Functional Properties of Composite Flours Produced From Blends of Fermented Maize (*Zea mays* L) And Fermented Soybean (*Glycine max*) Flour

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KEYWORDS

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ABSTRACT

The objective of this study was to determine the functional properties of composite flours produced from blends of fermented maize (Zea mays L) and fermented soybean (Glycine max) flour. Maize grains were sorted, cleaned, fermented for 48 h, oven dried (60 °C to constant weight), milled to flour and then sieved (250 μm) to produce maize flour. The soybean was sorted, cleaned, boiled, cooled, dehulled, and fermented for 48 h with Rhizopus oligosporus (0.4g per 100g of soybean), oven dried (60 °C to constant weight), milled and sieved (250 μm) to produce fermented soybean flour. Using mixture design, maize and soybean flour samples were blended in the ratios 90:10, 80:20, 70:30, 60:40, and 50:50 to obtain composite flours while 100% maize flour and 100% soybean flour served as controls. Functional properties of the samples were evaluated. Inclusion of fermented soybean to fermented maize flour significantly (p<0.05) increased bulk density, oil absorption capacity, swelling capacity, foaming capacity and pH while water absorption and emulsification capacities decreased. Flour sample with 90:10 – fermented maize:fermented soybean flour had the highest water absorption capacity (2.96g/mL) while flour sample with 60:40 – fermented maize:fermented soybean flour had the highest bulk density (14.67g/mL) and oil absorption capacity (4.45mL/g). These findings suggest that incorporating fermented soybean flour into fermented maize flour enhances its suitability for use in baked goods, emulsified foods, and thickening agents. It is recommended that fermented soybean inclusion levels of 40 -50% be used for baked products requiring higher bulk density and oil retention.

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INTRODUCTION

Maize, scientifically referred to as (*Zea mays L*) is the foremost cereal crop globally and a crucial calorie source for a significant majority of the global populace (Chaves-López *et al.*, 2020). It contributes to 40% of the overall cereal production in sub-Saharan Africa and serves as the provider of approximately 30% of the total calorie consumption for over 4.5 billion individuals in developing nations (Chaves-López *et al.*, 2020). Nevertheless, while maize is a valuable calorie and nutrient source, its protein content is comparatively lower in nutritional quality compared to proteins found in milk, soybeans, peas, and lupins. Maize protein lacks essential amino acids such as lysine and threonine, which are crucial for optimal nutritional benefits (Dewettinck *et al*., 2008).

Soybean (*Glycine max*) is extensively cultivated due to its valuable bean, which is rich in protein. The protein content in these beans can range from 33% to 50%, depending on factors such as the specific variety and the processing methods employed (Oyeyinka *et al.*, 2020). Soybean grains are excellent sources of phytochemicals such as phytic acid, alpha-linolenic acid, and the isoflavones-genistein and daidzein (Basson *et al.*, 2021). Soybean, like other legumes, contains crucial minerals like calcium and phosphorus, as well as essential vitamins such as A, B group vitamins, and C (Igyor *et al.*, 2011). Because of these nutritional qualities, soybean and other legumes have been over the years incorporated into diverse food products to address the limited availability of protein (Innocent *et al.*, 2019). They serve as an affordable protein source that can potentially be used to enhance staple foods like maize meal in developing nations (Oyeyinka *et al.*, 2020).

To enhance the nutritional value of legumes and maize-based products, functionality, as well as to reduce the anti-nutrients they contain, fermentation is commonly employed (Olaleye, Oresanya, and Ogundipe, 2020). Fermentation technology stands at the forefront of food technology as a powerful tool, offering a strong basis for the creation of safe food products that possess enhanced nutritional and functional characteristics (Whakshama and Akueshi, 2008). Fermentation has the ability of enhancing functional properties, nutritional value, flavour, colour, taste, and aroma, protein, amino acid, and lipid profiles (Whakshama and Akueshi, 2009). This is due to the fact that legumes are rich in essential nutrients such as proteins, minerals, vitamins B, and lysine, which is an amino acid that is often limited in most cereals (Jideani and Onwubali, 2009). Therefore, by blending legumes with cereals at the appropriate ratio, they can complement each other functionally and nutritionally (Okoye and Okaka, 2009). In the present era of advancing functional food, the application of bioprocessing methods like fermentation is driving notable changes in the realm of food and nutrition (Tsafrakidou *et al*., 2020).

Composite flour is a mix of several flours produced from roots, tubers, cereals and legumes either with or without the addition of wheat flour (Shittu *et al.,* 2007). Composite flours have been widely and effectively utilized in the manufacturing of baked goods. The raw materials used in formulating composite flour influence their functional properties. Functional properties have been defined as those characteristics that govern the behaviour of nutrients in food during processing, storage and preparation as they affect food quality and acceptability (Onwuka, 2018). Some important functional properties that influence the utility of certain foods are Bulk Density, Water Absorption Capacity, Emulsion Capacity, Foam Capacity, Foam Stability, Viscosity, Swelling Capacity, Gelatinization Temperature, Solubility and pH (Onwuka, 2018). Functional properties are the intrinsic physicochemical characteristics which may affect the behaviour of food systems during processing and storage (Adebowale, Henle, and Schwarzenbolz, 2009). Details on the functional properties of mazie-soybean flour abound but there exists some gap in knowledge regarding the functional properties of composite flours produced from fermented maize and fermented soybean.

MATERIALS AND METHOD

Sources of Raw Materials

Maize grains were purchased from Eke Awka Market in Awka, Anambra State, Nigeria while *Rhizopus oligosoprus was* purchased from Indonesia (Ragi Tempe, Raprima Inokulum Tempe, PT.Aneka Fermentasi Industri, Sandung 40553 -Indonesia).

Experimental Design

Mixture design was adopted for the ratio mix of fermented maize:fermented soybean. The composite flours were made from flour blends as presented in table 1

Table 1: Mixture design formulation

SAMPLE	MAIZE	SOYBEAN
CHR	100	0
IST	0	100
ABE	90	10
OBI	80	20
NME	70	30
SOM	60	40
JAN	50	50

Production of fermented maize flour

The maize flour was prepared according to the method of Houssou and Ayemor (2002). The maize grains (free from dirt, damaged and contaminated grains) were cleaned and washed then soaked in potable water for 48 h with occasional change of the soak water for fermentation to occur. After 48 h, the soaked grains were drained, rinsed and oven dried at 60°C to constant weight. The dried grains were milled with an attrition mill into flour. The powder obtained was sieved through a sieve of 250 μm aperture size into a clean plastic bowl. The maize flour produced was packaged in an airtight plastic container for further use.

Production of fermented soybean flour

The soybean flour was produced according to the method described by Edema *et al*. (2005). The soybean seeds were sorted to remove pebbles, stones and other extraneous materials. The seeds were washed with water and steeped in water for 2 h. The steeped soybeans were drained and boiled for 30 min at 100°C, dehulled manually by rubbing in between the palms and the hulls were removed by floatation and rinsed with clean water. The dehulled soybeans were inoculated with *Rhizopus oligosporus* (0.4g per 100g of beans) and vinegar (2.85mL per 1000g of beans) and left to ferment for 48 h. The fermented beans were oven dried at 60°C to constant weight and milled in attrition mill. The soybean powder was sieved through a sieve of 250μm aperture size to obtain smooth flour. The soy bean flour was packaged in a low-density polyethylene bag until used.

Determination of the Functional Properties of fermented maize-fermented soybean flour

Bulk density determination

The bulk densities of the samples were calculated according to the methods described by Onwuka (2018). A measured amount of the flour sample was filled into the weighed calibrated measuring cylinder till the 10 mL mark. The measured cylinder was continuously tapped until there was no further change in the sample level. The bulk density was determined using the following formula;

$$\text{Bulk density} = \frac{\text{Weight of sample (g)}}{\text{Volume of sample after tapping (mL)}}$$

Determination of oil absorption capacity

The weight of oil absorbed and retained by 1 gram of the sample was determined. The method outlined by AOAC (2010) was modified according to the description provided by Onwuka (2005). In this procedure, 1 gram of the sample was weighed into a graduated centrifuge tube. A warring whirl mixer was utilized to thoroughly mix the sample with 10 mL of oil for a duration of 30 seconds. The mixture was allowed to stand at room temperature for 30 minutes, after which it was centrifuged at a speed of 3,500 rpm for 30 minutes. The resulting volume of oil (known as supernatant) was decanted, measured, and recorded. The oil absorption capacity was determined by subtracting the volume of oil (supernatant) from the initial volume of oil (10 mL). It was thus calculated:

$OAC = V_O — V_I$,

where OAC = Oil absorption capacity, V_O = Initial volume of oil (10mL), V_I = Volume of oil (supernatant).

Determination of water absorption capacity

The weight of water absorbed and retained by 1 gram of the sample was determined. The procedure outlined in AOAC (2010) was adopted. A measured weight of 1g of the sample was carefully measured and placed in a graduated centrifuge tube. A high-speed mixer was utilized to thoroughly mix the sample with 10 mL of distilled water for a duration of 30 seconds. The mixture was left undisturbed at room temperature for 30 minutes and subsequently centrifuged at a speed of 3,500 revolutions per minute for 30 minutes. The resulting volume of water (known as the supernatant) was decanted, measured, and recorded. The water absorption capacity was determined by subtracting the volume of the supernatant from the initial volume of water (10 mL).

$WAC = V_O — V_I$,

WAC = Water Absorption capacity, V_O = Initial volume of water (10mL)

V_I = Volume of water (supernatant)

Determination of swelling capacity

The procedure described by Onwuka (2018) was utilized in determining the swelling capacity. Ten (10g) grams of flour was measured in a 300 mL measuring cylinder, and the observed volume was recorded.

Subsequently, 150 mL of distilled water was added to the flour and allowed to stand for 4-hours. The final volume after swelling was noted, and the percentage swelling was calculated. The percentage swelling was calculated as:

$$\% \text{ Swelling capacity} = \frac{(\text{final volume} - \text{initial volume})}{\text{initial volume}} \times 100.$$

Determination of pH

A 10% W/V suspension of the sample in distilled water was prepared and thoroughly mixed in a warring micro-blender. The pH of each sample was measured with a pH meter using the method described by Neto *et al.* (2001).

Determination of foaming capacity (FC)

Foaming capacity was determined by the method of Coffman and Garcia (2002). The flour blend (2g) was dispersed in distilled water (100 mL) and homogenized properly for two minutes in a kitchen blender. The mixture was poured into a 250mL measuring cylinder, and the volume after 30 seconds was recorded. Volumes were recorded before and after homogenization and percent increase in the volume was calculated as FC of the flour by using the following formula:

$$\text{FC } (\%) = \frac{(V_2 - V_1)}{V_1} \times 100$$

Where, V_1 = Volume before homogenization, V_2 = Volume after homogenization.

Determination of emulsification capacity

Emulsification capacity of flours and blends were determined by the method documented by Neto *et al.* (2001). The flour sample (2 g) was dispersed in distilled water (25 mL) and blended thoroughly for 30 seconds in a warring blender. The solution was homogenized with refined canola oil (5 mL) for another 30 seconds and the resulting emulsion was centrifuged at 1,600 rpm for 5 minutes. The height of the emulsified layer was measured and the emulsion capacity was calculated as the percent increase in the height of the solution by following equation:

$$\text{Emulsion capacity } (\%) = [H_2 / H_1] \times 100$$

where H_1= height of whole solution in centrifuge, H_2 = height of the emulsified layer.

RESULTS AND DISCUSSION

The functional properties of fermented composite maize-soybean flour were evaluated and the result presented in Table1.

Bulk Density of fermented maize-fermented soybean composite flour

Bulk density ranged from 11.7 g/mL (OBI) to 15.67 g/mL (IST). The highest bulk density was observed in 100% soybean (IST), while the lowest was recorded in the 80% maize:20% soybean sample (OBI). An increase in soybean inclusion generally led to an increase in bulk density, with some fluctuations. Higher bulk density suggests better packaging and reduced porosity, which may enhance storage stability (Adedeji and Tadawus, 2019). Compared to other studies on maize flour, reported bulk density values range from 0.45 - 0.53 g/mL (Adedeji and Tadawus, 2019). The observed values in this study exceed this range, indicating the possible impact of soybean addition on the flour's compactness. Higher bulk density is beneficial in food formulations where high density is required, such as in baking applications.

Oil Absorption Capacity of fermented maize-fermented soybean composite flour

Oil absorption capacity varied from 3.83 mL/g (CHR) to 4.45 mL/g (SOM). The highest oil absorption capacity was recorded in 60% maize:40% soybean (SOM), while 100% maize (CHR) had the lowest. Increased soybean inclusion resulted in higher oil absorption capacity, which may be attributed to the higher protein content of soybean, enhancing its ability to bind lipids (Oyeyinka *et al.*, 2020). Maize flour oil absorption values of 1.19 – 2.34 mL/g was reported by Adedeji and Tadawus (2019) indicating that soybean inclusion significantly enhances oil absorption. This is advantageous for food products like meat extenders and emulsified products where oil retention is crucial for texture and flavor development.

Table 2: Functional properties of fermented maize-soybean composite flour

Sample Code	Bulk density (g/mL)	Oil absorption (mL/g)	Water absorption (mL/g)	Emulsion capacity (%)	Swelling capacity (%)	Foaming capacity (%)	pH
CHR	$12.73^{d}\pm0.25$	$3.83^{b}\pm0.15$	$2.95^{a}\pm0.05$	$9.30^{a}\pm0.10$	$15.5^{e}\pm0.50$	$16.03^{f}\pm0.21$	$5.51^{e}\pm0.03$
IST	$15.67^{a}\pm0.31$	$3.87^{b}\pm0.15$	$2.75^{b}\pm0.05$	$8.15^{cd}\pm0.05$	$19.63^{a}\pm0.32$	$14.58^{g}\pm0.08$	$6.31^{a}\pm0.09$
ABE	$12.43^{d}\pm0.51$	$4.37^{a}\pm0.15$	$2.96^{a}\pm0.04$	$7.95^{d}\pm0.08$	$15.9^{e}\pm0.10$	$16.50^{e}\pm0.25$	$5.73^{d}\pm0.03$
OBI	$11.7^{e}\pm0.26$	$4.33^{a}\pm0.15$	$2.85^{ab}\pm0.05$	$6.22^{f}\pm0.10$	$18.8^{b}\pm0.15$	$16.96^{d}\pm0.12$	$6.08^{b}\pm0.08$
NME	$12.53^{d}\pm0.42$	$4.33^{a}\pm0.15$	$2.88^{ab}\pm0.10$	$8.60^{b}\pm0.26$	$17.8^{c}\pm0.20$	$17.79^{c}\pm0.09$	$6.12^{b}\pm0.02$
SOM	$14.67^{b}\pm0.31$	$4.45^{a}\pm0.05$	$2.78^{ab}\pm0.19$	$8.37^{bc}\pm0.15$	$17.3^{d}\pm0.15$	$18.61^{b}\pm0.05$	$6.02^{bc}\pm0.09$
JAN	$13.73^{c}\pm0.31$	$4.42^{a}\pm0.05$	$2.70^{b}\pm0.10$	$7.40^{e}\pm0.01$	$17.2^{d}\pm0.21$	$19.12^{a}\pm0.07$	$5.93^{c}\pm0.04$

Values are mean ±standard deviation of triplicate determinations. Values with different superscripts within the same column show significant difference ($p<0.05$).
KEY: CHR= 100% maize, IST= 100% soybean, ABE= 90% maize:10% soybeans, OBI= 80% maize: 20% soybean, NME= 70% maize: 30% soybean, SOM= 60% maize: 40% soybean, JAN= 50% maize: 50% soybean

Water Absorption Capacity of fermented maize-fermented soybean composite flour

Water absorption capacity ranged from 2.70 mL/g (JAN) to 2.96 mL/g (ABE). The highest value was found in 90% maize:10% soybean (ABE), while 50% maize:50% soybean (JAN) had the lowest. Water absorption significantly ($p<0.05$) decreased as soybean inclusion increased, likely due to the lower starch content in soybean compared to maize. A previous study reported maize flour water absorption values of 2.19 – 2.34 (Adedeji and Tadawus, 2019), which is lower than the values in this research. Fermentation of soybean could have contributed to the elevated water absorption capacity. Increased water absorption in high-soybean formulations may positively impact the hydration properties of the flour, potentially enhancing its applications in dough and batter formulations where high water retention is needed.

Emulsion Capacity of fermented maize-fermented soybean composite flour

Emulsion capacity ranged from 6.22% (OBI) to 9.30% (CHR). There were significant ($p<0.05$) differences amongst the samples. The highest emulsion capacity was recorded in 100% maize (CHR), with a decline as soybean inclusion increased. This decrease may be due to the higher lipid content of soybean interfering with the protein-stabilizing properties (Oyeyinka *et al.*, 2020). Lower emulsion capacity in soybean-rich samples suggests reduced stability in emulsified food products, making them less suitable for applications like mayonnaise or salad dressings.

Swelling Capacity of fermented maize-fermented soybean composite flour

Swelling capacity varied between 15.5% (CHR) and 19.63% (IST). There was also significant ($p<0.05$) difference amongst the samples. The highest swelling capacity was observed in 100% soybean (IST), while the lowest was found in 100% maize (CHR). Increased soybean inclusion generally enhanced swelling capacity. Previous studies report maize flour swelling capacities in the range of 5.44 – 5.85 % (Adedeji and Tadawus, 2019), indicating that soybean significantly contributes to swelling behaviour. Increased swelling capacity is beneficial in gelatinized food applications like porridges and thickening agents.

Foaming Capacity of fermented maize-fermented soybean composite flour

Foaming capacity ranged from 14.58% (IST) to 19.12% (JAN). The highest foaming capacity was found in 50% maize:50% soybean (JAN), whereas the lowest was in 100% soybean (IST). The increase in foaming capacity with moderate soybean inclusion suggests enhanced protein interaction, while higher soybean content appears to limit foaming (Basson *et al.*, 2021). Higher foaming capacity is beneficial in aerated food systems such as baked goods and whipped toppings.

pH of fermented maize-fermented soybean composite flour

The pH ranged from 5.51 (CHR) to 6.31 (IST). The highest pH was observed in 100% soybean (IST), while the lowest was recorded in 100% maize (CHR). The pH increased with soybean inclusion, likely due to the buffering properties of soybean proteins (Adedeji and Tadawus, 2019). Previous studies reported maize flour pH values between 5.4 and 6.0 (Amadi *et al*., 2018), indicating that soybean incorporation slightly raises the pH. This may have implications for the shelf-life and microbial stability of products made from the flour blends.

CONCLUSION

The study demonstrates that fermented soybean inclusion in fermented maize flour significantly alters its functional properties. Bulk density, oil absorption, swelling, foaming capacities, and pH increased with fermented soybean addition, while emulsification and water absorption capacities generally decreased. These findings suggest that incorporating fermented soybean flour into fermented maize flour enhances its suitability for certain food applications, particularly in baked goods, emulsified foods, and thickening agents. Based on these results, it is recommended that soybean inclusion levels be optimized depending on the intended application. For baked products requiring higher bulk density and oil retention, formulations with 40–50% soybean inclusion may be ideal. For emulsified food applications, lower soybean inclusion is preferable to maintain higher emulsion capacity.

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