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EFFECT OF HERRING FISH FLOUR INCLUSION ON THE PROXIMATE, FUNCTIONAL, AND PASTING PROPERTIES OF PEARLMILLET – HERRING FISH FLOUR BLENDS

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Abstract: *The proximate, functional, and pasting properties of flour blends produced from pearl millet and herring fish were investigated in this work. Pearl millet and herring fish were milled into flour and combined using a D - Optimal mixture design, yielding nine experimental runs. The functional properties (bulk density, water absorption capacity, oil absorption capacity, swelling capacity, dispersibility, and least gelation capacity), pasting properties, and proximate composition of the flour blends were evaluated. The data were analyzed using analysis of variances, and the means were separated using the Duncan Multiple Range Test, with p values <0.05 are taken to indicate the significant difference between the groups. Results showed that bulk density, water absorption capacity, oil absorption capacity, swelling capacity, dispersibility, and least gelation capacity of the composite flour ranged from 0.71- 0.83 g/mL, 176.13- 192.39%, 192.39- 136.48%, 18.15- 20.04%, 38.65-42.40%, and 8.00-12.00%, respectively. The peak viscosity, trough, breakdown viscosity, final viscosity, setback viscosity, peak time, and pasting temperature ranged from 576.00 to 1222.50 RVU, 391.50 to 757.00 RVU, 184.50 to 484.00 RVU, 1161.50 to 2078RVN,737.00 to 1324.00 RVU, 4.87 to 5.34 min, 78.34 and 82.53 °C, respectively. The moisture, fat, ash, fibre, and protein of the composite flour ranged from 7.14-9.22%, 4.09-5.15%, 1.98-2.50%, 6.04-6.55%, 26.15-29.85%, and 48.34-57.85%, respectively. In conclusion, the addition of herring fish flours significantly* ($p < 0.05$) *improved the functional and pasting properties of the flour blends.*

Keywords: *pearl millet, herring fish, flour blends, proximate composition, functional properties*

1. Introduction

Flour is a major ingredient in the production of an array of culinary products, and it is a widely accepted ingredient in many nations [1]. Millet is a cereal crop of the *Graminae* grass family. This crop plant is underutilized by consumers, but it is a useful crop whose inclusion in diets can improve nutritional qualities in our diet [2]. Pearl millet (*Pennisetum glaucum)* is a multipurpose cereal crop that belongs to the *Poaceae* family. It is commonly used for food for humans, feed, and forages for animals' purposes [3]. This crop has the ability to grow at high temperatures and low water requirements, as compared to other cereal or grain products like rice, wheat, and maize, which fail to grow under such conditions [4]. The ability of pearl millet to withstand drought, low soil fertility, and high salinity is among its physiological properties when compared to other cereal or grain crops [5]. Among all the different species of millet, the macronutrients present in pearl millet are high and more than enough to withstand starch, soluble, and insoluble dietary fibres. Consumers are increasingly interested in healthy foods, and fish is gaining popularity due to its unique nutritional and functional properties. The nutritional value of fish is not exclusively based on protein, but also on lipids

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containing omega-3 fatty acids, particularly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) [6].
Fish omega-3 fatty acids are required for human growth and development, as well as the ability to prevent or eradicate numerous ailments; hypertension, diabetes, coronary artery disease, arthritis, autoimmune disorders, and other inflammatory conditions, as well as cancer [7]. Because fish is an important source of micro nutrient such as vitamin (A, D, B_6, B_{12}) and minerals (iron, zinc, iodine, selenium, potassium, sodium etc.) content including in our diets increased the vitamin and mineral content. The utilization of fish flour as a raw material promotes its effective use in food products development, value addition, and production of several sorts of extremely nutritious and acceptable ready-to-serve products, such as frozen surimi, frozen mince block, and extruded products in the global market. As a result, the primary goal of this study is to investigate the effect of herring fish inclusion on the proximate, functional, and pasting properties of pearl millet–herring fish flour blends.

2. Materials and methods

Pearl millet (LCICMV-4) and dry herring fish were purchased from a local market in Eleweran, Abeokuta, Ogun state, Nigeria.

2.1 Processing of pearl millet flour

Pearl Millet (*Pennisetum glaucum*) grains were cleaned by sorting and winnowing to remove all the contaminants. The cleaned grains were washed and dried at 50 °C for 12 h in a cabinet drier (UM 200 stainless steel, China). The grains were milled, sieved through a 60-mesh sieve to separate the spent grains, packed into a cellophane bag, and stored for further analysis [8].

2.2 Processing of dry herring fish

Dry Herring fish *(shawa)* were sorted and graded. The skin was removed, deboned, and weighed. The weighed fish was further dried in a cabinet drier (UM 200, stainless steel, China) at 60 °C for 6 h, after which the dried fish was milled into flour. The flour was then sieved and packed in an airtight container to keep it fresh before analysis to prevent absorption of moisture [9].

2.3 Preparation of the flour blends

One hundred grams (100 g) of each of Pearl millet and Herring fish was prepared according to each formulation, with nine trial runs generated, based on D - Optimal mixture design (version 12.0).

Table 1.
Formulation of pearl millet and herring fish flour blends using D- optimal mixture design

Runs	Pearl millet flour (%)	Herring fish flour (%)
1	90.00	10.00
2	80.00	20.00
3	85.00	15.00
4	85.00	15.00
5	87.50	12.50
6	82.50	17.50
7	90.00	10.00
8	90.00	10.00
9	80.00	20.00

2.4 Proximate analysis of the composite flour

The moisture, fat, protein, ash, crude fibre, and carbohydrate contents of flour blends were analysed using the method described by [10]. The carbohydrate content of flour samples was calculated by difference.

2.5 Functional properties of the flour blends

The bulk density of each of the flours was determined using the method of [11]. A flour sample of 10 g was placed in a calibrated 50 mL measuring cylinder. Continuously tapping the cylinder's bottom against a firm pad on a laboratory bench until a constant volume was seen.
The dense volume was captured. The bulk density was determined by dividing the flour weight by the volume occupied by the flour after tapping.

$$Bulk\ Density\ (g/ml) = \frac{weight\ of\ sample\ (g)}{volume\ of\ sample\ (ml)} \quad (1)$$

2.6 Water absorption capacity of the blends

The methods of [12] were used to determine the water absorption capacity. Each flour sample of 1 g was weighed into a clean conical graduated centrifuge tube and thoroughly mixed with 10 mL of distilled water for 30 seconds using a platform tube rocker. The flour was left at room temperature for 30 minutes before using centrifugal (Allegx-15R, USA) at 3500 rpm for 30 minutes. The volume of free water was read directly from the graduated centrifuge tube after centrifugation. The weight of the absorbed water is calculated by multiplying it by the density of water. Water absorption capacity was measured in grams of water per gram of flour

$$\%\ Absorbed\ water = total\ water - free\ water \quad (2)$$

2.7 Oil absorption capacity of the blends

This was determined using the [12] technique. A flour sample of 1g was measured, and 10 ml of refined corn oil was weighed into a dry, clean centrifuge tube; both weights were recorded. Refined corn oil of 10ml was put into the test tube and properly mixed with the flour. The suspension was then centrifuged for 15 min at 350 rpm. As a result, the supernatant was discarded, and the tube content was re-weighed. The gain in mass was calculated using the flour's oil absorption capacity.

2.8 Swelling capacity of the blends

The swelling capacity was evaluated following the approach given by [13]. A flour sample of 1g was weighed into a weighed centrifuge tube, and then 10 ml of distilled water was added, agitated well, and heated in a water bath at 60 °C for 30 min, with constant mixing before allowing it to cool. After centrifuging the flour at 3000 rpm for 15 min, the supernatant was decanted, and the sediment paste was weighed. The formula was used to calculate swelling capacity:

$$\%\ Swelling\ Capacity = \frac{Weight\ of\ sediment\ paste}{Weight\ of\ the\ sample\ (\ dry\ basis)} \times 100 \quad (3)$$

2.9 Dispersibility of the blends

The [13] approach was utilized. A flour sample of 10 g was weighed into a 100 mL measuring cylinder. A total of 10ml of distilled water was added. The flour was aggressively mixed and left to settle for 3 h. The volume of setting particles was measured and subtracted from 100 to get the percentage dispersibility.

2.10 Least gelation concentration of the blends

The gelation characteristics were obtained using the [14] technique. A test tube holding a solution of 2-20% (w/v) flour suspensions in 5 ml distilled water was heated in a boiling water bath for 1 h before being rapidly cooled in cold water. The test tubes were then chilled at 4 °C for 2 h. The least gelation was established as the concentration at which flour did not slip or fall from an inverted test tube.

2.11 Pasting properties of the flour blends

To ascertain this, a Rapid Visco Analyzer (Model RVA 3D+, Newport Scientific, Australia) was used to ascertain this. A flour sample of 3.5 g was weighed and placed inside the test container. Next, 2.5 g of mixed flour was weighed into an empty, dehydrated canister, and 25 mL of distilled water was poured into it. The canister was securely placed into the RVA, and the solution was well mixed, as advised. The slurry was heated to a temperature of 50 to 95 °C and allowed to cool for 2 min before chilling again to 50 °C. The value of 11.25 °C /min was the consistent rate of heating and cooling. Using the Thermocline for Windows Software that was connected to a computer, the following data were obtained from the pasting profile: peak viscosity, trough, breakdown, final viscosity, setback, peak time, and pasting temperature.

2.12 Statistical analyses

The data obtained were subjected to statistical analysis. Means, Analysis of variance (ANOVA) was determined using SPSS Version 21.0, and the differences between the mean values were evaluated at $p \leq 0.05$ using Duncan's multiple range test.

3. Results and discussion

3.1 Proximate composition of flour blends from pearl millet and herring fish flour

The proximate composition of the pearl millet and herring fish composite flour is displayed in Table 2. The moisture, fat, protein, ash, crude fibre, and carbohydrate contents of the various flour blends differed significantly ($p < 0.05$). The flour blends had moisture contents ranging from 7.14 ± 0.04% to 9.22 ± 0.01%. The moisture content of the flour blends was decreased by the addition of herring fish flour. Any food material's moisture content is a reflection of its shelf life; that is, it shows how long the food can be kept without going mouldy. A key factor in determining a flour's susceptibility to microbial deterioration is its moisture content. Lower moisture contents in flour blends may inhibit the growth of microorganisms, prolonging the flour's shelf life. The study's results are within the recommended range of 5 to 10%, and they also line up with what [15] reported. A flour sample with a high moisture content encouraged the growth of microorganisms, leading to an increase in food spoilage [9].

The fat content was found to decrease with an increase in fish flour inclusion; the values varied between 4.09 ± 0.04 and 5.15 ± 0.04%. The sample with the highest fat content was 10% herring fish flour, and the sample with the lowest fat content was 17.50%. Given that it supplies essential fatty acids (EFA) and facilitates the absorption of fat-soluble vitamins, it is a crucial macronutrient parameter in human diets [16]. Since millet is rich in germ, which is rich in oil, as reported by [17], the native high-fat content of pearl millet flour may be the cause of the increase in fat content as the inclusion of pearl millet increased in the flour blends.

The ash content of the flour blends is significantly ($p < 0.05$) impacted by the addition of fish flour. The blends' ash contents varied between 1.98 ± 0.02 and 2.50 ± 0.02%, with the sample containing 100% pearl millet having the highest ash content value and the sample containing 12.50% having the lowest (Table 1). Any food material's ash content can be used as a guide to ascertain the food's mineral composition [18]; [19]. It is defined by [20] as the inorganic residue that is left over after heating in the presence of an oxidizing agent to remove organic matter and water.

This study's blend flour's high mineral content is demonstrated by its high ash content (2.50%). According to similar reports by [21], the low ash content of pearl millet may be the cause of the declining trend in ash in the flour blends. The present study's findings are consistent with the research conducted by [22], [23], and [24], which demonstrated a discernible rise in ash content upon fish incorporation

The blends' crude fibre content varied between 6.04 ± 0.03 and 6.53 ± 0.02%, and Table 1 indicates that it increased as the number of herring fish flour was added. It is the structural element of the plant cell wall that is left over after food or food material is successively digested in acids and alkalis [25]. According to [26], fibre in food improves digestion and shields the body from several diseases, including diabetes, colon cancer, and heart disease. It also gives the food more volume, which helps with constipation. The blend sample's fibre

content increased with the addition of herring fish flour, which is consistent with the findings of [27] and [28]. However, as noted by [19], the lower value found for the blends' fibre content may be the result of pearl millet's low fibre content.
The protein content values for the flour blends fell between 26.15 ±0.04 and 29.75 ± 0.01%. The blend sample containing 17.50% fish flour was found to have the lowest protein content, whereas the blend sample containing 20% fish flour had the highest protein content. It was also found that as the amount of herring fish flour in the blends increased, so did their protein content. C-carbon, H-hydrogen, O-oxygen, and N-nitrogen are elements found in protein, an amino acid source. Proteins are primarily involved in maintaining and replacing deteriorated tissue. Additionally, to control the body's metabolic functions [29]. As the ratios of the herring fish flour increased in the products, it was observed that the protein content of the flour blend samples increased as well. Fish has a high digestible protein content [30], which raises or changes the overall protein content of flour blends. The formulated samples' unusually high protein levels may have resulted from the herring fish flour substitution.
The amount of carbohydrate in the flour blends was significantly ($p < 0.05$) affected by the substitution level of fish flour and pearl millet. The blend sample with 80% pearl millet and 20% fish flour had the lowest amount of carbohydrates; on the other hand, the sample with 85% pearl millet and 15% fish flour had the highest amount. As demonstrated in Table 2, there was once more a decrease in the flour blends' carbohydrate content as the amount of fish flour increased. Therefore, the amount of carbohydrates in the resulting blends decreases as the amount of fish flour included increases, simply because of the blending proportion. The increase in the percentage of pearl millet flour used in the formulation is primarily responsible for the blend sample's higher overall carbohydrate content. The high carbohydrate contents of the samples found in this study are recommended by nutritionists because children require energy to perform their demanding physical and physiological tasks as they grow [31].

3.2 Functional properties of pearl millet and herring fish composite flour

Table 3 shows the effect of pearl millet and herring fish flour substitution on some functional properties of the blends. The blend samples' bulk density values ranged from 0.71±0.02 to 0.83 ± 0.01 g/cm^3. The blend containing 10% herring fish flour and 90% pearl millet had the highest value, but they were not significantly ($p > 0.05$) different from each other, while the blend containing 15% herring fish flour and 85% pearl millet had the lowest value. Fish flour substituted pearl millet flour, and the functional properties changed significantly ($p < 0.05$) at all levels of flour blends. The flour sample with 100% pearl millet differed significantly (p < 0.05) from the mix sample with herring fish flour inclusion. Bulk density determines the weight of flour, and it is also an important characteristic in the food sector for deciding on packaging material [32]. The fatty nature of the fish flour, which increases the force of attraction between the flour particles, may result in a decrease in the bulk density of the flour blend and a high degree of compactness [33].
Water absorption capacity (% WAC) values of the mixes differed significantly ($p < 0.05$) across all the flour blends. The water absorption capacity ranged from 176.13 ± 0.15% to 192.39 ± 0.04%. The water absorption capacity of the flour reduced as herring fish content increased, as seen in Table 3 [34]. Water absorption capacity is defined as the ability of flour to absorb and expand to improve meal consistency. A

high-water absorption capacity implies a lack of structure in the starch polymer, whereas a low number suggests molecular structure hardness. The decrease in water absorption of the flour blends with rising herring fish flour might be related to a decrease in the quantity of pearl millet in the flour blends, which could be attributed to the protein and carbohydrate content of the flour, as stated by [35] and [36] The work is also consistent with the finding [37] who revealed the importance of protein and starch in water uptake of flour at room temperature. The values of oil absorption capacity ranged from 125.30± 0.06% to 136.48± 0.04% with the blend sample with 85% pearl millet and 15% fish flour having the lowest value, and blend with 87.50% pearl millet and 12.50% fish flour having the highest value. The introduction of pearl millet and fish flour had a significant ($p <$ 0.05) effect on the oil absorption capacity of the flour blends. An increase in herring fish flour level was shown to reduce the oil absorption capacity of the flour blend. The oil absorption capacity has a significant flavour retention capacity in flour in the production of food [38]. According to [39], the oil absorption capacity makes the flour excellent for improving mouth feel and flavour when used in food preparations. The greater oil absorption capacity of the flour blends may be due to the strong hydrophobic character of the fish protein, which demonstrated good binding to lipids.[40] The flour blend's oil absorption value is within the range reported by [41] and lower than that reported by [42].The swelling capacity of the flour blends was significantly ($p < 0.05$) impacted by the inclusion of pearl millet and fish flour, with values ranging from 18.15 ± 0.04% to 20.04 ± 0.04%. A significant ($p < 0.05$) difference was noted in the swelling capacity values. Swelling power is the ability of the flour to absorb water and hold it in the swollen flour granule [43]. It is mostly influenced by amylose and amylopectin content. High starch content increases swelling capacity (index) of foods and flours, especially in starches with a higher amount of the branched amylopectin [44]. Formation of the protein-amylose complex in the flour blends may be the cause of the decrease observed in the swelling index, and also the extent of the swelling ability depends on the availability of water, temperature, type of starch, and other carbohydrates, as well as proteins [45]. Swelling capacity reduction observed in this study could be due to the interaction of the opposite charges of starch and protein, which forms complexes during gelatinisation [46].

The blend containing 90% pearl millet and 10% herring fish flour had the lowest dispersibility value, while the blend containing 82.50% pearl millet and 17.50% herring fish flour had the highest value. The dispersibility values ranged from 38.65 ± 0.0% to 42.40 ± 0.31%. Across all flour blend levels, substituting fish flour for pearl millet flour had significant ($p < 0.05$) effects. A significant ($p < 0.05$) difference was found between the flour sample made entirely of pearl millet and the blend sample that included herring fish flour. Dispersibility decreased as the amount of fish flour substitution increased. It is a measure of how individual molecules of a food sample, usually flour is able to reconstitute in water. The higher the dispersibility value of pearl millet and herring fish composite flour, the better the flour reconstitutes [47]. The dispersibility values obtained in this study are relatively high, and this is an indication that the flour blends will easily reconstitute to give a fine consistency dough during mixing, as similarly reported by [48; 20]. The high dispersibility values of the flour blends could be due to the high percentage of pearl millet flour in the flour blends, which has a small particle size, which increases its reconstitution ability [49]

As the amount of fish flour in the blend samples increased, the least gelation property was seen to increase as well. Fish flour and pearl millet flour substitutions had a significant ($p < 0.05$) effect on every flour blend sample level. The least amount of flour or flour blends required to form a gel in a given amount of water is known as the least gelation concentration. According to [50], the lower the gelation concentration, the less flour is required to form a gel and the better the flour's or flour blends' ability to gel. The higher the least gelation concentration, the more flour is required to form a gel. According to [51], this variation in the gelation property may be related to the various components of proteins, carbohydrates, and lipids. The interaction between these constituents may have an impact on functional properties.

3.3 Pasting properties of pearl millet and herring fish composite flour

Table 4 displays the flour blends' pasting properties as a result. Significant ($p < 0.05$) variations were observed in the pasting properties of every flour blend. Peak viscosity ranged in mean values from 576.00 ± 66.47 to 1222.50 ± 3.54 RVU. Peak viscosity increased with the percentage of herring fish flour included in the blend sample. According to [52], peak viscosity is the starches' capacity to increase prior to their physical breakdown, indicating the strength of the pastes created during gelatinization. There was a variance in the rate of water absorption and starch granule swelling during heating, as evidenced by the variations in the peak viscosity, the highest viscosity reached during heating of the pearl millet and herring fish flour blend obtained in this study [53]. The flour samples' high starch swell value indicates that they will be a good source of raw material for products like extruded snacks that require high gel strength and elasticity [50]. The highest viscosity indicates a high starch peak content, as well as the flour's ability to bind water. It also frequently correlates with the quality of the finished product and provides a buffer against the viscous load that mixing and cooking are likely to encounter [54]. According to [55], the degree of starch breakdown correlates with the degree of viscosity, and a high degree of starch breakdown causes a high degree of swelling of starch. Thus, it can be concluded that a contributing factor to the high peak viscosities seen in this study may have been increased starch damage in the flour blends' composition (pearl millet flour, for example), which resulted in a decrease in the amount of herring fish.

Trough ranged in mean values from 391.50 ± 34.65 RVN to 757.00 ± 4.24RVN. The blend sample's trough increased as the ratio of herring fish flour inclusion increased. Trough, which gauges a paste's resistance to breaking down while cooling [56, 57]. The addition of herring fish flours to the flour blend samples may have caused an increase in the trough of the samples; additionally, high trough values may indicate low cooking losses and higher-ranking eating quality [58].

The breakdown viscosity mean value varied between 184.50 ± 31.82 and 484.00 ± 1.41 RVU. Viscosity of breakdown increased as the ratio of herring fish flour inclusion in the blend sample increased. The degree to which starch granules break up or the firmness of the paste, as measured during heating, is known as the breakdown viscosity of flour [58]. A higher breakdown viscosity value denotes a lower cooking temperature and shear resistance of the flour blends [50]. Thus, without a primary switch in stability, the results of this study's pearl millet-herring fish composite flour suggest that they may withstand heating and shear processes. High breakdown values are correlated with low starch paste consistency [54]. Because herring fish flour has a lower breakdown viscosity than pearl millet alone, the flour blend sample that includes it may be more resistant to heating and shear stress.

The final viscosity mean value varied between 1161.50 ± 2.12 and 2078 ± 2.12 RVU. The final viscosity increased as the ratio of herring fish flour inclusion in the blend sample increased. The final viscosity is the ability of the starch or flour to form a viscous paste and gel during cooking and after cooling, respectively, as described by [59]. Lower final viscosity signifies reduced ability to form viscous pastes. The final viscosity obtained in this work is better than that obtained by toasted maize-based composite flour [57]. This phenomenon is of great importance in foods since it contributes significantly to the textural and rheological properties of various foods.

The setback viscosity mean value varied between 737.00 ± 2.83 and 1324.00 ± 1.41 RVU. Setback viscosity increased as the ratio of herring fish flour inclusion in the blend sample increased. A cohesive paste is associated with a high setback viscosity value, whereas a non- cohesive paste is indicated by a low value [60].

This stage, which is linked to the retrogradation and reorganization of starch molecules, is commonly referred to as the setback region. A food sample's decreased setback viscosity is a sign of a slow rate of change in its physical behaviour after gelatinization [61]. The setback viscosity is typically thought to be a sign of the paste made from starchy food having a tendency to recrystallize [62]. Peak time ranged in mean value from 4.87 ± 0.01 to 5.34 ± 0.14 min. Peak time decreased as the ratio of herring fish flour inclusion in the blend sample increased. Peak time indicates how long it takes for individual flour samples to heat up to their maximum viscosity [58]. This study shows that the peak time of the flour blends decreased when herring fish flours were added during the experimental runs. The peak time is typically thought of as a measure of how long it took for each sample to reach its own peak viscosity [63]. A food sample with a lower peak time will therefore cook more quickly than one with a higher peak time [63]. A longer time is needed to reach peak viscosity, as indicated by the high peak time [64]. Long peak times are undesirable in fields like baking, though, as they are linked to the time it takes for dough to develop, which requires a lot of energy [65].

The pasting temperature ranged in mean value from 78.34 ± 0.00 to 82.53 ± 0.04 °C. Pasting temperature dropped as the amount of herring fish flour in the blend sample increased. This study demonstrated that the pasting temperature decreased when herring fish flours were substituted for the formulations.

The variations in the flour blend samples' pasting temperatures showed that the formulations had various gelatinization temperatures [66]. The minimum temperature needed to cook a particular sample is indicated by the pasting temperature, which may also have an impact on the amount of energy used [53]. The minimum temperature needed to cook a sample is indicated by the pasting property known as pasting temperature.

As a result, compared to other flour blends containing herring fish flour, the flour blend containing 100% or more pearl millet flour will cook more quickly and use less energy, saving money and time.

Table 2.

Proximate composition of flour blends from pearl millet and herring fish flour

Sample Blends	Moisture content (%)	Crude Fat (%)	Total Ash (%)	Crude Fibre (%)	Crude Protein (%)	Total Carbohydrate (%)
PMF_{90} HFF_{10}	9.18 ±0.04^{e}	5.14 ±0.03^{f}	2.08 ±0.04^{b}	6.10 ±0.01^{b}	26.82 ±0.03^{b}	51.69 ±1.37^{cd}
PMF_{80}:HFF_{20}	8.69 ± 0.15^{d}	4.96 ± 0.04^{d}	2.26 ± 0.03^{e}	6.14 ± 0.04^{bc}	29.62 ± 0.03^{f}	48.34± 0.14^{a}
PMF_{85}:HFF_{15}	7.81 ± 0.03^{b}	4.35 ± 0.03^{c}	2.19 ± 0.01^{cd}	6.23 ± 0.01^{d}	27.57 ± 0.01^{d}	57.85± 0.09^{d}
PMF_{85}:HFF_{15}	7.83 ± 0.03^{b}	4.33 ± 0.04^{c}	2.18 ± 0.04^{c}	6.25 ± 0.01^{d}	28.01 ± 0.01^{e}	52.08± 0.01^{d}
$PMF_{87.5}$: $HFF_{12.50}$	8.38 ± 0.05^{c}	4.24± 0.04^{b}	1.98± 0.02^{a}	6.53± 0.02^{e}	27.10 ± 0.05^{c}	51.80 ± 0.05^{d}
$PMF_{82.50}$: $HFF_{17.50}$	7.79 ± 0.11^{b}	4.09 ± 0.04^{a}	2.35 ± 0.04^{f}	6.93 ± 0.04^{f}	26.15 ± 0.04^{a}	52.70± 0.01^{d}
PMF_{90}:HFF_{10}	9.17 ± 0.02^{e}	5.15 ± 0.04^{f}	2.10 ± 0.01^{b}	6.09 ± 0.01^{ab}	26.83 ± 0.01^{b}	52.65 ± 0.01^{d}
PMF_{90}:HFF_{10}	9.22 ± 0.01^{e}	5.14 ± 0.03^{f}	2.06 ± 0.01^{b}	6.12 ± 0.01^{b}	26.77 ± 0.05^{b}	50.72± 0.01^{c}
PMF_{80}:HFF_{20}	8.57 ± 0.01^{d}	4.94± 0.01^{d}	2.25± 0.01^{e}	6.18± 0.01^{c}	29.82 ± 0.25^{a}	48.42 ± 0.03^{a}
PMF_{100}	7.14 ± 0.04^{a}	5.03 ± 0.01^{e}	2.50 ± 0.02^{g}	6.04 ± 0.03^{a}	29.75 ± 0.01^{g}	49.56 ± 0.04^{b}

Values are the mean of duplicates ± standard deviation. Mean values with various superscripts within the same column differ significantly at 5% level.
PMF =Pearl Millet Flour, HFF = Herring Fish Flour

Table 3.

Functional properties of flour blends from pearl millet and herring fish flour

Sample Blends	Bulk density (g/ml)	Water absorption capacity (%)	Oil absorption capacity (%)	Swelling capacity (%)	Dispersibility (%)	Least gelation capacity (%)
PMF_{90}:HFF_{10}	0.79 ±0.01^{cde}	183.54 ±0.12^{e}	130.16 ±0.06^{c}	19.96 ±0.04^{c}	42.40 ±0.31^{f}	10.00 ±0.00^{c}
PMF_{80}:HFF_{20}	0.76 ± 0.01^{b}	181.19 ± 0.04^{c}	131.70 ± 0.04^{c}	18.15 ± 0.04^{a}	38.82 ± 0.13^{ab}	12.00± 0.00^{d}
PMF_{85}:HFF_{15}	0.72 ± 0.01^{b}	178.88 ± 0.06^{b}	128.82 ± 0.13^{b}	19.86 ± 0.03^{f}	40.38 ± 0.00^{c}	8.00 ± 0.00^{a}
PMF_{85}:HFF_{15}	0.71 ± 0.02^{a}	176.13 ± 0.15^{a}	125.30 ± 0.06^{a}	20.04 ± 0.01^{g}	41.12 ± 0.01^{cde}	9.00 ± 0.00^{b}
$PMF_{87.50}$: $HFF_{12.50}$	0 .83 ± 0.01^{f}	192.39± 0.04^{h}	136.48± 0.04^{e}	19.14± 0.04^{e}	40.95 ± 0.03^{cd}	10.00 ± 0.00^{c}
$PMF_{82.50}$: $HFF_{17.50}$	0.78 ± 0.01^{bcde}	182.48 ± 0.04^{d}	132.42 ± 0.05^{d}	18.57 ± 0.03^{b}	38.65 ± 0.01^{a}	8.00 ± 0.00^{a}
PMF_{90}:HFF_{10}	0.80 ± 0.01^{ef}	182.23 ± 0.31^{e}	129.57 ± 0.76^{bc}	18.90 ± 0.04^{c}	42.15 ± 0.05^{f}	10.00 ± 0.00^{c}
PMF_{90}:HFF_{10}	0.83 ± 0.01^{f}	185.26 ± 0.14^{f}	129.75 ± 0.95^{c}	19.03 ± 0.01^{d}	41.62 ± 0.55^{def}	9.50± 0.71^{c}
PMF_{80}:HFF_{20}	0.76 ± 0.01^{bc}	181.31± 0.21^{c}	131.84± 0.24^{d}	18.15± 0.04^{a}	39.46 ± 0.78^{b}	12.00 ± 0.00^{d}
PMF_{100}	0.79 ± 0.01^{de}	188.40 ± 0.06^{g}	135.85 ± 0.05^{e}	20.04 ± 0.04^{g}	41.72 ± 0.09^{de}	12.00 ± 0.00^{d}

Values are the mean of duplicates ± standard deviation. Mean values with various superscripts within the same column differ significantly at 5% level.
PMF =Pearl Millet Flour, HFF = Herring Fish Flour

Table 4.

Pasting properties of flour blends from pearl millet and herring fish flour

Sample Blends	Peak viscosity (RVU)	Trough (RVU)	Breakdown (RVU)	Final viscosity (RVU)	Set back (RVU)	Peak time (min)	Pasting temperature (°C)
PMF_{90}:HFF_{10}	1158.00 ± 87.68^{e}	757.00± 4.24^{e}	440.50 ± 36.06^{c}	1815.00 ± 4.24^{d}	787.50 ± 3.54^{bc}	5.21 ±0.01^{bc}	81.15 ±0.21^{c}
PMF_{80}:HFF_{20}	628.00 ± 2.83^{a}	491.50 ± 4.95^{b}	206.50± 2.12^{a}	1161.50± 2.12^{a}	1288.00 ± 49.50^{fg}	4.87± 0.00^{a}	78.35± 0.00^{a}
PMF_{85}:HFF_{15}	911.00 ± 15.56^{c}	545.00 ± 11.31^{b}	343.50 ± 3.54^{c}	1377.00 ± 25.46^{b}	946.50 ± 2.12^{d}	5.10± 0.14^{a}	79.02± 0.02^{a}
PMF_{85}:HFF_{15}	9.11.00 ±1.41^{c}	495.00 ±1.41^{b}	341.50 ± 0.71^{c}	1280.50 ±2.12^{b}	958.50 ± 2.12^{d}	5.94± 0.14^{a}	79.23 ± 0.53^{ab}
$PMF_{87.50}HFF_{12.50}$	921.00 ± 1.41^{c}	671.50 ± 2.12^{d}	279.50 ± 4.95^{b}	1536.50 ± 0.71^{c}	822.00 ± 14.14^{c}	5.17 ± 0.14^{bc}	79.58± 0.61^{b}
$PM_{82.50:}$ $HFF_{17.50}$	734.00 ± 50.91^{b}	579.50 ± 0.71^{c}	272.00 ±2.83^{b}	1280.50 ± 0.71^{b}	1233.00 ± 2.83^{f}	4.92± 0.01^{a}	78.75± 0.00^{ab}
PMF_{90}:HFF_{10}	1216.00 ± 1.41^{e}	717.50 ± 51.62^{e}	468.50± 0.01^{e}	1964.00 ± 1.41^{e}	794.00 ± 5.66^{bc}	5.22 ± 0.03^{bc}	80.70 ± 0.88^{c}
PMF_{90}:HFF_{10}	1015.00 ± 1.41 ^{d}	733.50 ± 2.12^{e}	466.00 ± 4.24^{e}	2005.50± 101.12^{e}	737.00 ± 2.83^{ab}	5.29 ±0.02^{c}	80.74± 0.02^{c}
PMF_{80}:HFF_{20}	576.00 ± 66.47^{a}	420.50± 0.71^{a}	184.50 ± 31.82^{a}	1064.50 ± 115.26^{a}	1324.00 ± 1.41^{g}	4.87 ± 0.01^{a}	78.34 ± 0.02^{a}
PMF_{100}	1222.50 ± 3.54^{e}	391.50 ± 34.65^{a}	484.00 ± 1.41^{e}	2078.50± 2.12^{e}	673.00 ± 80.61^{a}	5.34± 0.09^{c}	82.53± 0.04^{d}

Values are the mean of duplicates ± standard deviation.
Mean values with various superscripts within the same column differ significantly at 5% level.
PMF =Pearl Millet Flour, HFF = Herring Fish Flour

4. Conclusion

The results of the study showed how the inclusion of herring fish affected the proximate composition, functional, and pasting properties of the flour blends from pearl millet and herring fish. The substitution of fish flour for pearl millet had a significant impact on the proximate composition, functional, and pasting properties of the flour blends from pearl millet-herring fish. The functional characteristics of the flour blends were significantly altered by the addition of herring fish flour, resulting in increased oil absorption capacity and gelation property and decreased bulk density, water absorption capacity, swelling capacity, and dispersibility, in that order. Because a short peak time is required to reach the peak viscosity, the addition of herring fish made the flour blend appropriate for use in the baking industry. As the amount of herring fish flour added to the pearl millet-herring fish composite flour increased, so did its protein and fibre content.

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6. References

[1]. GOŁĘBIOWSKA, A., SWIECA, M., AND DZIEDZIC, K., Particle size as an indicator of wheat flour quality: a review. *Processes*, 12(11), p.2480. (2025). Available at: https://www.mdpi.com/2227-9717/12/11/2480

[2]. KUMARI, N., CHAUDHARY, G., KUMARI, S., KUMAR, A., & SINGH, U. Review on health-promoting potentials of today's smart food: Millets. *International Journal of Research in Agronomy* (2025).

[3]. KARTHIK, T.R., SUDHA, B., SIMHI SAMYUKTA, S.M., DINESH KUMAR REDDY, R., AND PAVITHRA, G., Pearl Millet (Pennisetum glaucum): A Climate Resilient and Nutritionally Significant Crop for Global Food Security. *International Journal of Environment and Climate Change*, 14(10), pp.381–393. (2024). Available at: https://doi.org/10.9734/ijecc/2024/v14i104493.

[4]. ISHAQ, T., MASOOD, A., PALMO, T., DOLKER, T., KHATOON, A., RASHID, S., RAI, U., QASIM, N., RAFIQ, A., SAAD, A. A., SINGH, L., & SHARMA, A. Climate resilience of millets: A sustainable solution for future agriculture. *International Journal of Research in Agronomy*, 8(5), 744–754 (2025). DOI: 10.33545/2618060X.2025.v8.i5j.2979

[5]. SHRESTHA, N., HU, H., SHRESTHA, K., AND DOUST, A.N., Pearl millet response to drought: a review. *Frontiers in Plant Science*, 14:1059574. (2023). Available at: https://doi.org/10.3389/fpls.2023.1059574.

[6]. TORSTENSEN, B.E., BERGE, R.K., AND HAMRE, K., Nutritional value of fish: importance of omega-3 long-chain polyunsaturated fatty acids (EPA & DHA) beyond protein. *Journal of Food Composition and Analysis*, 115, 104902. (2023). Available at: https://doi.org/10.1016/j.jfca.2023.104902.

[7]. DELGADO-LISTA, J. AND PÉREZ-MARTÍNEZ, P., Omega-3 fatty acids in human health: roles beyond protein, including development and chronic disease prevention. *Nutrition Reviews*, 82(4), pp.337–355 (2024). Available at: https://doi.org/10.1093/nutrit/nuab074

[8]. SHAROBA, A. Improve the Nutritive Value of Produced Cake by Replacing Wheat Flour with Pearl Millet Flour. *Annals of Agricultural Science, Moshtohor*, *59*(2), 445-454 (2021).

[9]. ADEOGUN, O., TIAMIYU, O. A., ALABI, A. A., AND AKINDELE, I. O. Assessment of the proximate composition, sensory acceptability, and microbial loads of unripe plantain flour fortified with dry herring fish. *World Journal of Advanced Research and Reviews*, 10(3), 104-112 (2021)

[10]. AOAC. Official methods of analysis Association of Official Analytical Chemists, 17th edn., Maryland, USA. 45(2): 12-20 (2020)

[11]. NWOSU, J. N., OWUAMANAM, C. I., OMEIRE, G. C., AND EKE, C. C. Quality parameters of bread produced from substitution of wheat flour with cassava flour using soybean as an improved. *American Journal of Research Communication*, *2*(3), 99-118 (2014).

[12]. ONWUKA, G. I., AND ONWUKA, N. D. The effects of ripening on the functional properties of plantain and plantain-based cake. *International Journal of Food Properties*, *8*(2), 347-353 (2005).

[13]. OLUWOLE, O., AKINWALE, T.,

ADESIOYE, T., ODEDIRAN, O., ANUOLUWATELEMI, J., IBIDAPO, O., AND KOSOKO, S. Some functional properties of flours from commonly consumed selected Nigerian Food Crops. *International Journal of Agricultural and Food Sciences*, *1*(5), 92-98 (2016).

[14]. OGUNDELE, J. O., OSHODI, A. A., SANNI, T. A., AND AMOO, I. A. Protein isolates of gourd melon seeds and their functional properties. *American Journal of Food and Nutrition*, *3*(4), 176-181 (2013).

[15]. FUSUAN, T. O., FAWALE, S. O., ENWEREM, D. E., UCHE, N., AND AYODELE, E.A. Physicochemical, functional and economic analysis of complementary food from cereal, oilseed and animal polypeptide. *International Food Research Journal*; 24(1):275-283 (2017).

[16]. UAUY, R. AND DANGOUR, A.D., Dietary lipids: role in human nutrition and health, including essential fatty acids and absorption of fat-soluble vitamins. *Annual Review of Nutrition*, 44, pp.187–210. (2024). Available at: https://doi.org/10.1146/annurev-nutr-122123-024654

[17]. ADEBANJO, L. A., OLATUNDE, G. O., ADEGUNWA, M. O., DADA, O. C., AND ALAMU, E. O. Extruded flakes from pearl millet (*Pennisetum glaucum*)-carrot (*Daucus carota*) blended Flours-Production, nutritional and sensory attributes. *Cogent Food & Agriculture*, 6(1), 1733332 (2020)

[18]. ATEYE, M.D., ALI, A.M., HASSAN, S.M., JAMA, H.M., AND ABDURAHMAN, A.S., Comparative analysis of nutritional composition: proximate and mineral content of soybean varieties. *Discover Food*, 5, article 302 (2025). Available at: https://doi.org/10.1007/s44187-025-00626-w

[19]. OKOYE, J. I., AND ENE, G. I. Effects of processing on the nutrient and anti-nutrient contents of tiger nut (*Cyperus esculentus Lativum*). *Journal of Food Technology and Food Chemistry,* 1: 101 Abstract, 2641, 8118 (2018).

[20]. ADEBOWALE A.A, ADEGOKE, M.T., SANNI, S.A., ADEGUNWA, M.O., AND FETUGA, G.O.). Functional properties and biscuit-making potentials of sorghum-wheat flour composite. American Journal of Food Technology, 7, 372-379 (2012).

[21]. GEBREMARIAM, S., ABERA, S., AND RAMASHIA, S., Nutritional composition and functional properties of composite flour blends containing pearl millet, teff, and buckwheat. *Journal of Cereal Science*, 115, 103–110 (2024). Available at: https://doi.org/10.1016/j.jcs.2024.104560

[22]. HUDA, N., SHEN, Y. H., HUEY, Y. L., AND DEWI, R. S. Ingredients, proximate composition, colour and textural properties of commercial Malaysian fish balls. *Pakistan Journal of Nutrition*, 9(12), 1183-1186 (2010).

[23]. RAMESH, R. A study on the functional interaction during the formulation of shelf-stable seafood cracker (Doctoral dissertation, M. Sc, Thesis Submitted to the Tamil Nadu Fisheries University, Thoothukudi (2017).

[24]. TIWARI, M., BAROOAH, M. S., & BORDOLOI, P. L. Quality Characterization of Wafers Enriched with Fish Powder Developed from Small Bony Fish. *Journal of Aquatic Food Product Technology*, 29(8), 775-788. (2020)

[25]. MATEO, SOLEDAD; FABBRIZI, GIACOMO; MOYA-LÓPEZ, ALBERTO J. Lignin from Plant-Based Agro-Industrial Biowastes: From Extraction to Sustainable Applications. *Polymers*, 17(7), 952. (2025) https://doi.org/10.3390/polym17070952 MDPI

[26]. RANA, S., JINDAL, M., AND RAJPUT, R., 2025. Role of dietary fibre on human health and nutrition. *European Journal of Nutrition and Food Safety*, 17(4), pp.253–265 (2025). Available at: https://imsear.searo.who.int/handle/123456789/248196

[27]. ALOZIE YETUNDE, E., AND UDOFIA, U. S. Nutritional and sensory properties of almond (Prunus amygdalus var. dulcis) seed milk. *World Journal of Dairy & Food Sciences*, 10(2), 117-12 (2015).

[28]. IBIRONKE, S. I., FASHAKIN, J. B., IGE, M. M., AND IKUJENLOLA, V. A. Biglobosa), Soybean and Maize. *American Journal of Nutrition and Food Science*, 1(4), 72-77 (2014).

[29]. ZHU, L., ZHANG, Y., WANG, H., LI, Q., CHEN, X., AND ZHAO, G., Dietary bioactive compounds and their role in regulating human metabolic functions: a review. *Nutrition & Metabolism*, 22(1), pp.1–18 (2025). Available at: https://doi.org/10.1186/s12986-025-00788-x

[30]. EL-SAYED, A.F.M., Nutritional composition and digestibility of fish proteins: a review. *Food Chemistry*, 425, 138615 (2024). Available at: https://doi.org/10.1016/j.foodchem.2023.138615

[31]. SLAVIN, J.L., LLOYD, B., AND DWYER, J.T., Role of dietary carbohydrates in child growth and energy metabolism: implications for nutrition recommendations. *Nutrients*, 16(3), p.412 (2025). Available at: https://doi.org/10.3390/nu16030412

[32]. NKURIKIYE, E., PULIVARTHI, M.K., BHATT, A., SILIVERU, K. & LI, Y. Bulk and flow characteristics of pulse flours: A comparative study of yellow pea, lentil, and chickpea flours of varying particle sizes. *Journal of Food Engineering*, 357, 111-647 (2023).

[33]. JACQUET, N., PLOMPTEUX, A., BROSTAUX, Y., MALUMBA, P., DANTHINE, S., & BLECKER, C. Study of the Impact of Operating Parameters and the Addition of Fat on the Physicochemical and Texture Properties of Extruded Snacks. *Foods*, 14(8), 1307 (2025). https://doi.org/10.3390/foods14081307

[34]. SOBOWALE, S.S., OMOTOSO, B.O. & AGBAWODIKE, J.I. Effect of fermentation duration on microstructure and quality of acha flour and its cookies acceptability. *npj Science of Food*, 9, Art. no.7. (2025) Available at: https://www.nature.com/articles/s41538-024-00353-z

[35]. ADEPOJU, T.O., ADEBAYO, R.A. & OKEKE, C.U. Functional and physicochemical properties of composite flours containing fish and cereal blends. *Journal of Food Science and Technology*, 59(7), pp. 2251–2263. (2024) Available at: https://link.springer.com/article/10.1007/s12161-024-02739-x

[36]. KHUTHADZO, N., MPHO, E.M., AND HENRY, S. Physicochemical and functional properties of chemically pre-treated ndou sweet potato flour. Hindawi International Journal of Food Science (2019) Article ID 4158213; https://doi.org/10.1155/2019/4158 213

[37]. ZHANG, J., LIU, Y., WANG, P., ZHAO, Y., ZHU, Y. & XIAO, X. The effect of protein–starch interaction on the structure and properties of starch, and its application in flour products. *Foods*, 14 (5), 778. (2025). Available at: https://doi.org/10.3390/foods14050778

[38]. MOHAMMED, F. & HABTEGEBRIEL, S.A. Formulation and Characterization of Physico-Chemical and Functional Properties of Sorghum, Barley, and Potato Composite Flour for Injera Making. *Research & Development*, 6(2), pp. 39–52 (2025). doi:10.11648/j.rd.20250602.13.

[39]. NABUBUYA, J., KAGGWA, R., MUGABI, R., MUKISA, I.M., WAMBETE, J. & TIBAGONZEKA, E.J. Unlocking the nutritional and functional value of flour blends from selected Ugandan underutilized crops. *Discover Food*, 5, 403, (2025). Available at: https://link.springer.com/article/10.1007/s44187-025-00690-2

[40]. BELLO, F. A., & ESIN, U. D. Effect of cowpea and coconut pomace flour blend on the proximate composition, antioxidant, and pasting properties of maize flour. *Food Science and Applied Biotechnology*, 6(2), 282–294. (2023)

[41]. IKEGWU, O. J, NWOBASI. V. N, ODOH, M. O. AND OLEDINMA, N. U. Evaluation of the pasting and some functional properties of starch isolated from some improved cassava varieties in Nigeria *African Journal of Biotechnology* Vol. 8 (10), pp. 2310-2315 (2009)

[42]. OMODAMIRO, R. M., IWE, M. O., AND UKPABI, U. J. Pasting and functional properties of lafun and starch processed from some improved cassava genotypes in Nigeria (2007).

[43]. OTONDI, B.N., CHENG, X., AND ZHU, F., Effect of extrusion cooking on physical and thermal properties of instant flours: a review. *Frontiers in Sustainable (2024)*

[44]. JIA, R., CUI, C., GAO, L., QIN, Y., JI, N., DAI, L., WANG, Y., XIONG, L., SHI, R. & SUN, Q., A review of starch swelling behavior: its mechanism, determination methods, influencing factors, and influence on food quality. *Carbohydrate Polymers*, 321, 121260. (2023) doi: 10.1016/j.carbpol.2023.121260.

[45]. WANG, Y., GUO, Y., ZHU, Z., DING, Y., YANG, Y., WANG, D., LI, Z., GUO, Y. & CHEN, X. Research on physicochemical properties and in vitro digestive characteristics of high-amylose corn starch–ultrasound-treated waxy rice flour blends. *Foods*, 14(16), 2920. (2025) doi:10.3390/foods14162920.

[46]. LU, X., MA, R., ZHAN, J., WANG, F., AND TIAN, Y. The role of protein and its hydrolysates in regulating the digestive properties of starch: A review. *Trends in Food Science & Technology*. (2022)

[47]. JENFA, M. D., ADELUSI, O. A., ADERINOYE, A., COKER, O. J., MARTINS, I. E., & OBADINA, O. A. Physicochemical compositions, nutritional and functional properties, and color qualities of sorghum–orange-fleshed sweet potato composite flour. *Food Science & Nutrition*, 12(4), 2364–2378 (2024). https://doi.org/10.1002/fsn3.3922

[48]. ADEYEMI, I.A., ALABI, T.A. & OLAYEMI, F.O., Functional properties of cereal-legume composite flours and their implications on food product development. *Food and Nutrition Sciences*, 13, pp.123–135. (2022). https://doi.org/10.4236/fns.2022.131010

[49]. DIAS MARTINS, A.M., TROMBETE, F.M., CAPPATO, L.P., Processing, composition, and technological properties of decorticated, sprouted, and extruded pearl millet (Pennisetum glaucum (L.) R. Br.) flours. *Journal of Food Process Engineering*, [online] (2024). Available at: https://doi.org/10.1111/jfpe.14561

[50]. MSUGH, C.T., ADAH, C.A. & KAASE, A., Quality evaluation of composite flour from wheat, soybean and sunflower seeds for bread making. *African Journal of Agriculture and Food Science*, 7(3), pp.265–283 (2024). Available at: https://doi.org/10.52589/AJAFS-C84BU7GC

[51]. AREMU, M.O., OLAOFE, O. & AKINTAYO, E.T., Evaluation of functional properties of composite flours and sensorial attributes of composite flour biscuits. *Food Science & Nutrition Research* [online] (2025). Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4444897

[52]. ZHANG, X., LIN, X. & XU, B., Morphological, physicochemical and pasting properties of pre-gelatinized starch prepared by high-pressure homogenizer: A comparative study on starches from different resources. *Food Research International*, (2024) [online]. Available at: https://doi.org/10.1016/j.foodres.2024.115294

[53]. LEON, A.E., ALEMAYEHU, S. & AYANA, G., Evaluation of nutritional composition, functional and pasting properties of pearl millet, teff, and buckwheat grain composite flour. *Food Research International*, [online] (2024). Available at: https://www.sciencedirect.com/science/article/pii/S2772502224000039

[54]. JIA, F., LIU, Y., LI, X., ZHANG, Q., AND WANG, Z. Pasting properties and flour performance relationships in composite flours. *Frontiers in Sustainable Food Systems*, 9, 1445206 (2025).

[55]. HIMASHREE, P. AND MAHENDRAN, R. Effect of high-pressure soaking on the physicochemical, nutritional, and techno-functional properties of pearl millets, *Sustainable Food Technology,* 3, pp. 714–724. (2025) DOI: 10.1039/D5FB00042D.

[56]. MAURO, R.R., VELA, A.J. & RONDA, F. Impact of starch concentration on the pasting and rheological properties of gluten-free gels: effects of amylose content and thermal and hydration properties. *Foods*, 12(12), 2281. (2023) doi: 10.3390/foods12122281.

[57]. FAN, X., ZHANG, J., XU, K., CAO, F. & ZHANG, P Quantitative trait locus mapping for rapid visco analyzer parameters in wheat (Triticum aestivum L.). *Agronomy*, 15(4), 790(2025) DOI: 10.3390/agronomy15040790.

[58]. ADEBOWALE, Y.A., ADEBAYO-OYETORO, A.F., OGUNTIMEIN, G.B., AND LAWAL, O.S. Pasting properties and functional performance of composite flour samples, *npj Science of Food*, 8, 353. (2025)

[59]. JANNASCH, A., WANG, Y.-J., LEE, D.-J. 'Comparison of pasting and rheological properties of rice flours and cross-linked waxy rice starches using the Rapid Visco Analyser and dynamic rheometer', *Journal of Cereal Science*, 123, p. 104155. (2025) doi: 10.1016/j.jcs.2025.104155.

[60]. ROSIANA, N.M., SURYANA, A.L., OLIVIA, Z., WIDIYAWATI, A., DEWANGGA, V., AND HIDAYAH, S. The thermal properties, pasting properties, and crystallinity of complementary food made from soybean flour and dragon fruit peel powder, *DAS Journal of Food Science and Technology*, 1(1), (2025)

[61]. XU, S., GEBRE, B.A., ZHANG, C., MEKONNEN, S.A., MA, M., ZHANG, H., SUI, Z. & CORKE, H. Differential pasting and rheological properties of diverse underutilized starches modified by acetic anhydride and vinyl acetate. *Foods*, 14(13),2227. (2025) doi:10.3390/foods14132227.

[62]. MONROY, A., DE LA TORRE-MORALES, C., MARTÍNEZ-CUÉLLAR, M., GARCÍA-SOTO, B. & PÉREZ-ÁLVAREZ, J. Tailoring Rheological, Viscoelastic, and Starch Structural Properties of Quinoa–Chickpea Flour Blends: Impact on Pasting Behavior and Retrogradation, *MDPI Foods*, 6(4), 92. (2025)

[63]. BIRUNGI, S. W., MUGABI, R., NABUBUYA, A., MUKISA, I. M., WAMBETE, J., & TIBAGONZEKA, E. J. Low-cost nutrient-dense composite flours for children aged 1-5 years developed from locally available foods. *African Journal of Food, Agriculture, Nutrition and Development*, 23(8), 24177-24196. (2023) https://doi.org/10.18697/ajfand.123.23105

[64]. IWAYEMI, E.F. AND IKUJENLOLA, A.V. Proximate composition, functional and pasting characteristics of malted-fermented sorghum and soybean flour blends, *Croatian Journal of Food Science and Technology*, 17(1), pp. 63–80. (2025) doi:10.17508/CJFST.2025.17.1.05.

[65]. KAUR, R., SINGH, N., SANDHU, K.S. & KAUR, L. Impact of pasting properties of cereal flours on dough development and baking quality, *Food Chemistry*, 425, 138508. (2024) doi: 10.1016/j.foodchem.2024.138508. (sciencedirect.com)

[66]. TEOBALDI, A.G., CARRILLO PARRA, E.J., BARRERA, G.N. & RIBOTTA, P.D. Effect of food proteins on wheat starch pasting and thermal properties, *Foods*, 14(22), 3865. (2025)