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Research Article

Functional and Phytochemical Properties of Malted Cereal Formulated from Bambara Groundnut, Soybean and Wheat and Fortified with Ginger, Clove and Date

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Abstract

This study evaluated the functional properties and quantitative phytochemical composition of a malted cereal formulated from Bambara groundnut, soybean and wheat and fortified with ginger, date and clove. Five formulations (A-E) were evaluated, with sample A consisting of 100% malted wheat and samples B-E containing 35% wheat, progressively increasing soybean (30-45%), decreasing Bambara groundnut (30-15%), and constant ginger, date and clove at 2%, 2% and 1%, respectively. Functional properties included bulk density, water absorption capacity (WAC), oil absorption capacity (OAC), swelling capacity, foaming capacity, foam stability, least gelation capacity, wettability, gelatinization temperature and emulsion capacity. Quantitative phytochemical parameters included flavonoids, alkaloids, cardiac glycosides, phenols and terpenoids. Bulk density ranged from 0.887 to 0.991 g/mL, WAC from 10.403 to 17.603%, OAC from 10.801 to 14.235%, swelling capacity from 3.831 to 4.875, foam capacity from 27.586 to 51.724%, foam stability from 32.184 to 48.276%, least gelation capacity from 12.40 to 18.30%, wettability from 5.48 to 8.48 s, gelatinization temperature from 55.40 to 81.20°C, and emulsion capacity from 44.00 to 64.00%. Flavonoids ranged from 4.228 to 10.791%, alkaloids from 6.438 to 13.233%, cardiac glycosides from 2.134 to 6.143%, phenols from 3.511 to 6.807 mg/g, and terpenoids from 8.465 to 15.350%. The results indicate that progressive substitution of Bambara groundnut with soybean altered the functional and phytochemical profiles of the malted cereal. Because the reported observations were not replicated, inferential statistical significance was not established.

Keywords

Bambara Groundnut, Soybean, Wheat, Malted Cereal, Functional Properties, Phytochemicals, Nutritional Composition, Food Fortification

1. Introduction

Cereal-legume combinations are useful in food formulation because cereals and legumes contribute complementary nutritional and technological characteristics. Legumes provide protein and other nutrients, whereas cereals contribute starch and structural properties relevant to processing. Recent studies show that incorporating Bambara groundnut into composite flour systems can alter water and oil absorption, swelling, pasting and other functional characteristics, demonstrating its potential as a functional ingredient in cereal-based foods [1-5].

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Bambara groundnut (Vigna subterranea) is an underutilized African legume with considerable potential for food-product development. Recent processing studies indicate that malting, fermentation, roasting and other treatments can modify its swelling behaviour, metabolite profile, phenolic composition and functional performance [2-5]. Soybean (Glycine max) is another protein-rich ingredient whose proteins contribute hydration, emulsification and foaming properties to food systems. These properties are particularly important when composite flours are intended for products requiring dispersion, reconstitution or stabilization of air or oil-water interfaces.

Malting is increasingly being investigated as a low-cost processing approach for improving the technological and nutritional properties of cereal and legume ingredients. Recent work on malted finger millet, malted maize and bioprocessed wheat has shown that germination and subsequent drying can modify functional, thermal, antioxidant and structural characteristics [6-8]. Such changes are associated with biochemical transformations during germination, including changes in starch and protein accessibility and the generation or release of bioactive compounds.

Functional properties are important indicators of flour suitability for food processing. Bulk density affects handling and packaging; WAC and OAC influence hydration, texture and flavour retention; swelling and gelatinization affect viscosity and heat response; while foaming, gelation and emulsification provide information about the behaviour of proteins and other surface-active constituents. Studies of composite cereal and legume flours consistently demonstrate that changing the proportion of component flours can alter these properties [3, 4, 7, 8].

The use of ginger (Zingiber officinale), clove (Syzygium aromaticum) and date (Phoenix dactylifera) may further diversify the phytochemical profile of cereal formulations. Recent reviews and analytical studies identify phenolic compounds, flavonoids, terpenoid-related constituents and other bioactive compounds in these plant materials [10-15]. Ginger contains phenolic compounds and essential-oil constituents of interest in functional-food development [10]. Clove is particularly rich in phenolic constituents, including eugenol-related compounds, and has been investigated for food applications [11, 12]. Date fruit contains diverse phenolic compounds and dietary fibre and has been proposed as a functional food ingredient [13-15].

The objective of this study was therefore to evaluate the functional properties and quantitative phytochemical composition of malted cereal formulations produced from Bambara groundnut, soybean and wheat and fortified with ginger, date and clove.

2. Materials and Methods

2.1. Experimental Formulation

Five formulations designated A-E were prepared. Sample A consisted of 100% malted wheat and served as the control. Samples B-E contained 35% wheat, progressively increasing soybean from 30% to 45%, decreasing Bambara groundnut from 30% to 15%, and constant ginger, date and clove at 2%, 2% and 1%, respectively. The design therefore isolated the effect of changing the relative proportions of the two legume ingredients within the composite formulations.

Table 1. *Formulation of the malted cereal samples.*

Sample	Wheat (%)	Soybean (%)	Bambara groundnut (%)	Ginger (%)	Date (%)	Clove (%)
A	100	-	-	-	-	-
B	35	30	30	2	2	1
C	35	35	25	2	2	1
D	35	40	20	2	2	1
E	35	45	15	2	2	1

2.2. Determination of Functional Properties

The functional properties evaluated were bulk density, WAC, OAC, swelling capacity, foaming capacity, foam stability, least gelation capacity, wettability, gelatinization temperature and emulsion capacity. The procedures were based on established flour and protein functional-property approaches and were interpreted in the context of recent cereal and legume processing studies [3, 4, 6-8].

Bulk density was determined by filling a graduated cylinder with flour and relating the mass of flour to the occupied volume:

Bulk density (g/mL) = weight of sample (g) / volume of sample (mL).

WAC was determined after mixing the flour with distilled water, followed by centrifugation and weighing of the recovered material. WAC (%) = $(M_2 - M_1) / M_1 \times 100$.

OAC was determined after mixing the flour with oil, stirring and centrifuging before weighing the recovered material. OAC (%) = $(M_1 - M_0) / M_0 \times 100$.

Swelling capacity was determined by dispersing the flour in water, heating under controlled conditions, cooling and centrifuging, after which the volume of the swollen material was compared with the initial volume.

Foaming capacity was calculated from the increase in volume after whipping: foaming capacity (%) = (volume after whipping − volume before whipping) / volume before whipping × 100. Foam stability (%) = foam volume after time t / initial foam volume × 100.

Least gelation capacity was determined by heating aqueous flour suspensions, cooling them and recording the lowest flour concentration that formed a stable gel on tube inversion. Wettability was recorded as the time required for the flour to become completely wet after contact with distilled water. Gelatinization temperature was recorded as the temperature at which visible gelatinization occurred during heating with continuous stirring. Emulsion capacity was determined after dispersing flour in water, mixing with oil and quantifying the emulsified fraction after centrifugation.

2.3. Quantitative Phytochemical Analysis

Quantitative phytochemical analyses were performed for flavonoids, alkaloids, cardiac glycosides, phenols and terpenoids using gravimetric and spectrophotometric procedures. These classes of compounds are commonly used to characterize the phytochemical profiles of plant-based food ingredients [10-15].

For flavonoids, the sample was extracted with 80% aqueous methanol, filtered and evaporated to dryness, and the residue was weighed. Flavonoids (%) = (weight of crucible + residue − weight of crucible) / weight of sample × 100.

For alkaloids, the sample was extracted with 20% acetic acid in ethanol. The extract was concentrated, ammonium hydroxide was added to precipitate the alkaloids, and the precipitate was filtered, dried and weighed. Alkaloids (%) = (weight of filter paper + residue − weight of filter paper) / weight of sample × 100.

Cardiac glycosides were extracted with distilled water and treated with the specified reagents. After heating and filtration, the residue was dried and expressed relative to the original sample mass.

For total phenols, extracts were reacted for colour development and absorbance was measured spectrophotometrically. Phenol content was calculated relative to the standard as: phenol content = absorbance of sample × concentration of standard / absorbance of standard.

Terpenoids were extracted with ethanol, partitioned using petroleum ether, evaporated and expressed as the mass of residue relative to the original sample mass.

2.4. Statistical Analysis

The present dataset contains one reported observation for each formulation and property. Consequently, the results are presented as observed values without mean ± standard deviation, analysis of variance or post-hoc significance letters. This limitation is retained explicitly to avoid implying statistical significance that cannot be supported by the available data.

3. Results

3.1. Functional Properties

Table 2. *Functional properties of the malted cereal samples.*

Functional property	A	B	C	D	E
Bulk density (g/mL)	0.977	0.991	0.919	0.956	0.887
Water absorption capacity (%)	13.494	17.603	10.403	16.485	16.122
Oil absorption capacity (%)	13.781	14.235	10.801	11.928	11.487
Swelling capacity	4.158	3.831	4.626	4.427	4.875
Foam capacity (%)	39.655	27.586	51.724	43.103	36.206
Foam stability (%)	39.080	44.828	48.276	32.184	37.931
Least gelation capacity (%)	12.40	14.30	18.30	16.41	16.50
Wettability (s)	7.48	6.32	5.48	8.40	8.48

Functional property	A	B	C	D	E
Gelatinization temperature (°C)	66.40	73.30	68.90	55.40	81.20
Emulsion capacity (%)	44.00	48.00	58.00	61.00	64.00

Functional properties varied among the formulations. Sample B had the highest bulk density (0.991 g/mL) and WAC (17.603%). Sample C had the highest foam capacity (51.724%) and foam stability (48.276%). Sample E had the highest swelling capacity (4.875), gelatinization temperature (81.20 ℃) and emulsion capacity (64.00%).

3.2. Phytochemical Composition

Table 3. Quantitative phytochemical composition of the malted cereal samples.

Phytochemical	A	B	C	D	E
Flavonoids (%)	9.742	4.228	10.437	10.791	8.238
Alkaloids (%)	6.438	11.567	13.233	9.358	8.461
Cardiac glycosides (%)	2.134	3.914	6.143	5.763	5.893
Phenols (mg/g)	3.716	3.665	6.064	3.511	6.807
Terpenoids (%)	15.350	12.673	8.465	12.716	11.808

Flavonoids ranged from 4.228% in sample B to 10.791% in sample D. Alkaloids ranged from 6.438% in sample A to 13.233% in sample C. Cardiac glycosides ranged from 2.134% in sample A to 6.143% in sample C. Phenols ranged from 3.511 mg/g in sample D to 6.807 mg/g in sample E, while terpenoids ranged from 8.465% in sample C to 15.350% in sample A.

4. Discussion

4.1. Functional Properties

The observed variation in functional properties is consistent with evidence that composite flour behaviour depends on the relative contributions of cereal starch, legume proteins, fibre and processing history. Recent studies on Bambara groundnut flour have shown that processing and inclusion level can modify swelling, water absorption, oil absorption, foaming and other functional characteristics [1-5]. Similarly, studies of malted cereals report changes in water absorption, bulk density, swelling and thermal properties after germination and drying [6-8].

Bulk density was highest in sample B and lowest in sample E. The progressive replacement of Bambara groundnut with soybean therefore coincided with a lower bulk density at the highest soybean level. Bulk density is affected by particle characteristics, packing and composition. Recent work on malted and composite flours likewise demonstrates that changes in ingredient composition and processing can alter flour density and related handling characteristics [4, 6-8]. The present pattern should, however, be regarded as descriptive because the available dataset contains no replicate observations.

WAC was highest in sample B and lowest in sample C, whereas OAC ranged from 10.801% in sample C to 14.235% in sample B. Water absorption is influenced by hydrophilic groups in proteins, starch and fibre, while oil absorption is associated with hydrophobic interactions and the physical structure of the flour matrix. Variation in these properties following processing has been reported for Bambara groundnut and other composite flours [2-5]. The lack of a monotonic trend across the present formulations indicates that functional behaviour was not determined solely by soybean concentration.

Sample E had the highest swelling capacity, while sample B had the lowest. Recent research on Bambara groundnut indicates that malting can improve swelling power, whereas roasting and other thermal treatments may produce different responses [2]. Changes in starch structure and its interaction with water during germination and subsequent drying can therefore contribute to differences among malted flour systems.

Sample C displayed the highest foam capacity and foam

stability. Foaming is influenced by protein concentration, molecular structure and the ability of proteins to adsorb at the air-water interface. The intermediate formulation may have provided a favourable balance between soybean, Bambara groundnut and wheat components. Recent work on cereal-legume processing similarly shows that formulation and processing conditions can modify foaming and related interfacial properties [2, 4].

Least gelation capacity ranged from 12.40% in sample A to 18.30% in sample C. A higher least-gelation value indicates that more flour was required to form a stable gel under the test conditions. Differences in protein and starch composition and their interactions during heating and cooling can influence gel formation. Wettability was fastest in sample C (5.48 s) and slowest in sample E (8.48 s), indicating differences in the rate at which the flour particles interacted with water.

Gelatinization temperature varied markedly from 55.40 ℃ in sample D to 81.20 ℃ in sample E. Such differences are plausible in composite systems because starch structure, protein interactions and processing history influence thermal transitions. Recent studies of malted maize, malted millet and bioprocessed wheat have documented changes in thermal and techno-functional properties associated with germination and processing [6-8].

Emulsion capacity increased from 44% in sample A to 64% in sample E. The progressive increase coincided with increasing soybean content, suggesting a possible contribution of soybean proteins to interfacial stabilization. This interpretation is consistent with the recognized emulsifying functionality of plant proteins, although the present observations do not establish causality. The trend also indicates that the higher-soybean formulation may have potential for food systems where oil-water stabilization is desirable.

4.2. Phytochemical Composition

All formulations contained measurable flavonoids, alkaloids, cardiac glycosides, phenols and terpenoids, but the concentrations varied among formulations. Such variation is expected because botanical source, ingredient ratio and processing conditions can influence the composition and extractability of plant secondary metabolites [2, 5, 10-15].

Flavonoids were highest in sample D and lowest in sample B. Ginger and clove are recognized sources of phenolic and related bioactive compounds, while dates also contribute diverse phenolics and flavonoids [10-15]. Because ginger, date and clove were held constant in samples B-E, the differences among those formulations are more plausibly associated with the changing proportions of soybean, Bambara groundnut and wheat and with matrix effects on extraction. However, the present design does not allow the individual contribution of each ingredient to be separated.

Alkaloids and cardiac glycosides were highest in sample C, whereas the wheat control contained the lowest alkaloid and cardiac glycoside values. The result indicates that replacing part of the wheat with the legume and fortified ingredients altered the measured phytochemical profile. Recent characterization of Bambara groundnut accessions has also demonstrated substantial variation in phytochemical traits, supporting the view that ingredient composition can contribute materially to the phytochemical profile of composite foods [9].

Phenolic content was highest in sample E (6.807 mg/g). This observation is compatible with recent literature showing that dates, ginger, clove and processed legume ingredients contain phenolic compounds of potential food-functional relevance [5, 10-15]. Date studies have identified phenolic acids and flavonoids as important constituents, while clove is particularly associated with eugenol and other phenolic compounds [11-15].

Terpenoids were highest in sample A and lowest in sample C. The higher value in the wheat control indicates that the measured terpenoid fraction did not simply increase with the addition of fortified plant materials. Differences may reflect the botanical composition of the ingredients, extraction behaviour and interactions within the composite flour matrix. Consequently, the results should be interpreted as comparative analytical observations rather than evidence of biological activity.

Overall, the findings indicate that progressive substitution of Bambara groundnut with soybean changed both technological and phytochemical characteristics of the malted cereal. The results are broadly consistent with recent evidence that processing and formulation modify the functional and bioactive characteristics of cereal-legume flours [2-8]. Nevertheless, replication and appropriate statistical analysis are required before differences can be described as statistically significant.

5. Conclusion

The malted cereal formulations produced from Bambara groundnut, soybean and wheat and fortified with ginger, clove and date showed substantial variation in functional and quantitative phytochemical characteristics. Sample B had the highest bulk density and WAC; sample C had the highest foam capacity and foam stability; and sample E had the highest swelling capacity, gelatinization temperature and emulsion capacity. Among the phytochemicals, sample D had the highest flavonoid content, sample C had the highest alkaloid and cardiac glycoside contents, sample E had the highest phenolic content, and sample A had the highest terpenoid content. These observations support the potential of cereal-legume malting and formulation as a means of modifying flour functionality and phytochemical composition. However, because the available results represent single observations, the findings should be regarded as descriptive. Future laboratory work should include independent replicates and appropriate statistical analysis before claims of significant differences are made.

Abbreviations

WAC	Water Absorption Capacity
OAC	Oil Absorption Capacity
g/mL	Grams Per Millilitre
mg/g	Milligrams Per Gram
°C	Degrees Celsius
s	Seconds

Author Contributions

Simcha Chinyere Okeyahweh: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Resources, Visualization, Writing – original draft, Writing – review & editing

Conflicts of Interest

The author declares no conflicts of interest.

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