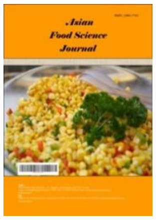

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Functional Properties of Complementary Food from Millet (*Pennisetum glaucum*), African Yam Bean (*Sphenostylis stenocarpa*), and Jackfruit (*Artocarpus heterophyllus*) Flour Blends: A Comparative Study

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The progress towards exploring the potentials of underutilized indigenous food sources via product development to curb food wastage and agro-food extinction is a way of attaining food nutrition and security within a region. In this context, a comparative study involving some functional properties of complementary food from some underutilized foods (millet, African yam bean, and jackfruit) was carried out. Briefly, millet, African yam bean, and jackfruit were subjected to series of processing treatments such as malting, pre-gelatinization, drying, and milling, followed by blending into various

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ratios to obtain different samples of composite flours as a complementary food. From these, the functional properties, that is, water absorption capacity (WAC), loose bulk density (LBD), packed bulk density (PBD), foam capacity (FC), swelling index (SI), dispersibility, wettability, and sinkability were determined. Results showed that malting and pre-gelatinization influenced the intrinsic functional properties of the flour blends. In addition, composite flours containing malted samples had significantly lower ($p<0.05$) dispersibility, SI, WAC, LBD, and PBD, but significantly higher ($p<0.05$) wettability and sinkability. The variations in flour substitution showed no impact on the flour functionality except for SI and dispersibility. All composite flours exhibited an appreciable level of functionality and suitability to be used as a complementary food for weaning purposes. Overall, this research has demonstrated the potentials of utilizing millet, African yam bean, and jackfruit as sustainable nutrient-dense food materials for the production of complementary food.

Keywords: Product development; infant and young child feeding; complementary feeding; millet; African yam bean; jackfruit, weaning food.

1. INTRODUCTION

Breast milk is a conventional feeding method that confers numerous benefits to the infant ranging from the supply of high-quality nutrients, rapid growth, reduction in risk of some diseases, malnourishment and infant mortality, to a healthier and active lifestyle [1]. After the age of 6 months, infants can no longer meet their nutrient requirement from human milk alone as the need for energy and essential nutrients begins to exceed what breast milk provides. At this point, the infant is developmentally ready for alternative foods and such transition is referred to as complementary feeding. Within this interval of complementary feeding, other foods (semisolids, gruel, solids, liquids, etc.) are given to a young child along with breast milk. Given this, such nutrient-dense food or liquid besides breast milk provided to a young child during this time is regarded as complementary food.

Complementary foods are a combination of different nutritional formulations that are rich in protein, fat, carbohydrate, vitamins and minerals, obtained from cereals, legumes, fruits/vegetables and other sources which are necessary for the healthy living of young children [2,3,4]. The right transition from breastfeeding to the full use of family foods for weaning purposes is ensured when infants receive adequate, safe, timely, and appropriate amounts of complementary food [5]. However, most traditional weaning foods in sub-Saharan Africa are largely starchy foods that are poor in protein quality, high in energy content, bulk density, viscosity, and generally low in nutrients. Efforts to improve the nutritional status of complementary food have been based on fortification with legumes to provide some deficient amino acids and other essential nutrients that are critical for a child's enhanced growth and healthy living [6,7,8].

Traditionally, the formulation of weaning foods in most sub-Saharan Africa is based on the utilization of local staples where many of the foods are prepared mainly from cereal and legumes grains, either singly or in combination. Cereals and legumes are vital staple food ingredients of a balanced human diet in many parts of the world due to their high starch, protein, and some amino acid contents [9,10,11]. Cereals such as maize, sorghum, millet, and rice form an important part of the human diet in many regions of the world. Cereals are used for making porridges and starch-based meals which are used for breakfast formulations and are major sources of carbohydrates, proteins, vitamins, and minerals [12-16]. Besides being a low source of protein and some minerals (iron and zinc), cereals have an adequate amount of some essential amino acids (methionine and cysteine), which can be combined with legumes that are rich in lysine, tryptophan, and threonine, to complement each other and obtain a balanced meal.

Further, a lot of infants in developing and underdeveloped nations suffer from malnutrition not only because of the country's poor economic status but because of the inability to utilize the available raw material to meet their nutritional needs or requirements [17]. In Nigeria for instance, there are lots of cheap locally available nutritional agro-food products that can offer great potential as raw materials for the formulation of complementary foods with a high promise of meeting the nutrient requirement of infants but unfortunately, have been neglected and underutilized. To mention a few, African yam bean and jackfruit are on the verge of extinction

[18,19] due to the high premium placed on the major and well-known legumes such as cowpea, soybean, groundnut, mung bean, lima bean, etc. [20,21,22] and fruits such as orange, pawpaw, banana, amongst others. The postharvest losses recorded on jackfruits and the current low status of African yam bean shows that its potential is largely unexploited due to little research attention. Therefore the supplementation of complementary food which is densely composed of carbohydrate (mainly starch) with jackfruit pulp and legume crop that is rich in protein for instance Africa yam bean, is very fitting in expanding the nutritional scope of complementary foods for weaning purposes.

In addition, as cereal and legume grains form the basic raw materials for the production of complementary food, its conventional processing method does not offer enhanced functionality of their starches due to the unmodified or native state of their starches. However, some processing applications or treatment of cereal and legume grains have been shown to yield favourable responses such as reduction in anti-nutrients, shelf-life extension, enhanced nutrient bioavailability, and improved rheological and flavour characteristics. Examples of these processing treatments include soaking, germination, extrusion, heat treatment, pre-gelatinization, etc. [23,24]. Research has shown that some starches are unsuitable for a certain type of processing in their native state [25], owed to poor shear and thermal stability, as well as a high degree of retrogradation [26]. Therefore to enhance starch utilization in various food applications, it is imperative to restructure virtually all starches employing various modifications to meet specific and targeted use. To improve the texture, viscosity, amongst other desired functional properties for various foods, starch and its derivatives are modified via biotechnological, physical, and chemical approaches. Furthermore, as a result of the increased consciousness on the potential dangers of starch modification by some chemical means [27,28], there is increased adoption of the physical modification method like pre-gelatinization in food processing [29]. Specifically, pre-gelatinization is a cheap and efficient technology for enhancing flour starch properties (for example, the ability to form paste in cold water) and available food nutrients such as antioxidants, dietary fibres, minerals, by diminishing the anti-nutritional factors in cereals and legumes [30-33]. The physical method of legume and cereal starch modification owed to pre-gelatinization of starches has been shown to influence the functionality of starches [34,35,36]. The pre-gelatinization of cereal and legume starches is usually accompanied by some transformations such as loss of crystallinity, disruption of starch granule structure, granule swelling, among others [37,38,39].

On the other hand, malting is another modification method that provides legume and cereal flours with improved nutritional quality, functionality, and enhanced physicochemical properties than their unmalted (raw) counterparts [40]. Malting is well-known as a controlled steeping and germination process, followed by controlled drying of germinated kernels. It plays a significant role in grain starch modification [41] and in promoting the development of hydrolytic enzymes, which are not present in non-germinated grains. It allows the preparation of low-bulk foods through the elaboration of amylases resulting in reduced viscosity of the gelled germinated starch [42,43]. Additionally, Hejazi and Orsat [44] and Saithalavi et al. [45] also reported that malting of grains increases protein and carbohydrate digestibility, enhances some of their vitamin contents, reduces anti-nutritional factors and improves their overall nutritional quality. It is well-known that the functionality of cereal and legume grains are dependent on their starch, lipid, and protein content [24]. To understand the effect of some processing treatments such as malting and pre-gelatinization on the flow behaviour of complementary foods, some functional properties were determined. Therefore, the objective of this work was to determine the functional properties of complementary foods from blends of millet, Africa yam bean, and jackfruit pulp as sustainable locally available indigenous nutrient-dense raw materials.

2. MATERIALS AND METHODS

2.1 Diagrammatic Synopsis of the Experimental Program

The diagrammatic synopsis of the experimental program presents the crucial phases from raw materials to laboratory analyses of flour blends as shown in Fig. 1. Notably, this research was designed to study some functional properties of different blends of complementary food through a comparative approach. Briefly, the procured raw materials which include millet, African yam bean, and jackfruit were subjected to series of processing treatments such as malting, pre-gelatinization, and drying to obtain their corresponding flours, followed by blending in different ratios to obtain different samples of complementary food. Subsequently, the emergent complementary food was analysed for functional properties. Notably, maize which was pre-gelatinized, dried and converted to flour, was used as a control because it is the most frequently and widely used complementary food by African mothers for feeding their young children.

2.2 Procurement of Raw Materials

African Yam Bean seeds (*Sphenostylis stenocarpa*) were purchased from New Market in Enugu State, Nigeria, millet (*Pennisetum glaucum*) and maize (*Zea mays*) were purchased from Mile 3 Market Diobu, Port Harcourt, Rivers State, Nigeria, and Jackfruit (*Artocarpus heterophyllus*) was procured from Uzi-ossah in Umuahia, Abia State, Nigeria.

2.3 Procurement of Chemicals

Analytical grade reagents and chemicals [Hydrochloric acid (HCl), deionized water, ammonium thiocyanate solution (NH_4SCN), iron (iii) chloride ($FeCl_3$) solution, standard tannic acid ($C_{76}H_{52}O_{46}$), folin-denis reagent (Phosphomolybdate and phosphotungstate mixture), sodium bicarbonate (Na_2CO_3) solution, methyl ketone-pyridine-water-acetic acid ($C_8H_9NO_2$)] used for the analysis of samples were obtained from Food Science and Technology Laboratories Rivers State University, Port Harcourt Rivers State.

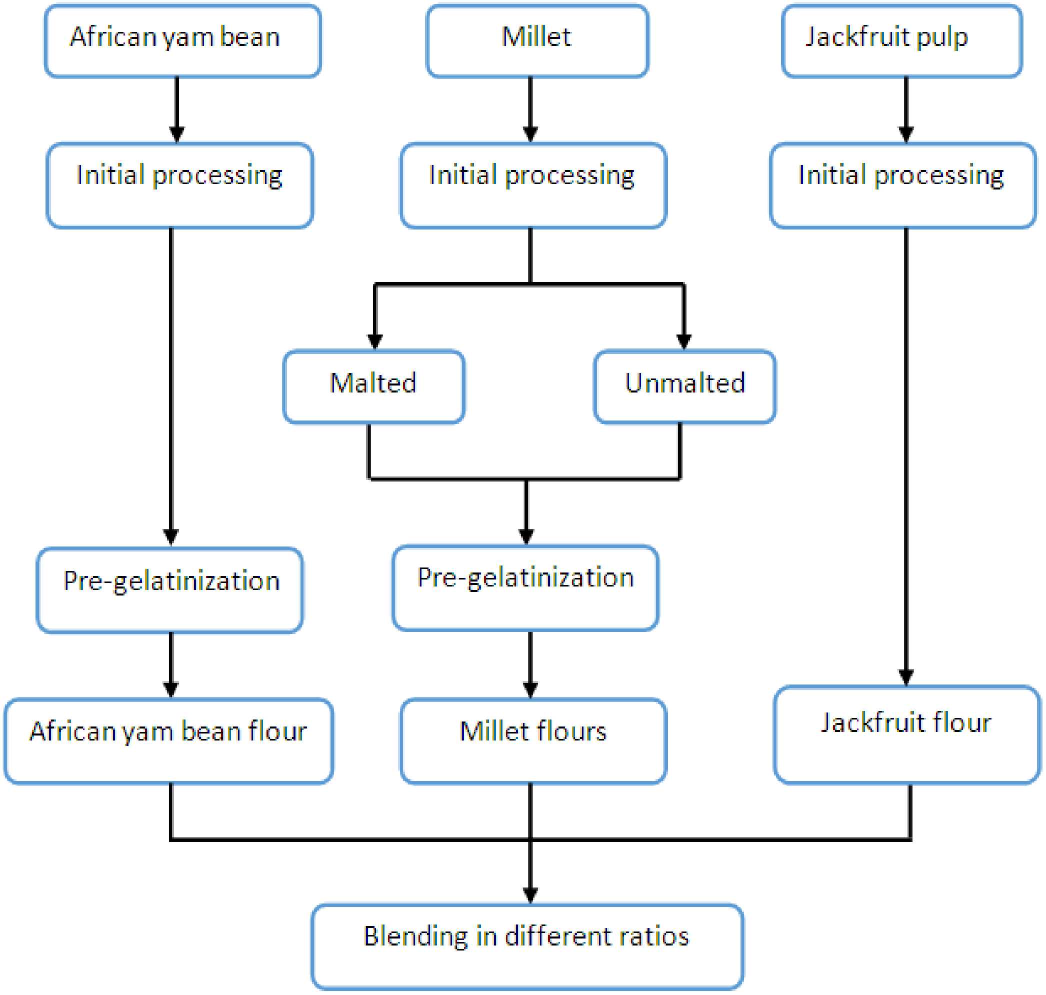

Fig. 1. Diagrammatic synopsis of the experimental program

2.4 Sample Preparation

The raw materials were processed and prepared to flour. African yam bean was processed by pre-gelatinization, drying and milling to the flour while jackfruit pulps were dried and milled to flour. Millet was processed into two portions of malted and unmalted, which were subsequently processed by pre-gelatinization, drying, and milling to flour. The production of these samples is briefly described below.

2.4.1 Malting of millet

The method of Sengev et al., [46] was adopted for the processing of the millet. Millet grains were sorted to discard damaged seeds and other contaminants prior to winnowing to remove dust and then divided into two portions. Following this, the cleaned millet grains were disinfected by washing in water containing sodium metabisulphite (0.20%). Briefly, a portion was malted by steeping in potable water for 8 hours, with successive air rests for 20 minutes after every 2 hour steeping period. The steeped grains were germinated for 72 hours at room temperature (25 to 28^{0}C) by spreading on a heat-sterilized muslin cloth and sparingly sprinkling water at intervals to aid germination/sprouting. The germinated samples were dried in a hot air oven (Model QUB 305010G, Gallenkamp, UK) at 55^{0}C for 8 hours till moisture was reduced to an appreciable percentage. Following this, millet samples (malted and unmalted) were pre-gelatinized by allowing grains to boil at 100^{0}C for 30 minutes. Subsequently, millet samples were drained, cooled to room temperature, dried in a hot air oven at 55^{0}C for 8 hours and milled to flour using a hammer mill (Model MXAC2105, Panasonic, Japan). Milled millet samples were then sieved using a mesh size of 150 µm and packaged in zip lock bags for further use.

2.4.2 Production of African yam bean flour

The African yam bean seeds were cleaned, sorted by removing foreign matter, broken, cracked and damaged seeds, followed by winnowing to remove dust. The seeds were soaked for 8 hours to achieve desired palatability and digestibility. The soaked African yam bean was boiled at 100^{0}C for 30min to reduce the inherent anti-nutrients, aid faster removal of skin coat, and initiate pre-gelatinization of the legume grain. It was decorticated manually, rinsed with potable water, drained, and dried using a hot air oven at 55 ^{0}C for 8 hours. Dried African yam bean samples were milled by using a conventional milling machine (Model MXAC2105, Panasonic, Japan) and sieved using a mesh size of 150 µm to remove unwanted skin coating derived from the milling process. The flour obtained was packed in a polythene bag and refrigerated (4^{0}C) for further use.

Table 1. Recipe for the formulation of complementary food from blends of millet, African yam bean and jackfruit pulp

Sample ID	Levels of substitution (%)			
	Malted millet flour	unmalted millet flour	African yam bean flour	Jackfruit flour
A ((Maize 100%)	-	-	-	-
B	100	-	-	-
C	90	-	10	-
D	80	-	10	10
E	70	-	15	15
F	60	-	20	20
G	50	-	25	25
H	-	100	-	-
I	-	90	10	
J	-	80	10	10
K	-	70	15	15
L	-	60	20	20
M	-	50	25	25

2.4.3 Production of jack fruit flour

The matured ripe jackfruit was washed with potable water and peeled with a stainless steel knife. The seeds and pulps were removed from perianths and separated manually. Thereafter, the pulps were dried in a dalle tray dehydrator (Model DH410, Dalle Group, China) at 57^{0}C for 7 hours, cooled for 20 minutes at room temperature, milled using a hammer milling machine, sieved using a mesh size of 150 µm and packaged in a polythene bag for further usage.

2.4.4 Formulation of flour blends

Flours of African yam bean, jackfruit pulp, malted and unmalted millet were blended in various proportions as shown in Table 1, to formulate varieties of complementary foods as a function of their level of flour substitution.

2.5 Determination of Functional Properties of Formulated Complementary Food

2.5.1 Bulk density

The procedure of Okaka [47] was used to determine the bulk density of the samples. Each sample (50 g) was weighed into a 100 ml graduated measuring cylinder and the volume was recorded. The cylinder was tapped against a table several times until there was no further change in volume. The bulk density was calculated as:

$$\text{Bulk density (g/ml)} = \frac{Weight\ of\ sample\ (g)}{Volume\ of\ sample\ (ml)} \quad (1)$$

2.5.2 Water absorption capacity, foam capacity, and swelling index

The water absorption properties (WAC), foam capacity (FC), and swelling index (SI) of the composite flour samples were determined using the recommended method of AOAC [48]. The WAC, FC, and SI expressed as g/g, %, and% respectively were calculated below;

$$\text{Water absorption capacity (g/g)} = \frac{Weight\ of\ sample\ after\ centrifuging}{Weight\ of\ sample\ before\ centrifuging} \quad (2)$$

$$\text{Foam capacity (\%)} = \frac{Volume\ after\ whipping - Volume\ before\ whipping}{Volume\ before\ whipping} \times 100 \quad (3)$$

$$\text{Swelling power (\%)} = \frac{Final\ volume}{Initial\ volume} \times 100 \quad (4)$$

2.6 Dispersibility

The dispersibility of flour blends was determined using the method described by Balami et al., [49]. Distilled water (100 ml) was added to 5 g of flour sample and stirred vigorously for 30 min using the laboratory shaker to obtain a homogenous mixture. The mixture was allowed to stand for 3 hours and the volume of settled particles was recorded. The dispersibility expressed as a percentage (%) was calculated thus;

$$\text{Dispersibility (\%)} = 100 - \text{volume of settled particle (ml)} \quad (5)$$

2.7 Wettability and Sinkability

The method described by AOAC [49] was adopted. 1 g of sample was added into a 25 ml graduated cylinder with a diameter of 1cm. Placing a finger over the open end of the cylinder, it was inverted and clamped at a height of 10cm from the surface of a 600ml beaker containing 500 ml of distilled water. The finger was removed and the time required for the sample to become completely wet was recorded as its wettability and the time required for the sample to drop at the base of the graduated cylinder is referred to as sinkability.

Note: The weight and how fine the particle size of a sample are determining factors in the timing of wettability and sinkability.

2.8 Statistical Analysis

The statistical analyses were carried out using IBM SPSS software version 20 (IBM Corp., New York, USA). The assumptions of Analysis of Variance (ANOVA) were investigated for normality, outliers, and homogeneity of variances using Kurtosis, box plot, and Levene's test. Data obtained from triplicate determinations of the sample were subjected to a 6 × 2 multilevel factorial design as shown in Table 2. A two-way Analysis of Variance (ANOVA) was conducted, which considered formulation-type and processing method/treatment. Results of the functional properties were expressed as mean ± standard deviation (SD) and the mean differences were resolved using Fisher's least significant difference (LSD) with the significance level set at 95% (p<0.05) confidence level.

Table 2. Multilevel factorial experimental design

	Factor A	Factor B
Name	Formulation-type	Processing method/treatment
Scale type	Nominal scale	Nominal scale
Levels	6	2
1	Pre-gelatinized	Malted
2	M+AYB (90:10)	Unmalted
3	M+AYB+JF (80:10:10)	-
4	M+AYB+JF (70:15:15)	-
5	M+AYB+JF (60:20:20)	-
6	M+AYB+JF (50:25:25)	-

Where M = Millet; AYB = African yam bean; JF = Jackfruit pulp

3. RESULTS

Tables 3 and 4 present the variations in the studied functional properties (Loose bulk density [LBD], packed bulk density [PBD], water absorption capacity [WAC], foaming capacity [FC], swelling index [SI], dispersibility, wettability, and sinkability) of composite flour blends of complementary food. Table 5 shows a two-factor (first-order) ANOVA of the effect of formulation type and treatment on the functional properties of the composite flour blends of complementary food. The LBD of composite flours ranged from 0.41 to 0.47 g/ml while the control sample recorded an LBD mean of 0.47 g/ml. There was no significant difference ($p>0.05$) between the LBD of composite flours studied. For the PBD, a significant difference ($p<0.05$) exists between the composite flours that ranged from 0.78 to 0.89 g/ml. the control sample (0.79 g/ml) of PBD was significantly different ($p<0.05$) with composite flour blends and also appears to be relatively lower. Further, the FC of the composite flour blends showed no significant difference ($p>0.05$) amongst each other, and with the control. The WAC of composite flours containing malted samples was not significantly different ($p>0.05$) from each other but showed a significant difference ($p<0.05$) with control. For composite flours containing unmalted samples, there was no significant difference ($p>0.05$) in the WAC between the formulated flour blends and control. However, the SI, dispersibility, wettability, and sinkability of composite flour blends, showed a significant difference ($p<0.05$) amongst each other and with the control sample. Interestingly, the control sample had lower wettability and sinkability compared to their corresponding composite flour blends. While the main effects of formulation type and treatment caused significant variations in the functional properties except for LBD & PBD (for formulation type) and LBD (for treatment), there were no significant interactions between formulation type and treatment except for SI, wettability, and sinkability (Refer to Table 5). This could be the reason for higher SI, wettability, and sinkability in the composite flour blends containing malted samples while LBD, PBD, WAC, FC, and dispersibility values were higher for composite flour blends containing unmalted samples.

4. DISCUSSION

4.1 Loose Bulk Density and Packed Bulk Density

The loose bulk density (LBD) (0.41 – 0.52 g/ml) and packed bulk density (PBD) (0.78 – 0.89g/ml) of composite flours are presented in Table 3, with the control having a 0.47 g/ml and 0.79 g/ml for both bulk densities respectively. There was no significant interaction ($p>0.05$) between the formulation-type and treatment for LBD and PBD (Refer to Table 5). The values of LBD in this current study is in agreement with the values of 0.43 to 0.51g/ml reported by Ayinde et al., [50] for "Kokoro" blended with beniseed while that of PBD is comparable with the findings of Sengev *et al.,* 2012 who reported 0.77 to 0.82g/ml for kunun-zaki flour from sorghum and mango mesocarp flour. However, the LBD and PBD of the current study are higher than the values of 0.39 – 0.47g/ml and 0.42 – 0.67 g/ml respectively reported by Amandikwa et al., [51] for wheat-yam composite flour. These variations could be a result of differences in raw materials for composite flour formulation. Importantly, the PBD of composite flours containing either malted or unmalted samples is significantly higher ($p<0.05$) than their corresponding loose bulk densities for flours containing either malted or unmalted samples respectively. There was no significant difference ($p>0.05$) amongst the composite flours containing either the malted or unmalted samples. The bulk density which depicts the weight or heaviness of particulate matter per unit volume

Table 3. Variations in loose bulk density, paced bulk density, foaming capacity, and water absorption capacity of complementary food

	Loose bulk density (g/ml)		Packed bulk density (g/ml)		Water absorption capacity (g/g)		Foaming capacity (%)	
Sample	**Malted**	**Unmalted**	**Malted**	**Unmalted**	**Malted**	**Unmalted**	**Malted**	**Unmalted**
M+AYB (90:10)	0.41^{a} ±0.03	0.47^{a} ± 0.02	0.81^{bc}±0.01	0.84^{b}±0.02	1.25^{b}±0.07	2.90^{a}±0.14	5.00^{a}±0.00	7.50^{a}±0.54
M+AYB+JF (80:10:10)	0.45^{a} ±0.05	0.49^{a} ±0.04	0.78^{d}±0.04	0.82^{b}±0.02	1.45^{b}±0.07	3.00^{a}±0.00	5.00^{a}±0.00	7.50^{a}±0.54
M+AYB+JF (70:15:15)	0.45^{a} ±0.00	0.47^{a}±0.01	0.80^{c}±0.01	0.88^{a}±0.03	1.40^{b}±0.00	3.10^{a}±0.14	5.00^{a}±0.00	7.50^{a}±0.54
M+AYB+JF (60:20:20)	0.47^{a} ±0.00	0.52^{a}±0.00	0.85^{a}±0.02	0.87^{a}±0.04	1.30^{b}±0.14	2.80^{a}±0.00	5.00^{a}±0.00	7.50^{a}±0.54
M+AYB+JF (50:25:25)	0.47^{a} ±0.06	0.47^{a}±0.04	0.83^{ab}±0.01	0.89^{a}±0.00	1.30^{b}±0.14	2.90^{a}±0.14	5.00^{a}±0.00	7.50^{a}±0.54
Control	0.47^{a} ±0.05	0.47^{a}±0.05	0.79^{d}±0.02	0.79^{c}±0.02	3.30^{a}±0.71	3.30^{a}±0.71	5.00^{a}±0.00	7.50^{a}±0.54

Values are means ± standard deviation of triplicate determinations

^{a,b} Means with common superscripts in the same column do not differ significantly according to Fisher's LSD test ($p > 0.05$)

Table 4. Variations in solubility, dispersibility, wettability, and sinkability of complementary food

	Swelling index (%)		Dispersibility (%)		Wettability (sec)		Sinkability (sec)	
Sample	**Malted**	**Unmalted**	**Malted**	**Unmalted**	**Malted**	**Unmalted**	**Malted**	**Unmalted**
M+AYB (90:10)	10.79^{d}±0.76	12.74^{f}±0.55	79.50^{b}±0.71	87.00^{a}±0.00	23.41^{e}±1.64	19.36^{c}±3.73	25.81^{d}±2.84	21.39^{d}±4.53
M+AYB+JF (80:10:10)	14.80^{c}±0.28	16.15^{d}±0.59	78.50^{bc}±0.71	84.50^{bc}±0.71	40.75^{c}±2.55	24.17^{b}±1.22	42.50^{b}±2.33	26.34^{c}±1.95
M+AYB+JF (70:15:15)	14.43^{c}±0.08	19.14^{c}±0.09	77.00^{c}±0.00	83.00^{d}±0.00	49.70^{a}±0.27	31.20^{a}±0.89	51.19^{a}±0.49	33.96^{ab}±0.97
M+AYB+JF (60:20:20)	18.45^{b}±1.23	21.94^{b}±0.07	77.00^{c}±0.00	83.50^{c}±0.71	43.81^{b}±3.03	30.27^{a}±1.22	46.43^{b}±2.54	31.94^{b}±1.03
M+AYB+JF (50:25:25)	19.98^{a}±0.59	24.77^{a}±0.45	77.00^{c}±0.00	82.00^{d}±0.00	32.75^{d}±2.60	32.64^{a}±2.25	35.09^{c}±1.48	36.70^{a}±2.43
Control	14.52^{c}±0.82	14.52^{e}±0.82	82.00^{a}±0.00	82.00^{d}±0.00	10.37^{f}±1.11	10.37^{d}±1.11	12.69^{e}±0.96	12.69^{e}±0.96

Values are means ± standard deviation of triplicate determinations

^{a,b} Means with common superscripts in the same column do not differ significantly according to Fisher's LSD test ($p > 0.05$)

Table 5. Two-factor ANOVA of formulation-type and treatment (processing method) on the functional properties of complementary food

Parameters	Variance ratios (*F* value)			Mean square error
	A (Formulation type)	B (Treatment)	Interaction (A ×B)	
Loose bulk density (LBD)	0.699^{NS}	2.558^{NS}	0.257^{NS}	0.002
Packed bulk density (PBD)	2.53^{NS}	6.299*	0.837^{NS}	0.010
Water absorption capacity (WAC)	7.113*	2979.150*	1.877^{NS}	0.004
Swelling index (SI)	11207.692*	8700.462*	404.118*	0.006
Foam capacity (FC)	-	-	-	0.000
Dispersibility	29.747*	617.000*	2.616^{NS}	0.309
Wettability	3486.087	9294.843*	1112.681*	0.059
Sinkability	2336.578*	5834.008*	787.446*	0.088

Analyses were done for five formulation-type and two treatments of malted and unmalted samples.
**F value is significant at p <0.05; NS implies not significant (p>0.05)*

is an important index of structural changes [52]. It is used to determine packaging requirements, material handling equipment, and application of the type of food in the food industry, [53]. Besides measuring the bulk solid of particle mass, bulk density (either loose or packed) also entails the amount of air in the void spaces between the particles. Overall, composite flour formulations containing unmalted samples had significantly higher (p<0.05) values of loose and PBD compared to composite flour formulations containing the malted sample. While LBD represents the bulk solid of flour that has not been compressed, PBD is the bulk solid that has been subjected to compression. Malting may have caused some structural deformations that resulted in reduced bulk density which is an indication of the production of small fibre (fine) particles with an increased amount of internal and/or external pores in the powder [54,41]. The results obtained were similar to the work of Otutu et al., [55] who reported a reduction in bulk density of sorghum starch as the germination period increases. According to Ashogbon and Akintayo [56], bulk density is an index that also measures the degree of flour coarseness. Therefore the higher the bulk density, the coarser the particles of the sample. Specifically in the composite flour with malted samples, metabolic actions of malting may have reduced the degree of coarseness and particle size distribution, thereby reducing the bulk density of the flour. Since porosity is directly related to bulk density, this suggests that flours with malted samples may have a higher ability to absorb water and oil [54]. In other words, the complementary food samples with low bulk densities could be prepared using a higher amount of water which gives a desirable energy nutrient density and semi-solid consistency that can easily be fed to an infant [57]. The bulk density of flour protein is important in the preparation of infant food formulations. High bulk density limits the calorie and nutrient intake per feed and it is advisable to be put into consideration in the formulation of food for people watching weight, while low bulk density is advantageous for the infant as both calorie and nutrient are enhanced per feed of the child [58,59].

4.2 Water Absorption Capacity

The water absorption capacity (WAC) of composite flours ranged from 1.25 – 1.70 g/g for flours containing malted samples, 2.80 – 3.10 g/g for flours containing unmalted samples, while the control had the highest WAC of 3.30 g/g (Refer to Table 3). There was no significant difference (p>0.05) within the composite flours containing the unmalted samples, but there were significant differences (p<0.05) amongst treatment and within the composite flours containing malted samples. Also, the formulation-type and treatment showed no significant interaction (p>0.05) (Refer to Table 5). The result somewhat compares favourably with the findings of Usman et al., [60] who reported a value of 1.52 – 3.81 g/ml. WAC is an index that reflects the maximum amount of water a food material can absorb [61]. The observed variation in different flours may be due to differences in starch content, protein concentration, degree of interaction with water and conformational characteristics [62]. The result showed that composite flours containing malted samples had higher WAC compared to those containing unmalted samples. Malting action increased the WAC of composite flour formulations in this current study. This result is the situation where insoluble dietary fiber and protein content increases during malting as a result of metabolic activities and the development of hydrolytic enzymes [24,40,63]. In addition, malting may have caused degradation and modification of the starch configuration which could give rise to losing the structure of the starch polymer, thereby increasing WAC of the flour, unlike flours containing unmalted sample with its starch structure still intact and compacted. This is in line with the findings of Otutu et al. [55] who reported an increase in WAC after malting of maize grain. Importantly, polysaccharides which are major constituents of available starch and polar amino acid residues of proteins greatly affect the WAC of starches [64] since they have an affinity for water molecules. Increased WAC may reflect low starch content, high dietary bulk [65] and also the availability of hydrophilic groups that bind water molecules which is ideal for infants. The characteristics of water absorption indicate a product's ability to associate with water [61]. While the low WAC of unmalted samples may be associated with a higher proportion of hydroxyl groups forming covalent and hydrogen bonds between starch molecules rather than water [66], the high WAC in the malted sample could be linked with malting action producing a higher proportion of protein subunits with more polar binding sites which could, in turn, increases its gel-forming ability [67]. It is therefore evident that malting enhanced the hydrophilic affinity of the composite flours, hence, can also be useful in confectionery products where hydration to improve handling is desired [53].

4.3 Foam Capacity

The foam capacity (FC) were uniform amongst each treatment as composite flours with malted samples had 5.00% while flours with unmalted samples had a value of 7.50% (Refer to Table 3). This is in agreement with the findings reported by Ayinde et al., [50] who reported a value of 4.50 to 7.40%. There was a significant difference ($p<0.05$) between composite flours with malted samples and their corresponding flours containing the unmalted samples. FC of protein is a measure of the amount of interfacial area that can be generated by whipping the protein [68,69]. Foam formation is dependent on protein type, pH, viscosity, treatment method, etc. [70]. The trend obtained in this current study is in line with the report of Adedeji et al., [71] who reported higher FC for unmalted maize when compared to malted maize. The reduction in FC in this current study could be due to less protein-protein interactions in the flour [62] and increased amylose leaching due to loss of native starch crystalline structure owed to malting action [72]. Brou et al. [73] reported that denatured protein provides lower FC than the native protein. Malting might have resulted in the production of a higher proportion of denatured proteins in form of amino acids with a lower molecular weight of about less than 10 kDa [74]. This result is a situation where smaller air bubbles are surrounded by thin and more flexible protein films (lower molecular weight) which may inhibit the coalescence of air bubbles, thereby resulting to lower FC [75,76]. However, low FC flours are desirable in food production, especially where excessive foaming is not required as it reduces loss due to foam spillage or the need for including extra steep or anti-foaming agents to check foaming [77].

4.4 Swelling Index

The swelling index (SI) of composite flours containing malted samples (10.65 – 19.98%), unmalted samples (10.09 – 24.77%), and control (14.52%) are presented in Table 4. There were significant differences ($p<0.05$) within the flour samples and amongst the treatment. The findings of this current study are comparable with the values of SI (10.00 – 17.00%) reported by Njintang et al., [78]. SI is a measure of flour's ability to imbibe water and increase in volume when mixed with water [79,80]. The formulation-type and treatment showed significant interaction ($p<0.05$) (Refer to Table 5). This implies that treatment and formulation-type associate significantly to influence changes in the SI of formulated complementary food. In other words, the variations in SI of this current study is a result of the malting and composition of flour blends as well as their levels of substitutions. Also, the results show that the SI of composite flours containing malted samples is significantly lower ($p<0.05$) than flours containing unmalted samples. According to Ezema [81], the degree of swelling is greatly dependent on the temperature, available water, protein, and the magnitude of starch damage due to processing treatment. Though some previous studies have reported a positive correlation between WAC and SI for starch-based flours, the result of this current study is not in agreement with such phenomenon, as flours containing malted samples had higher WAC and lower SI when compared to their corresponding flours containing unmalted samples. The variations could be attributed to differences in the type of substrate, nature of starch granules between legumes and cereals, pure starch in relation to whole grain flour, and processing/treatment method, which can cause different degrees of flour swelling [82]. Furthermore, both protein and starch have been shown to influence the swelling of flours, with starch playing a dominant role at high temperature and protein at low temperature [59,83] (Henshaw and Adebowale, 2004). Adebowale et al., [84] associated the lower SI in mung bean malt with high amylose content in the flour which resulted from the malting action. Additionally, the extent of starch solubility may be dependent on the protein-amylose complex formation in isolated starches which may cause a decrease in swelling power [85]. The action of malting on the protein molecules and starch configuration might have caused denaturation and structural modification or degradation respectively, thereby reducing the ability of composite flours containing malted samples to swell. Interestingly, high swelling power is not required in complementary foods as the food would have less solid resulting in high nutrient density for the infant due to absorption of more water.

4.5 Dispersibility

The dispersibility of composite flours containing unmalted samples (82.00 – 91.00%), malted samples (77.00 – 79.50%), and control (82.00%) are presented in Table 4. There were significant differences ($p<0.05$) within the flour samples and amongst the treatment. Also, the formulation-type and treatment showed no significant interaction ($p>0.05$) (Refer to Table 5). The findings of this current study are comparable with the dispersibility (61.73 – 86.51%) reported by Jha et al., [86] for instant Kheer mix (a mixture of agglomerated rice and spray-dried buffalo milk). Dispersibility is a rehydration index that measures the ease of flour reconstitution in water [87]. Besides comparing favourably with the control, the dispersibility of flours containing malted samples was significantly lower ($p<0.05$) than flours containing unmalted samples. Results show that the higher dispersibility of the composite flours containing unmalted samples appears to reconstitute easily to fine consistency during mixing. The lower dispersibility of composite flours containing malted samples could be an indication of the ability of its flour or powder to aggregate more when dispersed in water with gentle stirring [88]. Note worthily, dispersibility is a function of the particle size of powders. The starch polymer structural deformation associated with malting has been shown to produce significantly reduced particle sizes [54], compared to the particle size of its unmalted counterparts. Perhaps, the nature of the particle size of composite flours containing malted samples could be such that its fineness and higher porosity may cause agglomeration of its particles to form lumps which may be broken by mechanical stress [89]. This corroborates with the report of Sharma et al., [88] who stated that the dispersibility of powders decreases as the percentage of fine particles increases. On the contrary, the interaction between the larger and irregular shaped particles (powders) of composite flours with unmalted samples may result in agglomeration of particles that can fall apart with ease in water [90], thus giving rapid dispersion. According to Sharma et al., [88], powders with large particle size has superior dispersibility. Generally, all flour blends have relatively high dispersibility (>70%), which is an indication of how easily the flour blends can go into solution under normal home-mixing conditions.

4.6 Wettability

The wettability of composite flours ranged from 23.41 – 49.70 s for flours containing malted samples, 18.64 – 32.64 s for flours containing unmalted samples, while the control had the lowest wettability of 10.37 s (Refer to Table 4). There was a significant difference ($p<0.05$) within the composite flours containing the malted and unmalted samples, and there were significant differences ($p<0.05$) amongst treatments. Wettability is the ability of a powder to be wetted, to absorb water on the surface, to permeate the surface of still water, and the time taken for the powder to be completely wet. The formulation-type and treatment showed significant interaction ($p<0.05$) (Refer to Table 5). This implies that treatment and formulation-type associates significantly influence variations in the wettability of the formulated complementary food. In other words, the variations in wettability of this current study are a result of the malting and composition of flour blends as well as their levels of substitutions. The wetting time obtained for composite flours in this study is significantly higher ($p<0.05$) than that of skim milk powder that wetted in less than 15 s according to Kelly et al., [91]. In this study, high wetting time indicates low wettability and vice versa. Given this, the wettability of composite flours containing malted samples is significantly lower ($p<0.05$) since it recorded a higher wetting time compared to flours containing unmalted samples. As a function of ease of dispersing flour samples in water, flours containing unmalted samples with the lowest wetting time dissolve faster in water compared to their corresponding malted counterparts. Some factors that may influence the degree of wettability include but are not limited to particle size, porosity, density, surface area, surface charge, etc. However, the variations in the wettability could be attributed to differences in particle size as a result of malting and flour compositions. Further, malting has been shown to cause modification and deformation of structural characteristics which resulted in a higher proportion of reduced particle sizes, unlike the unmalted samples that retained most of their structural integrity of being coarse and compact, thus having large particle sizes. According to Sharma et al., [88], large particles favour faster wetting and that could be why many dispersible powders typically exhibit good wettability. This was evident in the result (Refer to Table 4) as composite flours containing unmalted samples having higher dispersibility, also had the lowest wetting time when compared to their corresponding malted counterparts. However, since the wettability of composite flours in this study ranged from 18.64 to 49.70 s, the flour blends have relatively appreciable wetting time, provided the wettability is ≤ 60 s [88,91].

4.7 Sinkability

The sinkability of composite flours containing malted samples (25.81 – 46.43 s), unmalted samples (20.52 – 36.70 s), and control (12.69 s) are presented in Table 4. There were significant differences ($p<0.05$) within the flour samples and amongst the treatment. Sinkability is the ability of flour (powder) particles to sink into the water after overcoming the surface tension of water [92]. According to Fang et al., [93], it is the time taken for the powder particles to drop below the surface of the water. However, there was significant interaction ($p<0.05$) between formulation-type and treatment (Refer to Table 5). This indicates that formulation-type and treatment associates significantly influence variations in the sinkability of the formulated complementary food. In other words, the variations in wettability of this current study are a result of the malting and composition of flour blends as well as their levels of substitutions. Also, results show that the composite flours containing malted samples are significantly higher ($p<0.05$) than their corresponding flours containing unmalted samples. This implies that malting caused an increase in the amount of time required for flour particles to be completely wet and sink below the water surface. As a rehydration index that is a function of particle density, less dense powder particles will take a longer time to be completely wet and vice versa. Obomeghei et al., [94] reported that flours with higher bulk density tend to have higher sinkability. In this study, flour blends with high sinking time indicate low sinkability and vice versa. However, there appears to be a positive correlation between bulk density, dispersibility, and sinkability, as flours containing unmalted samples seem to have higher bulk densities, dispersibility, and sinkability compared to their corresponding malted counterparts. Possibly, the modification and/or deformation of the starch polymer structural configuration by the action of malting may have reduced the coarse particle size and the number of intercellular spaces or void. Specifically, with regards to composite flours containing unmalted samples, their higher sinkability (low sinking time) when compared with their corresponding malted counterparts could be a result of the coarseness and particle size distribution of the flours which contributes greatly to the flour bulk density. Besides bulk density associating appreciably with the degree of flour coarseness, it is also well-known to be directly related to porosity [54]. The particle or powder void space (porosity) in composite flours containing unmalted samples could be such that it enhances water sorption, thereby replacing the intercellular spaces of the powder particles with water. The result is a situation where powder particles get wet easily and sink rapidly, thus increasing sinkability. Just like in wettability, since the sinkability of the composite flours being studied ranged from 20.52 to 46.43 s, the flour blends have a relatively appreciable sinking time, provided the sinkability is ≤ 60 s.

5. CONCLUSION

The functional properties of complementary food containing flour blends of millet, African yam bean, and jackfruit flours were investigated. The formulated composite flours exhibited an appreciable level of functionality with respect to the parameters determined and showed an acceptable aptitude to be used as a complementary food for weaning purposes. However, results show that malting and pre-gelatinization influenced the intrinsic functional properties of the flour blends. Malting caused significant changes in particle size thereby decreasing the bulk densities (loose and packed), SI, WAC, FC, and dispersibility, but increased wettability and sinkability. Further, increasing the proportion of African yam bean and jackfruit flour as the millet proportion decreases, showed no trend nor the significant impact on the functional properties of the flour blends except for SI and dispersibility. The rehydration index (dispersibility, wettability, and sinkability) of the flour blends appeared to be somewhat related. Beyond ascertaining the functional properties of these flour blends, carrying out other tests and analysis such as nutritional composition (amino acid profile, vitamin and mineral contents, antioxidants, etc.), sensory, physicochemical, and pasting properties, is also important in guiding processors and researchers towards an acceptable product selection. Overall, this research has demonstrated the potentials of utilizing millet, African yam bean and jackfruit as sustainable nutrient-dense food materials for the production of complementary food for people in under-developed and developing regions of the world.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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