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Functional Properties of Composite Flours Used in Breakfast Meal Formulation for Young Children

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Abstract: *The purpose of the study was to determine the functional properties of composite flours used in breakfast meal formulation for young children. The study adopted experimental design. Flours were produced from the various local foodstuff used for the study which included corn, date, sweet potato and bonga fish. Six samples of the breakfast meal was formulated at different ratios. Standard laboratory analytical method of Association of Official Analytical Chemists (AOAC) procedure was used to determine the functional properties of the samples. The functional properties analyzed were water absorption capacity (WAC), oil absorption capacity (OAC), swelling index (SI), foam capacity (FC), gelation temperature (GT) and bulk density (BD). The results on the functional properties shows the samples contained a reasonable and recommendable good amounts of WAC (1.93-3.00), AOC (1.79-2.41), BD (0.51-0.62), FC (17.63-20.87), SI (2.95-3.87) and GT (85.65-87.52). The result obtained showed that the functional properties of the breakfast composite flours are appreciable and the formulations are suitable to be used as meal for young children. The study recommends amongst others that the samples should be further characterized to determine their suitability for various applications, such as food formulation, nutritional supplementation, and pharmaceutical development.*

Keywords: Breakfast, functional properties, young children, formulation, composite flours.

Introduction

The word breakfast is the first meal of the day and its origin was derived from the late Middle English verbs break and fast. The word literally means to break the fasting period from the day before. Breakfast is often considered the most crucial meal, requiring a balance of nutrition and wholesomeness. Breakfast cereal (BFC) emerged as a top-tier source of daily nutrients for both children and adults, (Ferrentino, G. 2024). It provides a valuable option for those with time constraints or a lack of appetite in the morning due to its high nutritional value and easy preparation. Breakfast cereals are processed grain-based foods that are frequently consumed as the first meal of the day. Breakfast cereals, although being ingested dry in the early hours of the day, provide a good amount of strength, which is a crucial necessity for the human body (Ujong,

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Aniefiok & Onyekwe, 2023). Ready-to-eat breakfast cereals are increasingly gaining acceptance in most developing countries, and gradually displacing most traditional diets that serve as breakfast due to convenience, nutritional values, improved income, and status symbol and job demands (Edima-Nyah, Ntukidem & Etoro-Abasi, 2019). However, most breakfast cereals are limited in some essential amino acids like threonine and tryptophan, though rich in lysine but cannot effectively provide nutrients required by the body especially during the early hours of the day when the supply of nutrients from the previous day is exhausted. Hence, blends and consumption of proteins from plant and animal sources in food product development are required since combination of legumes and grains provide high quality cheaper protein that contains all essential amino acids in proper proportion, because their amino acids complement each other (Okafor & Usman, 2020).

The use of mixtures of flours derived from various food sources in meal formulation offers a range of nutritional benefits and culinary versatility. Each type of flour brings its unique flavor, texture, and nutritional profile, making it suitable for different dishes. Creating nutritious meals for children is essential for their growth and development. Combining various flours from different food sources not only enhances the nutritional profile but also improves flavor and texture, making meals more appealing to young eaters, (Foegeding *et al.*, 2019). Therefore, understanding the functional properties of these flours is crucial in harnessing their potential benefits.

Functional properties refer to the physical and chemical characteristics of food ingredients, particularly flours that influence their behavior during processing and preparation. Functional properties determine how ingredients interact in a food system and their impact on product quality. In practical applications, these properties help food scientists and manufacturers select the right types of flours or other ingredients to achieve desired textures and stability in different foods (Afolabi *et al*., 2023; *Hassan et al*., 2022). These properties affect the texture, structure, appearance, and sensory attributes of food products. Some of the most common functional properties include: Water Absorption Capacity (WAC) which is the ability of flour to absorb and retain water, which influences the moisture content and texture of food products like bread and cakes; Oil Absorption Capacity (OAC) which refers to the ability of flour to bind oil, thereby affecting the flavor, mouth feel, and texture of fried or baked goods; Gelatinization which is the process where starch granules in flour absorb water and swell when heated, forming a gel-like structure, which is essential for thickening soups, sauces, and doughs; Foaming Capacity and Stability which is the ability of flour proteins to trap air, forming foams, which is important for products like whipped toppings or baked goods that require aeration; Emulsion Stability which is the capacity of flour to help oil and water mix and remain stable, which is vital in products like dressings, soups, and sauces and the Swelling Power which refers to the extent to which flour granules can swell upon hydration, which impacts the texture and viscosity of the final product, (Oyenuga *et al*., 2020; Osman *et al*., 2023; Onwurafor *et al*., 2020; Dereje *et al*., 2020; Okoye *et al*., 2020). The functional properties of composite flours in breakfast meal formulations have been investigated in several studies. Adegunwa *et al*. (2019) evaluated the functional properties of composite flours made from wheat, maize, and soybean in breakfast meal formulations. The study found that the composite flours had improved nutritional and functional properties compared to single-ingredient flours. Specifically, the composite flours exhibited better water absorption capacity, emulsifying activity, and foaming capacity. More so, Onwuka *et al*. (2018) investigated the nutritional and functional properties of breakfast cereals made from composite flours of wheat, rice, and maize. The study found that the composite flours had better nutritional and functional properties than single-ingredient flours. Specifically, the composite flours had higher protein content, better texture, and improved sensory properties. These findings support the use of composite flours in breakfast cereal formulations to enhance the nutritional and functional properties of the final product. In addition, Singh *et al.* (2020) evaluated the functional properties of flours from different cereals, including wheat, rice, and maize, in breakfast meal formulations. The study found that the functional properties of the flours varied depending on the type of cereal used. Specifically, wheat flour had better dough-forming properties, while rice flour had better paste-forming properties (Singh *et al.*, 2020). These findings highlight the importance of selecting the appropriate type of cereal for specific applications.

Despite the growing recognition of the importance of composite flours in improving the nutritional quality of food products, there is a significant knowledge gap regarding their functional properties in breakfast meal formulations specifically designed for young children. Existing studies have primarily focused on the nutritional and sensory properties of composite flours, with limited attention to their functional properties, such as water absorption capacity, oil absorption capacity, and gelation temperature, which are critical determinants of product texture, stability, and acceptability. This study aims to bridge this gap by investigating the functional properties of composite flours used in breakfast meal formulations for young children, providing valuable insights for food manufacturers, policymakers, and caregivers to develop nutritious, safe, and appealing breakfast options that meet the unique needs of this vulnerable population. The functional properties of flours, such as those derived from corn, bonga fish, oat, sweet potato, and date palm, are critical in determining their suitability for food formulation, particularly in composite meals. These properties influence not only the sensory attributes but also the processing behavior and nutritional quality of the final products.

Purpose of the study

The main purpose of the study was to determine the functional properties of the composite flours used in breakfast meal formulation for young children, (corn, date fruit, sweet potato, oat and bonga fish). Specifically the study:

1. formulated a breakfast meal using the composite flour from corn, date, sweet potato, oat and bonga fish at different ratios;
2. determined the functional properties (water absorption capacity, swelling capacity, oil absorption capacity, bulk density, foam capacity, gelatinization temperature and gelatinization capacity) of the breakfast composite flour samples.

Research questions

1. How can breakfast meal be formulated using the composite flour from corn, date, sweet potato, oat and bonga fish at different ratios?
2. What are the functional properties (water absorption capacity, swelling capacity, oil absorption capacity, bulk density, foam capacity, gelatinization temperature and gelatinization capacity) of the breakfast composite flour samples?

Materials and Methods

The study adopted experimental research design. The equipment used were Gravimetric method and Moisture analyzer for determining Water Absorption Capacity; Gravimetric method using an analytical balance for analyzing Oil Absorption Capacity; Bulk density tester and Graduated cylinder for determining Bulk Density; Graduated cylinder or measuring cup for analyzing the

Swelling Index and Differential Scanning Calorimeter (DSC) for determining the Gelation Temperature.

Source of raw materials

The raw materials for the study are Corn, Dates, Sweet potato, Oat and Bonga fish. These were locally purchased from Eke, Awka market in Awka town, Anambra.

Sample preparation

The local foodstuffs were sorted to remove stones, dirt, dust, and chaff. It was washed, strained and allowed to dry. Some were toasted, roasted, oven dried and dehydrated, then aired and milled into flour. The resulting flour was sieved using a 0.4mm mesh size, and then stored in air tight container.

Figure 1: Flow Chart of Preparing Maize Flour

Date palm Fruit
↓
Sorting
↓
Washing
↓
Soaking
↓
De-seeded
↓
Dehydrated
↓
Milling
↓
Sieving
↓
Date Flour

Figure 2: Flow Chart for Preparing Date Flour

Sweet Potato
↓
Sorting
↓
Washing
↓
Peeling
↓
Cutting (Tiny Bits)
↓
Washing
↓
Dehydrate
↓
Milling
↓
Sieving
↓
Sweet Potato Flour

Figure 3: Flow Chart for Preparing Sweet potato

Figure 4: Flow Chart for Preparing Oat Flour

Figure 5: Flow Chart for Preparing Bonga Fish Flour

Formulation of breakfast samples using the composite flours

Six samples were used for the study. Six samples were products of various proportions of the food sources used in formulating the breakfast meal

- Sample A consisted of 25.6% corn, 22% sweet potato, 22% dates, 0.4% bonga fish, and 30% oat.
- Sample B was made up of 30% corn, 40% sweet potato, no dates, 0.4% bonga fish, and 29.6% oat.
- Sample C comprised 29.8% corn, 30% sweet potato, 10% dates, 0.4% bonga fish, and 29.8% oat.
- Sample D contained 30% corn, 10% sweet potato, 30% dates, no bonga fish, and 30% oat.
- Sample E consisted of 40% corn, 10% sweet potato, 20% dates, 0.4% bonga fish, and 27.6% oat.

- Sample F was composed of 29.6% corn, no sweet potato, 40% dates, 0.4% bonga fish, and 30% oat.

Laboratory/Functional Analysis

The water absorption capacity, swelling capacity, oil absorption capacity, bulk density, foam capacity, gelatinization temperature and gelatinization capacity of the breakfast composite flour samples were determined using Onwuka (2018) method. Where Bulk density (g/ml) was calculated as weight of sample (g)/volume of sample (ml), Water absorption was calculated as the amount of water absorbed (total minus free water) x 1 g/ml, the difference in volume was taken as the oil absorbed by the samples, swelling capacity taken as the ratio of the swollen volume to the original volume of a unit weight of the flour, at complete gel formation, the temperature was measured and taken as gelatinization temperature, and the gelation capacity is the least concentration determined as the concentration when the sample from the inverted test tubes will not fall or slip.

Method of Data Collection

Bulk density

A 10 ml capacity graduated measuring cylinder was weighed and sample gently filled into the cylinder. The bottom of the cylinder was gently tapped on the laboratory bench severally until there was no diminution of the sample level after filling to the 10 ml mark. Bulk density (g/ml) was calculated as weight of sample (g)/volume of sample (ml) according to Onwuka (2018).

Water absorption capacity (WAC)

Water absorption capacity was determined as described by Onwuka (2018). One gram (1g) of sample was weighed and placed into a conical graduated centrifuge tube. A waring whirl mixer was used to mix the sample thoroughly, 10 ml was added and sample allowed to stay for 30 mins at room temperature and then centrifuged at 5000 x g for 30 mins. The volume of the free water (supernatant) was read using 10 ml measuring cylinder. Water absorption was calculated as the amount of water absorbed (total minus free water) x 1 g/ml.

Oil absorption capacity (OAC)

The determination of OAC was done in accordance with Onwuka (2018). Refined soybean oil with density of 0.92 g/mL was used. Exactly 1 g of the sample was mixed with 10 mL of the oil (V_1) for 30s. The sample was allowed to stand for 30 min at room temperature and then centrifuged (Centurion scientific, Model k241) at 10,000 rpm for 30 min. The amount of oil separated as supernatant (V_2) was measured using 10 ml cylinder. The difference in volume was taken as the oil absorbed by the samples.

Swelling Index (SI)

This is the ratio of the swollen volume to the original volume of a unit weight of the flour. The method reported by Onwuka (2018) was used. One (1) gram of the flour sample was weighed into a clean dry measuring cylinder. The height occupied by the sample was recorded (H_1) and then 5 mL of distilled water added to the sample. This was left to stand undisturbed for 1 hr, after which the height was observed and recorded again (H_2).

Foam capacity (FC)

The foam capacity was determined by the method of Onwuka (2019). Two grams of the flour sample was dispersed in 100ml distilled water. The resulting solution was homogenized for 5 minutes at high speed. The volume remaining at interval of 0.00, 0.30, 1, 2, 3, 4 up to 24 h was noted for the study of foaming stability.

Gelation temperature (GT)

Gelatinization temperature was determined by Shinde (2018). One gram flour sample was weighed accurately and transferred to 20 mL screw capped tubes. Ten ml (10ml) of distilled water was added to the sample. The sample was heated slowly in a water bath until they form a solid gel. At complete gel formation, the temperature was measured and taken as gelatinization temperature. The researchers increased the reliability and accuracy of the results by controlling extraneous variables during functional properties analysis. The extraneous variables were controlled by maintaining consistent temperature, humidity, and lighting conditions throughout the experiment. More so to ensure standardized sample preparation, uniform handling, storage, and processing procedures was established to minimize variations. Furthermore, instrumentation calibration was checked by using regularly calibrate equipment and validate measurement techniques to reduce errors.

Method of Data Analysis

The statistical analysis for all the experiments was carried out in duplicates. The means and standard deviation values were calculated. Data obtained from the laboratory analysis of samples were subjected to statistical analysis using the Statistical Package for the Social Sciences (SPSS), version 20.0. Analysis of Variance (ANOVA) was used, and significance was accepted at $p <$ 0.05. Where significant differences existed, means were separated using Duncan' s Multiple Range Test (DMRT).

Results

Table 1 shows the result of the functional properties of the formulated breakfast meal using composite flour.

Table 1: Functional Properties of the Samples

S/N	WAC(g/g)	OAC(g/g)	BD (g/ml)	FC (%)	SI	GT (ºC)
A	$2.71^{c}\pm0.01$	$1.84^{d}\pm0.01$	$0.52^{d}\pm0.00$	$17.63^{d}\pm0.01$	$3.53^{b}\pm0.01$	$87.41^{a}\pm0.01$
B	$3.00^{a}\pm0.00$	$2.29^{b}\pm0.01$	$0.57^{b}\pm0.01$	$19.41^{b}\pm0.01$	$3.87^{a}\pm0.02$	$86.49^{c}\pm0.01$
C	$2.91^{b}\pm0.01$	$1.94^{c}\pm0.01$	$0.62^{a}\pm0.002$	$17.77^{d}\pm0.09$	$3.57^{b}\pm0.02$	$85.71^{d}\pm0.01$
D	$2.20^{e}\pm0.00$	$1.79^{e}\pm0.01$	$0.52^{d}\pm0.00$	$18.87^{c}\pm0.04$	$3.13^{c}\pm0.02$	$86.50^{c}\pm0.00$
E	$2.41^{d}\pm0.01$	$2.41^{a}\pm0.01$	$0.56^{c}\pm0.00$	$20.87^{a}\pm0.04$	$3.17^{c}\pm0.01$	$85.65^{d}\pm0.07$
F	$1.93^{f}\pm0.01$	$1.83^{d}\pm0.01$	$0.51^{d}\pm0.00$	$18.84^{c}\pm0.08$	$2.95^{d}\pm0.01$	$87.52^{b}\pm0.10^{a}$

Note: Water absorption capacity (WAC), Oil absorption capacity (OAC), Bulk density (BD), Foaming capacity (FC), Swelling index (SI), Gelation temperature (GT)

Table 1 present the results of the functional properties of the formulated breakfast. The result showed sample B had the highest WAC (3.00 ± 0.00 g/g), significantly higher than others, while Sample F has the lowest (1.93 ± 0.01 g/g). The high WAC of Sample B suggests it contains more hydrophilic components, such as starch or protein, which enhance water-binding (Aprianita *et al.*, 2014). Sample F's low WAC may limit its use in products requiring high water retention, like baked goods. Sample E exhibits the highest OAC (2.41 ± 0.01 g/g), while Sample D has the lowest (1.79 ± 0.01 g/g). High OAC in Sample E suggests a greater presence of non-polar sites or hydrophobic proteins, making it suitable for fat-based products (Seena and Sridhar, 2005). The low OAC of Sample D may indicate fewer lipophilic components, limiting its application in oil-rich formulations. The significant differences across samples suggest variations in protein or fiber content. For Bulk Density, Sample C has the highest BD (0.62 ± 0.002 g/ml), while Sample F has the lowest (0.51 ± 0.00 g/ml). Higher BD in Sample C suggests finer particle size or denser composition, which could reduce packaging volume but may affect flowability. Sample F's low BD indicates a lighter, possibly more porous structure, which could be advantageous for instant food products but may increase packaging costs. The significant differences imply processing techniques (e.g., milling) vary across samples. In Foaming Capacity (FC %), Sample E has the highest FC (20.87 ± 0.04%), while Samples A and C have the lowest (17.63 ± 0.01% and 17.77 ± 0.09%, respectively). High FC in Sample E suggests a higher protein content capable of forming stable interfacial films (Falade and Okafor, 2015). The lower FC in Samples A and C may limit their use in aerated products. The significant differences highlight variations in protein functionality among samples. In Swelling Index (SI), Sample B has the highest SI (3.87 ± 0.02), while Sample F has the lowest (2.95 ± 0.01). The high SI of Sample B correlates with its high WAC, suggesting strong water-binding and swelling properties, likely due to high starch or fiber content. Sample F's low SI indicates limited swelling, possibly due to lower polysaccharide content. These differences suggest varied applications in food systems requiring specific textural properties. In Gelation Temperature, Sample A has the highest GT (87.41 ± 0.01°C), while Sample E has the lowest (85.65 ± 0.07°C). A higher GT in Sample A suggests stronger molecular interactions, requiring more energy to form a gel, which may be due to higher protein or starch content. Sample E' s lower GT indicates easier gel formation, suitable for products processed at lower temperatures.

Discussion of Findings

The study found that there were significant differences ($P<0.05$) in the bulk density of the samples (A-F). Formulation F had the least bulk density followed by sample D, while sample C had the highest bulk density. A significant difference was also observed in the foam capacity of the samples, sample E had the highest while sample A had the least. Formulation E is significantly higher than other formulations. Foams capacity varied from 17.63 to 20.87%. Foam ability has been reported by Foegeding *et al*. (2019) to be related to the amount of polar and nonpolar lipids present in the samples. The gelatinization temperature varies from 78.50 to 87.52. Formulation F had the highest content of gelatinization temperature followed by sample A. In support of this blending sago flour with varying concentrations of fish flour (1%, 5%, and 10%) resulted in increased protein levels and improved functional properties like water absorption and gelation capacity. The optimal blend, containing 10% fish flour, exhibited a high protein content of 6.39% and a calcium content of 2869 mg/kg, indicating its potential for developing protein-enriched food products (Peter-Ikechukwu et al., 2020).

In addition, the findings reveal that there were significant differences in water absorption capacity of the formulations. Adding oat flour (5%-25%) to sweet potato flour improves rheological properties, water retention, and thermo mechanical characteristics of the dough. Optimal results were observed with 20%-25% oat flour addition, enhancing the texture and structure of steamed cake products, (Xinyu Wei *et al* 2024). Furthermore, the particle size of date seed flour significantly influences its water-holding capacity (WHC), oil-holding capacity (OHC), and swelling capacity (SWC). Larger particle sizes tend to exhibit higher WHC and OHC, which are beneficial for improving the texture and shelf-life of baked products (Nuria *et al*., 2024). The swelling index/emulsion capacity varied from (3.13-3.87) among the samples. Substituting wheat flour with sweet potato flour (5%-30%) in pastry products affects moisture content, pH, and functional properties like emulsion capacity. Sweet potato flour exhibited higher emulsion capacity (52.4%) compared to wheat flour (48.4%), indicating its potential in pastry applications, (Tortoe *et al,* 2017). The functional properties of these flours, ranging from water and oil absorption capacities to gelatinization and emulsion stability, contribute to their potential uses in composite food formulations. Each flour brings distinct advantages that enhance the overall quality of the formulated meal in terms of texture, moisture retention, and nutrient density.

Conclusion

This study investigated the functional properties of composite flours used in breakfast meal formulation for young children. The functional properties of six different samples were checked. The results revealed significant variations in the composition and properties of the samples. The findings of this study provide valuable information on the nutritional evaluation of the samples, which can be useful for various applications such as food formulation, nutritional supplementation, and pharmaceutical development. The study's results suggest that Sample E has the highest functional capacity. Hence we can conclude that the breakfast foods are good for children’ s normal nutrition and growth if handled with optimum care. The result of this study has shown that breakfast can be produced from composite flours blend of corn, sweet potato, dates, oat and bonga fish. The variations in the composition and properties of the samples observed in this study highlight the importance of proper characterization and analysis of food materials to ensure their safety and quality. Furthermore, the study's findings can be used to identify potential applications for the samples, such as functional foods, nutraceuticals, or pharmaceuticals.

Recommendations

Based on the findings of this study, the following recommendations are made:

1. The samples should be further characterized to determine their suitability for various applications, such as food formulation, nutritional supplementation, and pharmaceutical development.
2. Quality control measures should be implemented to ensure the consistency and quality of the samples.
3. Further studies should be conducted to investigate the potential health benefits of the samples.
4. Further analysis is needed to check the shelf-life of the breakfast samples to determine its commercial viability.

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Conflict of Interest

The authors declare that there is no competing interest that could have influenced this paper**.**

Authors' Contributions

Ifeanyichukwu, Obioma Irene and Ezema, Priscila Nnenna: Conception/design, development of data collection instrument, analysis, interpretation of data, revised manuscript (30%)
Ifeanyichukwu, Obioma Irene, Ezema, Priscila Nnenna and Nwakpadolu, Glory Mmachukwu: Conception/design, data collection, analysis, interpretation of data, editing and first draft (20%)
Ifeanyichukwu, Obioma Irene: Analysis and Interpretation of data (10%)
Ezema, Priscila Nnenna: Interpretation of data, first draft and revision (10%)
Ifeanyichukwu, Obioma Irene: Data collection, interpretation of data and first draft (10%)
Nwakpadolu, Glory Mmachukwu: Interpretation of data, first draft and editing (10%)
Ifeanyichukwu, Obioma Irene: Data collection, interpretation of data and first draft (10%)

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