Croatian Journal of Food Science and Technology
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Proximate composition, functional and pasting characteristics of malted-fermented sorghum and soybean flour blends

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ARTICLE INFO

TYPE: Original scientific paper
https://doi.org/10.17508/CJFST.2025.17.1.05

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ARTICLE HISTORY
Received: October 30, 2024
Accepted: January 7, 2025

CITATION
Iwayemi EF, Ikujenlola AV. Proximate composition, functional and pasting characteristics of malted-fermented sorghum and soybean flour blends. Croatian Journal of Food Science and Technology (2025) 17 (1) 63-80

KEYWORDS
fermentation; malting; malnutrition; sorghum; soybean

KEY CONTRIBUTION

The research indicates that the integration of malting and fermentation processes substantially enhances the nutritional profile of flours derived from sorghum and soybean, augmenting protein and fat levels. The study shows that malting and fermentation greatly reduce bulk density and viscosity. This makes the flour better for supporting newborn foods and lessens the safety concerns that come with high-viscosity diets. The results show that fermentation and malting increase the bioavailability of protein and fat, which are essential for baby's growth and development. The research presents an innovative method for developing complementary foods using a combination of malted and fermented sorghum and soybean flours, potentially establishing a framework for future investigations and applications in addressing malnutrition. The research aids in mitigating protein and energy malnutrition in babies in Nigeria and comparable settings, potentially decreasing infant death rates associated with malnutrition-related complications.

ABSTRACT

This study aimed to produce nutrient-rich complementary flours with low bulk density and viscosity from sorghum and soybean using malting and fermentation. Eight samples were prepared: four sorghum flours (unmalted, malted, fermented, and malted-fermented) and four soybean flours (unmalted, malted, fermented, and malted-fermented). The sorghum and soybean flours were then blended in a 70:30 ratio. The results demonstrated that malting, fermentation, and the combination of these processes reduced the bulk density (0.60-0.77 g/mL) of the flour samples. The peak viscosity of the samples ranged from 18.31 to 98.50 RVU; malting reduced the peak viscosity of the flours while fermentation and the combination of the two processes increased it. Protein (6.24 to 16.22%), total ash (1.07 to 5.34%), crude fat (3.07 to 11.20%), and energy value (377.77 to 405.96 kcal/100 g) increased with malting and the addition of soybean flour. The study concluded that using malted-fermented sorghum and soybean in complementary food formulations could alleviate protein and energy malnutrition, thereby reducing the infant mortality rate.

Introduction

Micronutrient and macronutrient deficits contribute to malnutrition (WHO, 2024). Acute malnutrition affects 2.5 million children in Nigeria, according to estimates (WHO, 2016). In Nigeria, 37% of children under the age of five are stunted, with the prevalence increasing with age and reaching a peak of 47% among children aged 24-35 months. While the national prevalence of stunting lessened from 41% in 2008 to 37% in recent years, and wasting declined from 14% in 2008 to 7% in 2018, 22% of children remain underweight. However, some regions continue to report alarmingly high rates of stunting, wasting, and underweight that have shown little to no improvement over time (National Population Commission, 2009; National Population Commission, 2019). Malnutrition directly or indirectly causes 45% of all deaths among children under the age of five (UNICEF, 2019).

Semi-arid environments support the growth of sorghum (*Sorghum bicolor*). The Food and Agricultural Organization ranked sorghum fifth in quantity after wheat, maize, rice, and barley in 2013. It is a major food crop worldwide. For millions of Africa's poorest, it is the main source of calories, proteins, vitamins, and minerals and the staple meal (Kinyua, 2016). Whole sorghum grain contains complex vitamins and minerals like iron, phosphorus, calcium, and magnesium, according to Onabanjo et al. (2009). It also lacks the essential amino acid lysine, so it must be combined with other easily available staple foods like legumes (such as soybeans) to provide a more nutrient-dense diet (Mosha et al., 2000). Protein levels in soybean seeds are exceptionally high. Dry soybean typically contains 5% ash (non-aqueous metal oxides), 35% carbohydrate, 20% soybean oil, and 40% or more protein (Ojewumi et al., 2018). As a result, among all species of legumes, soybean has the highest protein concentration (Ojewumi et al., 2018). Soybeans are by far the least expensive protein-rich food when compared to other options like meat, fish, and eggs. Additionally, it is rich in vitamins, iron, calcium, and phosphorus. It is the sole source of all the necessary amino acids (Ihekoronye and Ngoddy, 1985; Ojinnaka and Nnorom, 2015). Soy protein's heat-stable nature allows for high-temperature cooking and fermentation of soy seeds without compromising their chemical composition. Typically, people add soy protein as a supplement to enhance the quality of protein in various meal forms (Martines et al., 2010).

Processing techniques such as heating, soaking, malting, and fermentation can enhance the nutritional and practical qualities of plant seeds (Jirapa et al., 2001). Traditional complementary foods often contain high viscosity, which can cause choking and asphyxia in infants. According to research (Ikujenlola 2014; Abiose et al., 2015), malting is a process that can help reduce the viscosity of complementary foods, which are necessary to support growth and sustain healthy living (Adetuyi et al., 2009; Forsido et al., 2020). Bacteria, yeast, or other microorganisms transform substances into alcohol, carbon dioxide, or organic acids through the process of fermentation (Ojewumi, 2016). Researchers have used them to enhance the nutritional value of plant foods (Obadina et al., 2008). Wambugu et al. (2006) studied the addition of malted and fermented sorghum to improve extruded weaning porridges, while Simango (1997) examined traditional fermented weaning foods in Zimbabwe. Similarly, Abiose et al. (2015) and Ikujenlola et al. (2019) evaluated complementary blends of malted and fermented maize enriched with soybean, highlighting their improved nutritional quality.

Nigerian researchers have tried to combine cereals, legumes, and other staples to increase the protein efficiency of complementary foods to combat malnutrition. Previous research has used individual malting and fermentation processes to enhance the quality of cereals and legumes. However, there is limited information available on the combined use of both processes on a crop. Therefore, developing a complementary food using a blend of malted-fermented sorghum and soybean flour would be a significant step toward addressing the issue of malnutrition.

Materials and methods

Collection of materials

Sorghum, soybeans, and commercial complementary food (Control) were purchased from a local market in Ile-Ife, Osun State, Nigeria. The Department of Food Science and Technology at Obafemi Awolowo University, Ile-Ife, processed them all. All used chemicals were of analytical grade.

Production of samples

Production of unmalted and malted sorghum flour

Eight kilograms of sorghum grains were sorted, washed, and divided into four portions. The first portion was dried in the cabinet dryer at 60 °C for 6 hours and then milled to prepare the unmalted sorghum. The malted flour was prepared using the Abiose et al. (2015) method as shown in Fig. 1, and the grains were steeped in triple the amount of water to the weight of the sample for 8 hours.

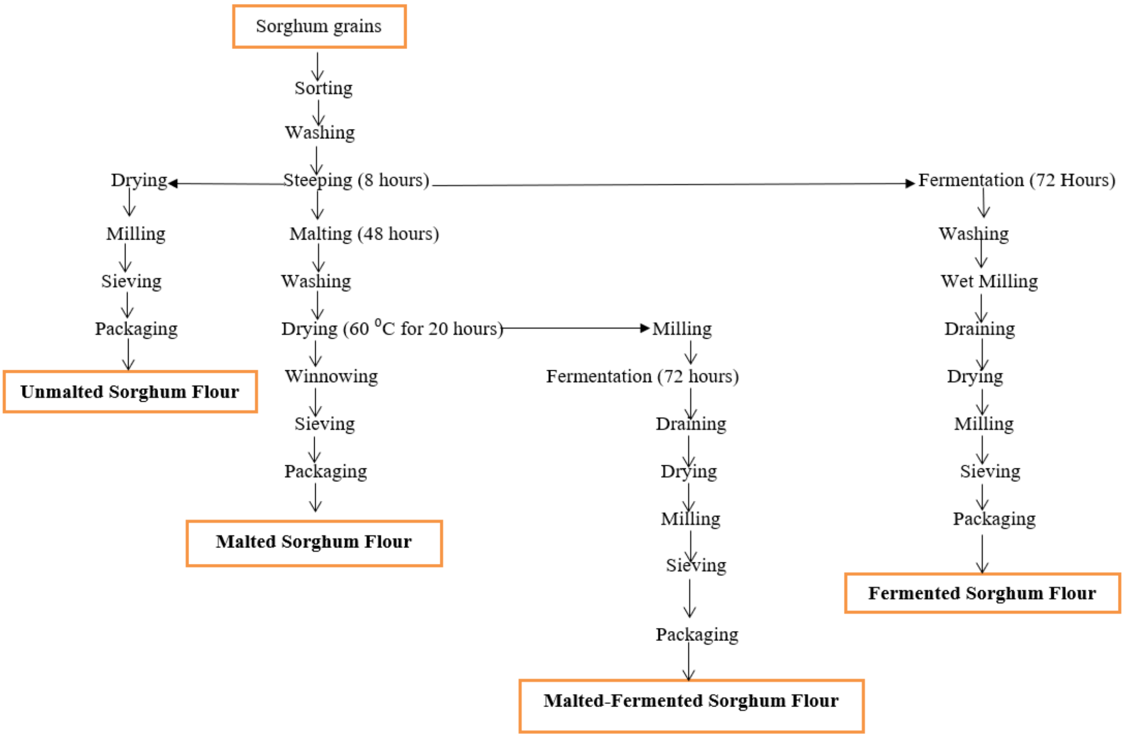

Figure 1. Flow chart for the production of unmalted, malted, fermented, and malted-fermented sorghum (Inyang and Idoko, 2006; Abiose et al., 2015).

The steeped grains were washed and spread evenly in a germinating chamber at about 1.5 cm loading depth for 48 hours, with watering two times daily. The germinated seeds were thoroughly washed and dried in the cabinet dryer at 60 °C for 20 hours. The dried sprout soybean grains were cleaned by winnowing and then dry-milled into flour, sieved (60 mesh), and packed.

Production of fermented, malted-fermented sorghum flour

We used the third portion from above to produce the fermented flour, soaking the grains in water and allowing them to ferment for 72 hours. The fermented grains were thoroughly washed, wetly milled, and allowed to settle for 3 hours, drained, dried (60 °C, 12 hours), milled, sieved (60 mesh), and then packaged (Inyang and Idoko, 2006; Abiose et al., 2015). The fourth portion was then steeped in triple the amount of water to the weight of the sample to produce the malted-fermented flour. The grains were steeped for 8 hours at room temperature and then drained; the steeped grains were spread in a germinating chamber for 48 hours to allow germination with watering two times daily. After 48 hours, the malting process was stopped, and grains were washed and milled. The milled slurry was fermented for 72 hours (Abiose et al., 2015). The fermented slurry was drained, dried (60 °C, 12 hours), milled again to a fine powder, sieved (60 mesh), and then packaged. Fig. 1 illustrates the flow process.

Production of soybean flour and malted soybean flour

Three kilograms of soybeans were thoroughly cleaned to remove dirt and other extraneous materials, such as stones and sticks, and divided into two portions. Soy flour was prepared according to the method described by Ndife et al (2011), as shown in Fig. 2. It was washed and cooked for 5 minutes, then decorticated. The decorticated grains were further cooked for 2 hours and 25 minutes. The cooked grains were then spread and dried at 60 °C for 20 hours in the cabinet dryer, then milled, sieved (60 mesh), and packaged. The second portion was steeped in tap water for 8 hours at ambient temperature. The steeped grains were washed and spread evenly in a germinating chamber at about 1.5 cm loading depth for 72 hours, with watering two times daily. The germinated seeds were thoroughly cleaned and cooked, decorticated, cooked again, and then dried. The dried grains were then milled, sieved (60 mesh), and packaged (Marero et al., 1988; Sajilata et al., 2002; Abiose et al., 2015).

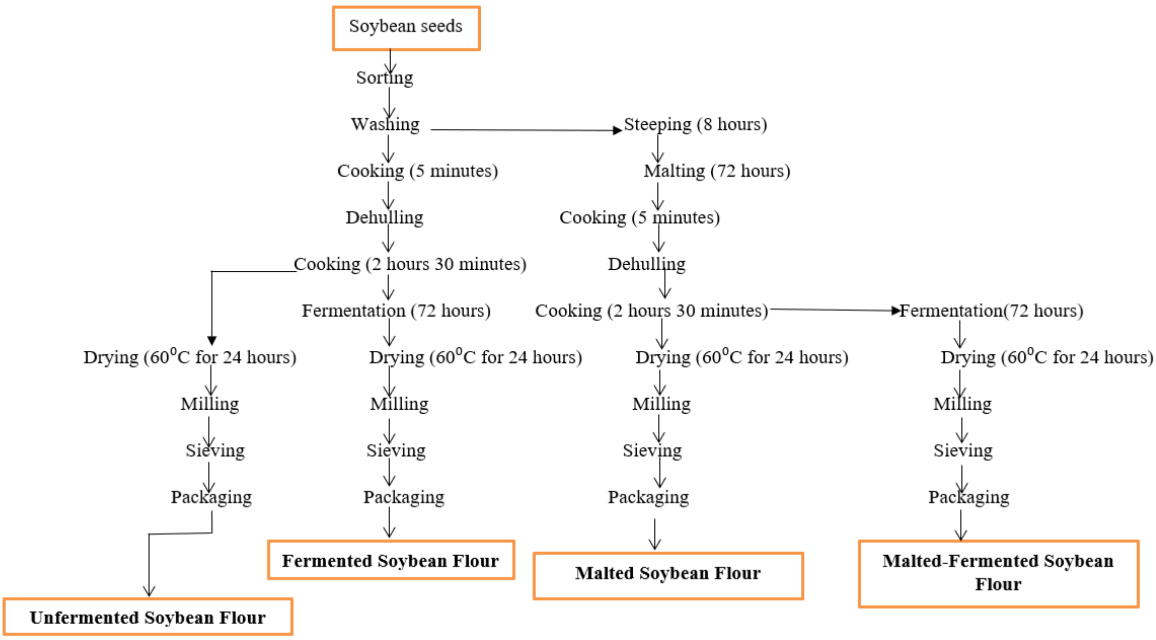

Figure 2. Flow chart for the production of unmalted, malted, fermented, and malted-fermented soybean. (Marero et al., 1988; Sajilata et al., 2002; Farinde et al., 2007; Ndife et al., 2011; Abiose and Ikujenlola, 2014; Abiose et al., 2015).

Production of fermented soybean and malted-fermented soybean flour

The soybean seeds were sorted and then washed with tap water. They were then cooked for 5 minutes and decorticated. The decorticated grains were further cooked for 2 hours and 25 minutes. The cooked grains were then spread inside a plastic colander lined with a sack and then covered with the sack. The colander was wrapped properly with a jute bag and placed in a warm place to ferment for 72 hours.

Fermentation was done naturally by allowing environmental microflora to colonize the legume seeds and cause lactic acid fermentation (Farinde et al., 2007; Abiose and Ikujenlola, 2014). The fermented soybean was dried and then milled into flour, sieved (60 mesh), and then packaged. The second part was malted using the process above, and the germinated grains were washed, cooked, decorticated, cooked again, fermented, dried, milled, and then packaged. The flow process is shown in Fig. 2.

Production of the flour and flour blends

The complementary food flour blends were formulated using the ratio in Table 1.

Table 1. Formulation of the flour and flour blends.

Flour Sample	Formulation
Flour A	100% Sorghum Flour
Flour B	100% Malted Sorghum Flour
Flour C	100% Fermented Sorghum Flour
Flour D	100% Malted-Fermented Sorghum Flour
Flour E	70% Malted-Fermented Sorghum Flour: 30 % Soybean Flour
Flour F	70% Malted-Fermented Sorghum Flour: 30 % Malted Soybean Flour
Flour G	70% Malted-Fermented Sorghum Flour: 30 % Fermented Soybean Flour
Flour H	70% Malted-Fermented Sorghum Flour: 30 % Malted-Fermented Soybean Flour

Methods

Proximate analyses

The Association of Official Analytical Chemists developed a technique of analysis to determine the levels of moisture, crude fat, crude protein, ash, crude fibre, and carbohydrate content (by difference) in the samples (AOAC, 2016). The difference between the two values was used to determine the total carbohydrate content, and the following formula was used to determine the energy content: The formula for calculating energy in terms of kilocalories is as follows:

$$Energy\ (kcal) = 4 \cdot \left(g_{protein} + g_{carbohydrate} \right) + 9 \cdot g_{fat} \tag{1}$$

Determination of functional properties

The functional qualities of the flour samples and blends were determined using the standard procedures. The water absorption capacity was determined by applying the modified methodology developed by the AACC (1995). The Beuchat (1997) approach was utilized in the process of determining the oil absorption capacity. The reconstitution index was computed with the method proposed by Akpapunam et al. (1997). The swelling capacity and dispersibility were computed with methods proposed by Takashi and Sieb (1988) and Kulkarni et al. (1991), respectively.

Swelling capacity

Takashi and Sieb (1988) provided the guidelines for measuring swelling capacity. One gram of sample (W1) was placed in a 2 cm diameter centrifuge tube, 10 mL of distilled water was added, and the mixture was stirred. The slurry was heated at 60, 70, 80, and 90 °C for 15 minutes, with gentle stirring to prevent clumping, then centrifuged at 1788×g for 10 minutes. The supernatant was decanted, and tubes were dried at 50 °C for 30 minutes, cooled, and weighed (W3). The initial weight of the empty tube (W2) was recorded, and swelling capacity was calculated:

$$Swelling\ Capacity\ (\%) = \left(\frac{W_3 - W_2}{W_1}\right) \times 100 \quad (2)$$

Determination of pasting characteristics

The pasting characteristics of the flour and the flour blends were determined using a Rapid Visco Analyser (Newport Scientific, 1998).

Results and discussion

Proximate composition of the flour and flour blends

The proximate composition values of the flours and flour blends, along with the significant differences among them are presented in Table 2. The moisture content of the flour samples ranged from 6.70 to 4.96%. The moisture content of all the samples was within the FAO/WHO-recommended safe limit (<10%), as higher moisture may affect the storage quality of the foods. Malting and fermentation reduced the moisture content of sorghum flour compared to the unprocessed sample, while their combination slightly increased it without significance. These findings align with Oladeji et al. (2018) and Adhikari and Acharya (2015), who reported reductions in moisture content due to fermentation and malting, respectively. The observed values fall within the FAO/WHO safe limit (<10%), ensuring better storage stability. Products with low moisture content, as seen in this study, are less prone to spoilage and can be stored at room temperature without quality degradation (Adedeji et al., 2015).

Table 2. Proximate composition of the flour and flour blends.

Samples	Moisture (%)	Ash (%)	Crude Lipid (%)	Crude Fibre (%)	Crude Protein (%)	CHO (%)	Energy (kcal)
A	6.67±0.24^{a}	1.76±0.09^{ab}	4.55±0.02^{d}	3.65±1.50^{ab}	6.24±0.00^{g}	77.13±1.66^{b}	377.77±27.12^{c}
B	5.32±0.06^{cd}	1.46±0.10^{ab}	3.07±0.05^{e}	2.37±1.30^{ab}	8.08±0.00^{e}	79.69±1.32^{b}	378.03±20.16^{c}
C	4.96±0.19^{d}	1.34±0.02^{b}	3.12±0.14^{e}	1.06±0.28^{b}	4.99±0.00^{h}	84.53±0.63^{a}	385.44±5.27^{c}
D	6.70±0.13^{a}	1.07±0.05^{b}	4.10±0.03^{d}	1.53±0.50^{b}	8.06±0.00^{f}	78.55±0.65^{b}	382.63±11.91^{bc}
E	5.46±0.28^{c}	2.26±0.01^{ab}	9.03±0.03^{c}	1.92±0.36^{ab}	12.50±0.00^{d}	68.83±0.06^{c}	405.96±2.08^{a}
F	4.96±0.12^{d}	2.25±0.12^{ab}	9.24±0.01^{c}	3.41±0.02^{ab}	14.91±0.00^{b}	65.23±0.21^{cd}	403.15±3.78^{b}
G	5.87±0.10^{b}	5.34±4.37^{a}	11.20±0.62^{a}	2.40±0.64^{ab}	13.67±0.00^{c}	61.51±4.25^{d}	401.05±47.56^{ab}
H	5.35±0.00^{cd}	2.59±0.02^{ab}	10.29±0.28^{b}	4.65±1.51^{a}	16.22±0.00^{a}	60.90±2.46^{d}	400.56±51.57^{ab}

Mean values with different superscripts in each column are significantly different at p≤0.05
A = 100% sorghum flour, B = 100% malted sorghum flour, C = 100% fermented sorghum flour, D = 100% malted-fermented sorghum flour, E = 70% malted-fermented sorghum flour and 30% soybean flour, F = 70% malted-fermented sorghum flour and 30% malted soybean flour, G = 70% malted-fermented sorghum flour and 30% fermented soybean flour, H = 70% malted-fermented sorghum flour and 30% malted-fermented soybean flour; CHO = carbohydrate

The ash content of the flour samples ranged from 1.07 to 5.34%. The ash content indicates the amount of minerals in a food sample. It is the inorganic residue remaining after the removal of water and organic matter by heating in the presence of an oxidizing agent (Shittu et al., 2008). Both malting and fermentation decreased ash content, with the combination of the two processes showing the greatest reduction, consistent with previous reports (Anila et al., 2016; Tamilselvan & Kushwaha, 2020). The decrease during malting is attributed to mineral utilization for root and shoot growth (Nour et al., 2016).

The addition of soybean flour, especially fermented soybean, significantly increased ash content due to the higher mineral content of soybean, as legumes are known to be rich in minerals (do Prado et al., 2022). These findings align with previous studies on composite flours (Edema et al., 2005; Bolarinwa et al., 2015).

The fat content of the flour samples ranged from 3.07 to 11.20%. The results showed that both malting and fermentation decreased the fat content of sorghum, and the combination of the two processes decreased it also, but not as significantly as separating the processes on sorghum. This is consistent with the findings of Forsido et al. (2020), who reported that extending the fermentation period and increasing malt concentration in cereal grains leads to a gradual reduction in crude fat content. The result showed that the addition of all soybean flours increased the fat content of malted-fermented sorghum flour. The fermented soybean exhibited a greater increase in fat content, indicating that fermentation had a significant impact on the fat content of the soybean flour. The increase in fat content could be due to the high fat content of the soybean, as observed by Iwe (2000). The increase in fat content could be a beneficial source of energy for the human body.

The fibre content of the flour samples ranged from 1.06 to 4.65%. The result showed that both malting, and fermentation decreased the fibre content of sorghum, and the combination of the two processes decreased it too. This result contradicts the findings of Tamilselvan and Kushwaha (2020), who reported that both malting and fermentation increased fibre content. Conversely, Ojokoh et al. (2020) observed a decrease in fibre content following fermentation. Similarly, Maleke et al. (2024) reported a reduction in the fibre content of sorghum after malting, but noted an increase in fibre content after fermentation. The low fibre content in diets would enable the children to consume more of the food samples, giving them a greater opportunity to meet their daily energy and other vital nutrient requirements (ljarotimi and Keshinro, 2013). Low fibre content encourages high digestibility and absorption of diets by infants. For the addition of soybean, there were no significant differences ($p>0.05$) in the fibre content of all the samples except for sample H (malted-fermented sorghum flour + malted-fermented soybean flour). The fibre content obtained in this study is similar to the fibre content (3.3 - 5.7%) of wheat and soy composite flour reported by Ndife et al. (2014).

The protein content of the flour samples ranged from 6.24 to 16.22%. The result showed that malting increased the protein content while fermentation decreased it; the combination of the two processes also increased it. The reduction in protein content in the fermented sample may be due to protein leaching into the fermenting water or the action of degrading enzymes breaking proteins into smaller fractions (Oladeji et al., 2018). Oladeji et al. (2018) observed a decrease in protein content in both normal and quality protein maize after fermentation, while Tamilselvan and Kushwaha (2020) reported reduced protein in malted sorghum, but increased protein in fermented samples. Similarly, Anila et al. (2016) noted an increase in protein content in soybean, sorghum, and maize after malting. The results for the blends showed that both malting and fermentation raise the protein content of soybean flour. The malted soybean sample had more protein than both the full-fat soybean sample and the fermented soybean sample. According to FAO/WHO (2004), the protein content of complementary foods should be between 12 and 15%, and the result of the blended samples falls within this range. It shows that complementation improves the quality of malted-fermented sorghum flour. This agrees with the report of Ikujenlola (2010), Bolarinwa et al. (2015), Asuk et al. (2015), and Onireti and Ikujenlola (2020) on the complementation of cereal with legumes which led to an appreciable increase in the level of protein in the diet.

The CHO content of the samples ranged between 60.90 and 84.53%. The fermented sample C had the highest CHO content, while the whole sorghum flour had the lowest. Fermentation is said to generally increase the CHO content of food. The carbohydrate range identified in this study aligns with findings from previous research on maize flour (Fasasi et al., 2007; Adejuyitan et al., 2012; Oladeji et al., 2018). For the blends, the addition of soybean flour (full fat and processed) decreased the CHO content significantly. The energy content of the samples ranged from 373.77 to 405.96 kcal. The result showed that both malting and fermentation increased the energy content of sorghum and also combined the two processes. The addition of soybean flour increased the energy content of the samples greatly, as all the samples with the soybean flour had higher energy content than the malted-fermented sorghum flour. An adequate supply of energy is essential to support all physiological functions required for a growing system (Onireti and Ikujenlola, 2020).

Functional properties

The values for each functional property of the flours and flour blends are shown in Table 3. The bulk density of the sorghum flour samples ranged between 0.40 and 0.50, 0.64 and 0.77 g/mL, for both loose and packed bulk density, respectively. There were significant differences (p<0.05) in the samples. The results also revealed that the bulk density of soybean flour varied between 0.42 and 0.47, 0.62 and 0.77 g/mL, for both loose and packed bulk density. There were significant differences (p<0.05) in the samples and for the blends, and the blended samples ranged between 0.39 and 0.41, 0.61 and 0.66 g/mL, for both loose and packed bulk density, respectively. Malting, fermentation, and the combination of the two processes reduced the bulk density of the flours and flour blends. Low bulk density for fermented flour is an advantage in making infant food. For the blends, full-fat soybean increased bulk density, fermented soybean did not and malted and malted-fermented soybean decreased bulk density. Ikujenlola (2014) malted acha and found the lowest bulk density, while Elkhalifa and Bernhardt (2018) observed that fermentation and malting lowered the bulk density of sorghum flour.

Table 3. Functional properties of the flour and flour blends.

Samples	Loose Bulk Density (mg/L)	Packed Bulk Density (mg/L)	WAC (%)	OAC (%)	Reconstitution Index (%)	Dispersibility (%)
A	0.50±0.00^{a}	0.77±0.01^{a}	119.00±1.41^{fg}	61.50±3.54^{h}	50.50±0.71^{b}	69.50±0.70^{a}
B	0.47±0.01^{ab}	0.70±0.01^{b}	109.00±0.00^{hi}	89.50±2.12^{de}	57.50±3.54^{a}	70.50±0.71^{b}
C	0.40±0.01^{cd}	0.69±0.00^{b}	114.00±1.41^{gh}	95.00±0.00^{cd}	0.00	69.75±0.35^{c}
D	0.40±0.01^{d}	0.64±0.01^{cd}	117.00±1.41^{g}	107.00±1.41^{a}	0.00	65.50±0.71^{b}
E	0.47±0.01^{ab}	0.70±0.01^{b}	182.50±4.95^{a}	99.00±1.41^{bc}	0.00	63.50±0.71^{bc}
F	0.40±0.00^{cd}	0.60±0.01^{d}	177.00±4.24^{b}	87.50±0.71^{e}	53.50±0.71^{b}	65.50±0.71^{b}
G	0.45±0.00^{abc}	0.66±0.07^{bc}	161.50±0.71^{d}	72.50±0.71^{g}	10.30±0.14^{c}	54.50±0.71^{d}
H	0.42±0.00^{bcd}	0.62±0.00^{cd}	167.00±1.41^{c}	81.00±1.41^{f}	53.50±3.54^{b}	54.50±0.71^{d}
I	0.41±0.06^{cd}	0.66±0.01^{cd}	123.00±1.41^{f}	102.00±0.00^{ab}	0.00	65.00±0.00^{b}
J	0.39±0.03^{cd}	0.61±0.03^{cd}	130.00±1.41^{e}	96.00±2.83^{c}	0.00	66.00±2.83^{b}
K	0.41±0.03^{cd}	0.64±0.00^{cd}	101.50±2.12^{j}	88.00±2.83^{e}	0.00	62.00±2.83^{c}
L	0.40±0.00^{cd}	0.62±0.03^{cd}	106.50±2.12^{ij}	94.00±5.65^{cd}	0.00	61.50±0.71^{c}

Mean values with different superscripts in each column are significantly different at p≤0.05
A = 100% sorghum flour, B = 100% malted sorghum flour, C = 100% fermented sorghum flour, D = 100% malted-fermented sorghum flour, E = 100% soybean flour, F = 100% malted soybean flour, G = 100% fermented soybean flour, H = 100% malted-fermented soybean flour, I = 70% malted-fermented sorghum flour and 30% soybean flour, J = 70% malted-fermented sorghum flour and 30% malted soybean flour, K = 70% malted-fermented sorghum flour and 30% fermented soybean flour, L = 70% malted-fermented sorghum flour and 30% malted-fermented soybean flour, WAC = water absorption capacity, OAC = Oil absorption capacity.

The WAC of the sorghum flour samples ranged between 109.00% and 119.00%; there were significant differences (*p*<0.05) in the samples. The results also show that the WAC of soybean flour ranged between 161.50% and 122.50%; there were significant differences (*p*<0.05) among the samples. For the blended samples, the WAC of the samples ranged between 101.30% and 130.00%; there were significant differences (*p*<0.05) in the samples. Malting, fermentation, and the combination of these processes resulted in a reduction in WAC. Malted sorghum's WAC reduction matches Tatsadjieu et al. (2004) germinated sorghum study. Malted flour samples absorb less water, according to Ikujenlola and Adurotoye (2014). Full-fat soybean and malted soybean raised the WAC of sample D (malted-fermented sorghum flour), while fermented soybean and malted fermented soybean decreased it. Awolu (2017) found that kidney beans increased pearl millet WAC, while Bolarinwa et al. (2015) discovered that soy flour substitution decreased malted sorghum-soybean mixes WAC. Legumes boost composite flour WAC (Awolu et al., 2015; Awolu et al., 2016).

The oil absorption capacity (OAC) for the flours ranged from 61.50% to 107.00 %. The results showed that the malted-fermented sorghum flour had the highest OAC, while the whole sorghum flour had the lowest. It was observed that both processes of malting and fermentation increased the OAC of sorghum flour; however, the fermentation process increased it significantly. The result aligns with the findings of Ojha et al. (2017), who reported an increase in the oil absorption capacity (OAC) of sorghum upon malting. Similarly, Atuna et al. (2022) observed that fermentation, malting, and roasting enhanced the OAC of sorghum flour. Oil absorption capacity is a critical assessment of flavour retention and increases the palatability of foods; it indicates the ability of the sample to retain flavour and improve mouthfeel (Kinsella and Melachouris, 1976). Both malting and fermentation reduce the oil absorption capacity (OAC) of soybean flour. The OAC of the blended flours was reduced because the soybean samples had a lower OAC compared to the malted-fermented sorghum flour.

The reconstitution index indicates the time it takes for the flour to reconstitute at a hot temperature. The reconstitution index is temperature and particle size-dependent (Igyor et al., 2011). The reconstitution index ranged from 0% to 57.50% for all the samples. For sorghum samples, the values ranged from 0.00% to 57.50%. There were significant differences (p<0.05) in the samples. The result showed that malting increased RI for sorghum because the whole sorghum flour had 50.50% RI. Fermented sorghum and malted-fermented sorghum samples had 0.00% RI; there was no clear separation of the mixture, and the flours dissolved in the hot water and formed an inseparable mixture. For the soybean samples, the RI value ranged from 0.00% to 53.50%. There were significant differences (p<0.05) in the samples. Full-fat soybean had 0.00% RI; there was no clear separation of the mixture, and the flour dissolved in hot water and formed a milky solution, while malted soybean had 53.50%; upon fermentation, the RI reduced to 10.30%. The RI value for all the blended samples was 0%, as all the samples dissolved in hot water and formed an inseparable mixture when mixed.

The dispersibility of the sorghum flour samples ranged between 65.50% and 70.50%. There were significant differences (p<0.05) in the samples except for B and D, which are not significantly different. Malted sorghum flour had the highest dispersibility value (70.50%) while malted-fermented sorghum flour had the lowest (65.50%) when compared with other flours. For soybean flour, the dispersibility ranged between 54.50% and 65.50%. There were significant differences (p<0.05) in the samples except for G and H, which are not significantly different. Malting increased it, and fermentation decreased the dispersibility value of soybean flour samples. A similar decrease in dispersibility values was observed in sorghum flour samples except for malted sorghum flour (sample B), whose dispersibility value increased from 69.50% to 70.50%. Cereals (sorghum) showed a higher dispersibility value than pulses (soybeans). Olamiti et al. (2024) reported that the dispersibility values of sorghum ranged from 46.84% to 56.34%.

Dispersibility reflects the ability of flours to reconstitute in water, which influences both preparation ease and sensory quality.

Swelling capacity

The result of the swelling capacity of the flours and the blends is presented in Fig 3. The swelling capacity of the flours ranged from 109.00 to 200.50% g/g at 60 °C, at 70 °C it ranged from 112.50 to 211.00% g/g, at 80 °C it ranged from 130.50 to 348.00% g/g, and at 90 °C it ranged from 143.50 to 621.50% g/g. The swelling capacity of the flours was significantly different (p<0.05). For sorghum flours, the values ranged from 109.00 to 151.00 g/g at 60 °C, at 70 °C the range was between 112.50 to 174.00% g/g, at 80 °C from 232.00 to 348.00% g/g, and at 90 °C from 311.50 to 621.50% g/g. The results indicated that both germination and fermentation, as well as the combination of these two processes, reduced the flour's swelling capacity. Germination and fermentation increased flour swelling strength with temperature. Starch granules may absorb water during gelatinization. Because the whole flour contained more starch, it swelled more than the other flours (Yusufu et al., 2018). Given the connection between swelling power and starch (amylopectin), metabolic activity during germination may have caused the malted sample to lose starch. For soybean flours, the values ranged from 119.00 to 200.50% g/g at 60 °C, at 70 °C from 127.00 to 211.00% g/g, at 80 °C from 130.50 to 229.50% g/g, and at 90 °C from 143.00 to 226.00% g/g. For soybean malting, which increased the swelling capacity of the flour while fermentation reduced it, both increased with an increase in temperature.

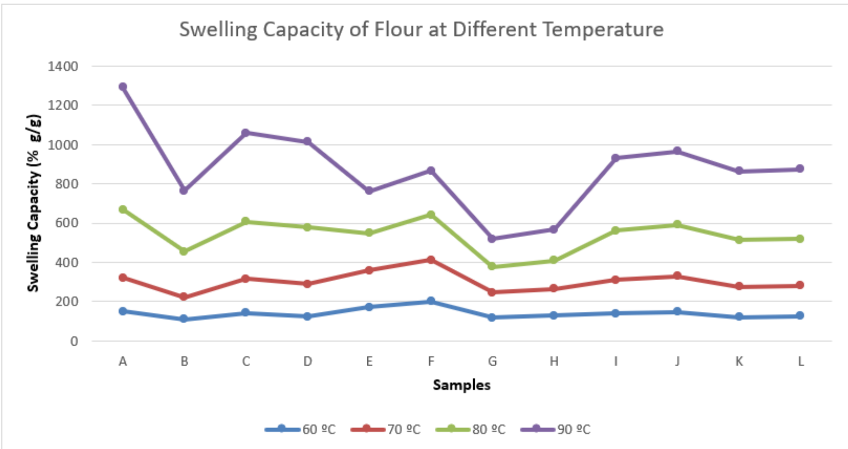

Figure 3. Swelling capacity of the flour and flour blends.

A = 100% sorghum flour, B = 100% malted sorghum flour, C = 100% fermented sorghum flour, D = 100% malted-fermented sorghum flour, E = 100% soybean Flour, F = 100% malted soybean flour, G = 100% fermented soybean Flour, H = 100% malted-fermented soybean flour, I = 70% malted-fermented sorghum flour and 30% soybean flour, J = 70% malted-fermented sorghum flour and 30% malted soybean flour, K = 70% malted-fermented sorghum flour and 30% fermented soybean flour, L = 70% malted-fermented sorghum flour and 30% malted-fermented soybean flour.

For the flour blends, the values ranged from 120.50 to 148.00% g/g at 60 °C, at 70 °C from 156.50 to 180.50% g/g, at 80 °C from 235.50 to 265.50% g/g, and at 90 °C ranged from 349.00 to 368.00% g/g. The blend's swelling capacity increased with temperature, which may be due to the soybean carbohydrate content. The results agree with the findings of Adetuyi et al. (2017) who observed an increase in the swelling capacity of malted and unmalted maize after it had been blended with soybean.

Pasting properties

The values for each pasting property and the significant differences among the flours and flour blends are shown in Table 4. The peak viscosity (PV) ranged from 18.21 to 98.50 RVU. For sorghum flour, the result showed that the fermentation process increased the peak viscosity while the malting process decreased it significantly. These agree with the findings of Akinsola et al. (2017) and Oladeji et al. (2018) who reported a significant increase (p<0.05) in the peak viscosities of cereal flours upon fermentation and also (Aluge et al., 2016); Usman et al.; 2016); Yusufu et al., 2018) reported inclusion of malted samples lowering peak viscosity which indicates lower tendency for swelling of starch granules. High peak viscosity is an index of high starch content (Iwe et al., 2016). The result showed that the addition of the soybean flour reduced the peak viscosity of the malted-fermented sorghum flour. The addition of full-fat soybean had the lowest value, followed by the addition of malted soybean, the addition of fermented soybean, and the addition of malted-fermented soybean, which had the highest value. This agrees with the findings of Ritika et al. (2016) who reported a decrease in the peak viscosity of maize flour with the addition of 20% malted cowpea and 20% fermented cowpea.

Table 4. Pasting properties of the flour and flour blends

Samples	Peak (RVU)	Trough (RVU)	Breakdown (RVU)	Final Visc (RVU)	Setback (RVU)	Peak Time (min)	Temperature
A	32.39±3.37^{d}	30.32±1.05^{c}	2.07±0.00^{f}	82.71±2.13^{c}	52.39±2.64^{b}	6.72±0.54^{a}	89.00±2.82^{a}
B	18.21±0.14^{e}	13.90±1.98^{d}	4.31±0.43^{e}	28.42±2.82^{e}	14.52±0.67^{bc}	4.54±0.65^{b}	82.50±0.70^{ab}
C	98.50±3.53^{a}	81.31±0.42^{a}	17.19±0.00^{ab}	129.48±4.24^{a}	48.17±0.00^{bc}	5.30±0.42^{ab}	85.00±1.41^{ab}
D	62.58±0.52^{b}	44.41±0.86^{b}	18.17±1.08^{a}	109.22±0.00^{b}	64.81±2.07^{a}	5.49±0.00^{ab}	84.00±0.00^{ab}
E	44.09±2.52^{c}	30.79±0.28^{c}	13.30±1.41^{d}	76.42±0.59^{d}	45.63±1.41^{c}	4.98±1.41^{ab}	72.38±0.73^{d}
F	46.87±2.82^{c}	30.92±1.41^{c}	13.95±0.00^{cd}	76.90±0.00^{d}	45.98±2.82^{c}	5.03±0.04^{ab}	74.70±1.69^{cd}
G	47.48±1.07^{c}	31.04±1.41^{c}	16.44±0.62^{cd}	77.11±0.15^{d}	46.07±0.09^{c}	5.21±1.00^{ab}	80.85±1.28^{bc}
H	48.13±2.66^{c}	32.61±0.55^{c}	15.52±0.87^{bc}	78.09±0.12^{d}	45.48±0.82^{c}	5.13±0.00^{ab}	79.32±2.02^{bcd}

Mean values with different superscripts in each column are significantly different at p≤0.05
Mean values with different superscripts in each column are significantly different at p≤0.05
A = 100% sorghum flour, B = 100% malted sorghum flour, C = 100% fermented sorghum flour, D = 100% malted-fermented sorghum flour, E = 100% soybean flour, F = 100% malted soybean flour, G = 100% fermented soybean flour, H = 100% malted-fermented soybean flour, I = 70% malted-fermented sorghum flour and 30% soybean flour, J = 70% malted-fermented sorghum flour and 30% malted soybean flour, K = 70% malted-fermented sorghum flour and 30% fermented soybean flour, L = 70 % malted-fermented sorghum flour and 30% malted-fermented soybean flour, WAC = water absorption capacity, OAC = Oil absorption capacity.

The trough ranged from 13.90 to 81.31 RVU. Trough is the minimum viscosity, which measures the ability of paste to withstand breakdown during cooling. This result showed that fermentation increases the trough viscosity of sorghum while malting reduces it. The result showed that the addition of the soybean flour samples decreased the trough. It is an indication of the breakdown or stability of the starch gel during cooking (Ragaee et al., 2006; Zaidhul et al., 2007). The results indicated that both malting and fermentation increased the trough of soybean flour, with fermentation increasing it more significantly. The result contradicts the findings of Atuna et al. (2022), who reported a decrease in the trough viscosity of sorghum, maize, and millet flours. However, it aligns with Akinsola et al. (2018), who observed a significant increase in the trough viscosity of malted maize-millet composite flour. The combination of these two processes significantly increased the trough when processed soybean samples were added. The trough viscosity is influenced by the rate of amylose exudation, amylose-lipid complex formation; granule swelling, and competition between exudate amylose and remaining granules for free water (Wickramasinghe and Noda, 2018).

The breakdown viscosity ranged from 2.24 to 17.77 RVU. Falade and Kolawole (2012) describe breakdown viscosity as a parameter that measures the resistance to heat, shear of dough, and stability of starch gel during cooking. The higher the breakdown viscosity, the lower the ability of samples to withstand heating and shearing stress during cooking (Adebowale et al., 2005). The result showed that both malting and fermentation increased the breakdown viscosity of sorghum flour, but fermentation increased it more and the combination of the two processes increased it more significantly. The addition of the soybean flours reduced it. The result showed that the addition of full-fat soybean had the lowest, while the addition of the malted-fermented soybean had the highest value. The reduced breakdown viscosity values upon the incorporation of soybean flours indicate that the pastes exhibit greater stability under elevated temperatures due to diminished starch concentration in the sample. Fermentation caused a significant decline in breakdown viscosity ($p < 0.001$) in maize and millet, as reported by Atuna et al. (2022). Similarly, Yusufu et al. (2018) observed low breakdown viscosity in malted-fermented sorghum. The final viscosity of the samples ranged from 28.42 to 129.48 RVU. Final viscosity indicates the ability of the material to form a viscous paste to gel after cooking and cooling, as well as the resistance of the paste to shear force during stirring (Adebowale et al., 2005). It has also been observed that the exhibition of final viscosity in a gelatinized paste is a result of the aggregation of the amylose molecules in the paste (Usman et al., 2016).

The setback viscosity of the samples ranged from 14.52 to 64.41 RVU. Setback viscosity is an essentially derived tool that describes the difference between final viscosity and trough viscosity. According to Amoo et al. (2014), low setback values are advantageous for complementary food products requiring low viscosity and stable pastes at low temperatures, making malted sorghum samples well-suited for such applications. The results revealed that incorporating soybean flour into malted-fermented sorghum flour reduced the setback value. This finding aligns with Oluwamukomi and Adeyemi (2015), who observed a decline in setback values as the level of soybean supplementation increased.

The peak time for the samples ranged from 4.52 to 6.72 minutes; the peak time is usually regarded as an indication of the total time taken by each blend to attain its respective peak viscosity (Usman et al., 2016). Thus, food with a lower peak time will cook faster than that with a higher peak time. The pasting property indicates the gelatinization temperature of the sample. The pasting temperature for the blended samples ranged from 72.38 °C to 80.85 °C. The pasting temperature indicates the minimum temperature required to cook a given sample (Bolarinwa et al., 2015). Yusufu et al. (2018) reported higher pasting temperatures but shorter peak times for malted and fermented sorghum danwake flour samples.

Conclusions

This study concluded that the combination of malting and fermentation reduced functional properties, like bulk density, which is desirable in complementary foods. The flour blends from malted-fermented sorghum and soybean were high in protein, fat, and ash. High protein supports growth and development, while high fat provides essential energy, making these flour blends highly suitable for complementary feeding. The combination of malting and fermentation also increased the viscosity of the flour, but not as much as fermentation. The inclusion of soybeans reduced the pasting properties of malted-fermented sorghum.

Author Contributions: E.F.I. - collecting and preparing samples, designing and executing the experiment, collating results, writing and editing the manuscript, and providing final approval. A.V.I. contributed to the experimental design, reading, editing, and approval of the final manuscript

Funding: None.

Acknowledgments: Sincere appreciation to the Department of Food Science and Technology, Obafemi Awolowo University, Ile-Ife, Nigeria for the support given during the research.
Conflicts of Interest**:** The authors declare no conflict of interest.

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