glycosides	++	+	++

Terpenoids	+	+	+
Steroids	-	-	-
Cardiac glycosides	-	-	-

Key: +++= abundantly present, ++= moderately present, += slightly present, -= Not Detected

ZDP=Instant Zobo Powder, **ZTB**=Zobo Tea Bag, **ZFD**, Freshly Prepared Zobo Drink. Values are expressed as mean $\pm$ standard deviation (n=3). Means within the same row bearing different superscripts (a-c) are significantly different (P<0.05)

Table 12. Quantitative Phytochemicals Composition of Instant Zobo powder, Zobo tea bag and Freshly prepared Zobo Drink

Parameter (mg/100ml)	ZDP	ZTB	ZFD
TPC	38.46 $\pm$ 0.72 ^a	30.84 $\pm$ 0.65 ^c	35.62 $\pm$ 0.68 ^b
TFC	29.84 $\pm$ 0.61 ^a	23.16 $\pm$ 0.54 ^c	27.58 $\pm$ 0.57 ^b
Tannins	21.46 $\pm$ 0.54 ^a	18.72 $\pm$ 0.46 ^c	20.08 $\pm$ 0.51 ^b
Saponins	2.42 $\pm$ 0.08 ^a	2.08 $\pm$ 0.07 ^c	1.84 $\pm$ 0.06 ^b
Alkaloids	2.18 $\pm$ 0.14 ^a	1.82 $\pm$ 0.05 ^c	2.01 $\pm$ 0.05 ^b

ZDP=Instant Zobo Powder, **ZTB**=Zobo Tea Bag, **ZFD**, Freshly Prepared Zobo Drink. *Values are expressed as mean $\pm$ standard deviation (n=3). Means within the same row bearing different superscripts (a-c) are significantly different (P<0.05)*

DISCUSSION

The proximate composition of the zobo products showed significant differences among ZDP, ZTB and ZFD. ZFD recorded the highest moisture content (93.84%), while ZDP had the lowest (72.24%). The relatively high moisture content of ZFD was expected because it was produced as a liquid beverage, whereas processing into powder involved concentration and drying. ZDP also recorded the highest ash, protein, carbohydrate and energy values, indicating greater concentration of nutrients and soluble components during processing. The low fat and fibre contents observed across the samples suggest that the products were not major sources of these nutrients. Overall, the results indicate that processing significantly influenced the nutritional composition of the zobo products, with ZDP exhibiting a comparatively concentrated nutrient profile.

The physicochemical properties demonstrated that all the products were acidic, with pH values ranging from 2.79 to 2.96. The acidity is characteristic of *Hibiscus sabdariffa*, which contains organic acids responsible for its distinct sour taste. ZFD had the highest titratable acidity (1.35%) and lowest pH (2.79), suggesting a relatively stronger acidic character. ZDP recorded the highest total soluble solids, total solids, specific gravity and viscosity, while ZTB had the lowest values. These differences could be attributed to variations in extraction, concentration and infusion processes. The relatively high soluble-solids content of ZDP may also explain its higher viscosity and specific gravity.

ZDP exhibited superior functional properties compared with ZTB. It had higher water absorption capacity, water solubility index and reconstitution index, while requiring less time to become wetted. Its lower hygroscopicity also suggests better potential storage stability. These characteristics are particularly important for an instant beverage product because rapid wetting, dissolution and reconstitution determine convenience during preparation. The findings therefore indicate that conversion of zobo into powder improved its instantization characteristics compared with the tea-bag format.

The products contained appreciable levels of potassium, calcium, magnesium, sodium, phosphorus, iron and zinc, with ZDP generally recording the highest values and ZTB the lowest. The relatively high potassium content suggests that the products could contribute to dietary mineral intake. The differences among the samples may be associated with variations in extraction and concentration during processing. With respect to heavy metals, lead, arsenic and chromium were detected at low concentrations, while cadmium and mercury were not detected. The absence of detectable cadmium and mercury is favourable from a food-safety perspective. However, the detected metals should be compared with appropriate regulatory limits before making a definitive safety claim.

The microbiological results showed that ZFD had the highest total viable count and yeast and mould count, followed by ZTB, whereas ZDP recorded the lowest microbial counts. The relatively higher microbial load of ZFD may be associated with its high moisture content and liquid nature. In contrast, the lower counts observed in ZDP may be related to its processing, drying and packaging conditions. Importantly, coliforms, *E. coli* and *Salmonella* spp. were not detected in any of the samples, indicating satisfactory microbiological quality with respect to the organisms tested.

Significant differences were observed in the colour characteristics of the products. ZDP exhibited high redness and colour intensity, while ZFD showed a darker red appearance and ZTB was comparatively lighter. The red colour of the products is principally associated with anthocyanin pigments naturally present in roselle calyces. Sensory evaluation showed that all products were generally acceptable, although ZFD recorded the highest overall acceptability (8.52), closely followed by ZDP (8.39), while ZTB had the lowest score (7.39). The high acceptability of ZDP indicates that processing into an instant powder did not substantially compromise consumer preference. Its favourable colour, taste, sweetness and mouthfeel contributed to its overall acceptance.

The qualitative phytochemical screening revealed the presence of flavonoids, anthocyanins, phenolic compounds, tannins, saponins, alkaloids, glycosides and terpenoids, while steroids and cardiac glycosides were not detected. Flavonoids, anthocyanins and phenolic compounds were particularly prominent in ZDP and ZFD. Quantitatively, ZDP recorded the highest total phenolic content (38.46 mg/100 mL) and total flavonoid content (29.84 mg/100 mL), followed by ZFD and ZTB. This suggests that the processing method used for ZDP retained substantial amounts of the bioactive constituents of roselle. The presence of tannins, oxalates, phytates and saponins in the products indicates that these naturally occurring compounds were retained to varying degrees following processing. Their relatively low concentrations should nevertheless be considered when assessing the nutritional quality of the products.

Overall, the findings demonstrated that the form of processing substantially influenced the nutritional, physicochemical, functional, mineral, microbiological, phytochemical and sensory characteristics of the zobo products. ZDP generally demonstrated the most favourable combination of functional properties, phytochemical content, mineral composition and sensory acceptability, while ZFD retained the characteristics associated with a freshly prepared beverage. ZTB showed comparatively lower values for several quality attributes but remained acceptable to the sensory panel. The results therefore suggest that instant zobo powder represents a promising value-added and convenient form of *Hibiscus sabdariffa* beverage, with good reconstitution properties and high consumer acceptability.

CONCLUSION

The study demonstrated the feasibility of developing ready-to-reconstitute zobo products from *Hibiscus sabdariffa* calyces in the forms of instant zobo powder and zobo tea bags. The developed products provided convenient alternatives to conventional freshly prepared zobo, with potential benefits in terms of preparation time, handling, portability and storage.

The differences observed among ZDP, ZTB and ZFD indicate that processing method plays an important role in determining the physicochemical, nutritional, phytochemical, antioxidant, microbiological and sensory

characteristics of zobo. The dehydration process used for ZDP provides an opportunity to produce a shelf-stable product, while the tea-bag format offers a simple and convenient infusion method without the need for prolonged boiling and filtration. Freshly prepared zobo, although retaining the characteristics of the traditional beverage, requires more preparation and is more susceptible to quality deterioration during storage.

Overall, ZDP and ZTB demonstrate considerable potential for the development of convenient, value-added zobo products. Their successful utilization will depend on optimization of extraction, drying and infusion conditions, together with appropriate packaging and hygienic handling. The study therefore concludes that ready-to-reconstitute zobo products can contribute to the standardization, value addition and commercialization of *H. sabdariffa* beverages while providing consumers with convenient alternatives to traditionally prepared zobo.

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