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Functional Characterization of Soybean-Enriched Composite Flour: Implications for Bakery and Food Thickening Applications

[1]*Lawrence Olusegun Ajala*, [2]*Temitope Omolayo Fasuan and* [3]*Badamasi Sarkin Kaya*
[1]*Department of Science Laboratory Technology, Akanu Ibiam Federal Polytechnic, Unwana, Nigeria*
[2]*Department of Animal Health and Production Technology, Federal College of Animal Health and Production Technology, Ibadan, Nigeria*
[3]*Department of Applied Sciences, Abdu Gusau Polytechnic, Talata Mafara, Nigeria*

ABSTRACT
Background and Objective: Composite flours, combining various cereal and legume flours, are gaining attention as functional ingredients in food processing due to their diverse nutritional and functional properties. This study aimed to assess the quality attributes of a composite flour consisting of wheat, corn and soybean flours, with a focus on both functional and physicochemical characteristics. **Materials and Methods:** Composite flours were formulated by partially replacing wheat flour with corn and soybean flour. The physicochemical properties of the blends such as the pH, titratable acidity, loose and packed bulk densities, porosity and moisture content were determined using approved standard methods. Functional properties of the blends such as gelation temperature, water absorption capacity, oil absorption capacity, emulsification capacity, foam capacity, foam stability, swelling index and least gelling concentration were also determined. **Results:** The incorporation of corn or soybean flour significantly augmented the water absorption capacity of wheat flour ($p<0.05$). The composite flour demonstrated high water absorption suitable for bakery products, meat products, doughnuts and pancakes and high oil absorption ideal for thickening oil-rich foods like soups and dressings. The composite flour with a low gelling concentration could serve as a bulky agent in confectionery and pie formulations. **Conclusion:** These findings offer valuable insights for both domestic and industrial applications of corn and wheat flour enriched with soybean flour, facilitating product development and innovation in the food industry.

KEYWORDS
Composite flour, functional properties, physicochemical properties, corn, soybean, wheat

INTRODUCTION
Flour is a major ingredient in the formulation of many food products such as snacks, bread and pasta, among others, some of which are staple foods. The enormous applications of flour in homes and food industries have made the availability of adequate supplies of flour a major economic issue at various times throughout history[1]. A composite flour is a mixture of two or more flours obtained by blending flours from

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other food sources with or without including wheat flour[2]. The primary purpose of formulating composite flour is to produce a better-baked product than using individual component flour. Although cereal flour is rich in amino acids containing sulphur but lacks lysine, its nutritional attributes can be improved by the addition of legume flours, which are rich in lysine. In the same way, by the addition of cereal flour, the nutritional value of protein-lacked root and tuber flours can satisfactorily be improved[3].

The amino acid profiles of cereals and legumes are complementary as they are good sources of protein[4]. Wheat flour is a good source of complex carbohydrates, the most efficient source of energy available to the human body. In most cases, wheat flour needed for baking pastry goods and other baked products had to be imported, since the climate conditions and soil did not permit wheat to be grown locally in some developing countries like Nigeria and Ghana[5]. To decrease the high dependence on imported wheat, bakers are being encouraged to incorporate flours from locally grown crops rich in protein as a partial replacement for wheat flour [6].

Soybean (*Glycine max*) is rich in quality protein and serves as a cheap source of protein for low-income countries. The protein in soybean is superior to all other plant foods due to a good balance of the essential amino acids, it contains a reasonable amount of methionine. The suitability of flour for use as a food or food ingredient solely depends on its functional properties[7]. Incorporation of other flours (soybean and corn) into wheat flour may change the physicochemical and functional properties of the composite flour.

Therefore, this study evaluated the quality attributes of composite flours of corn and wheat enriched with soybean to establish the domestic and industrial potentials for utilization as food ingredients.

MATERIALS AND METHODS

Study area: The study area, Afikpo is located in Ebonyi State, Nigeria and spans an area of approximately 164 km^2. It is situated between 5°52'59.99"N Latitude and 7°55'59.99"E Longitude. Afikpo is a hilly area occupying a region of low altitude of 110 m above sea level. It is a transitional area between open grassland and tropical forest. Like most of Nigeria, the study area enjoys two tropical climate seasons (wet and dry) with an average annual rainfall of 2,000 mm and temperatures varying from 18.89 to 35.4°C. The basic occupation of the people in the study area is predominantly farming and fishing[8].

Sample collection and preparation: A 3 kg of wheat flour and 2 kg each of corn and soybean were purchased at Eke Market, Afikpo, Nigeria in March, 2022. The corn and the soybean flours were prepared according to the standard method[7]. Corn grains were sorted, washed and dried in an oven (Uniscope, SM9053, England) at 50°C for 24 hrs. The dried grains were milled hammer mill (Double Win, FS450, China) mill to pass through a sieve with a mesh sieve of 212 μm. The formulation of the composite flour is illustrated in Fig. 1.

Soybean grains were sorted, washed, soaked in water for 2 hrs, deshelled and dried in an oven at 50°C for 36 hrs. The dried grains were milled by hammer mill (Double Win, FS450, China) mill to pass through a sieve with a mesh sieve of 212 μm (Fig. 1). Wheat flour was sieved using the same sieve to obtain the sample particle size with corn and soybean flours. The composite flour is obtained from the three samples as shown in (Fig. 1).

Experimental design:

A three-component augmented simplex design was used. The three mixture components evaluated in this study were wheat flour (X_1) soybean flour (X_2) and corn flour (X_3). The proportion for each component

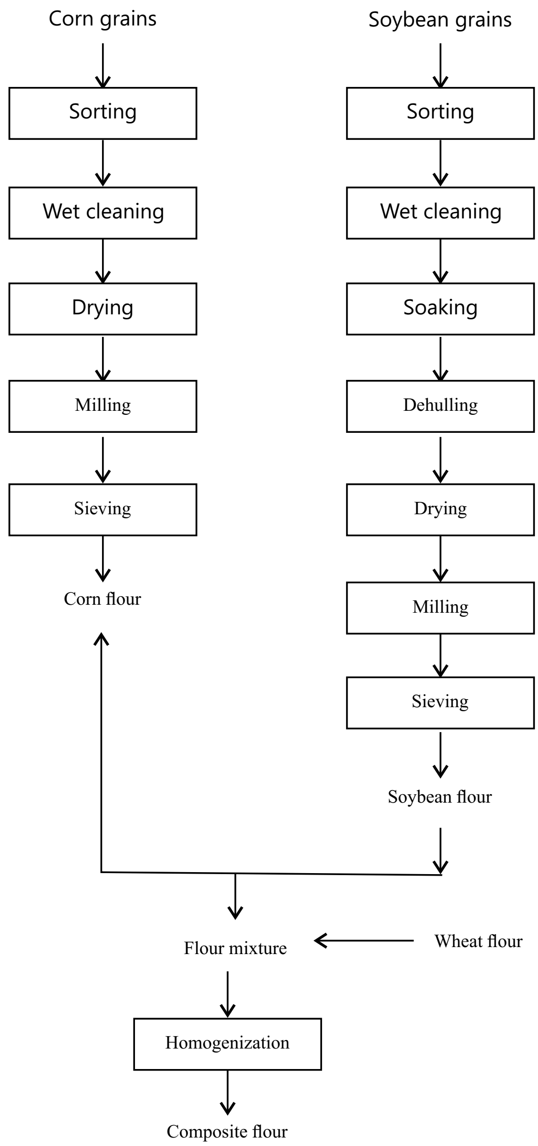

Fig. 1: Flow chart for preparation of composite flour of corn and wheat enriched with soybean

Table 1: Experimental design of composite flour of corn and wheat enriched with soybean flour

	Composition (%)		
Sample	Wheat flour	Soybean flour	Corn flour
WF	100	0	0
SF	0	100	0
CF	0	0	100
WF/SF	50	50	0
WF/CF	50	0	50
WF/SF/CF	33.3	33.3	33.3

WF: Wheat flour, SF: Soybean flour and CF: Corn flour

stated in Table 1 was expressed as a fraction of the mixture and for each treatment combination, the sum of the components' proportion was equal to one[9] as expressed in Equation 1:

$$\Sigma X_i = X_1 + X_2 + X_3 = 1 \quad (1)$$

Physicochemical properties: For each of the experimental samples, 10% (w/v) suspension was made in distilled water and was mixed thoroughly in a Sorex blender. The resulting solution was measured with a pH meter (H11270, Hanna Checker). The FAO[3] and AOAC[10] methods were used to determine total titratable acidity (TTA) and moisture content, respectively. The method of Adebowale *et al.*[11] was adopted to determine the (packed and loose) bulk density.

Functional properties: Oil absorption capacity (OAC) and water absorption capacity (WAC) were determined at room temperature and temperatures between 60 to 90°C as described by Adepeju *et al.*[12]. The foam capacity (FC) and foaming stability (FS) were evaluated as described by Adebowale *et al.*[11]. The gelation temperature (GT), swelling index (SI) and emulsification capacity (EC) were, respectively determined using the method of Adepeju *et al.*[12], Ojinnaka *et al.*[13] and Eriksson *et al.*[14].

Statistical analysis: All experiments were conducted in triplicate. Data reported are averages of three determinations. The mean values were compared using paired-samples T-test procedure of SPSS version 13.0 (SPSS, Chicago, USA).

RESULTS AND DISCUSSION

Physicochemical properties: The results of the physicochemical properties of the composite flour are shown in Table 2. The pH ranged from 5.87 to 6.84. This showed that all the different composite flours formulated were slightly acidic but soybean flour was more acidic, which could be due to the presence of certain acidic amino acids. Erikson *et al.*[14] reported pH values of 6.73 to 7.05 for cassava flours of different varieties. The pH was higher in composite flours formulated from corn and soybean and a mixture of corn, soybean and wheat flours than the 100% wheat flour. Similar trends were reported by Erikson *et al.*[14]. The pH showed that the different composite flours would not have a characteristic sour taste when used in food formulation. The pH of flour suspension is important since some functional properties such as solubility, emulsifying capacity and foaming properties are affected by pH[11].

The moisture content of the composite flour ranged from 7.5 to 20.75%. The composition of wheat and soybean flours recorded the highest value (20.75%), while corn flour recorded the lowest value (7.5%). The moisture values obtained for six samples were comparable to that of Bambarra groundnut flour[15].

The TTA is important in the food system. The TTA of the composite flour ranged from 0.11-0.56%. Wheat flour recorded the highest value while wheat-soybean flour composite recorded the lowest value. The TTA values obtained for the entire samples were comparable to a report in bambarra groundnut flour[15]. Erikson *et al.*[14] reported titratable acidity of 0.37-0.41% for different cassava varieties.

The PBD of the composite flour ranged from 0.32-0.47 g/mL. The composite of wheat and corn flours (50:50) recorded the highest PBD (0.47 g/mL) while 100% soybean flour had the lowest value (0.32 g/mL). The PBD of wheat flour decreased significantly ($p<0.05$) with the addition of soybean flour but

Table 2: Physicochemical properties of wheat, soybean, corn flours and composites

	Sample					
Parameter	WF	SF	CF	WF/SF	WF/CF	WF/CF/SF
Moisture (%)	14.50±0.71^{b}	9.50±0.00^{cd}	7.50±0.00^{d}	20.75±0.14^{a}	14.50±0.71^{b}	10.75±0.05^{c}
pH	5.87±0.01^{f}	6.84±0.01^{a}	6.33±0.03^{d}	6.62±0.12^{b}	6.01±0.03^{e}	6.54±0.01^{c}
TTA (%)	0.56±0.02^{a}	0.53±0.00^{b}	0.31±0.00^{d}	0.11±0.01^{f}	0.40±0.00^{c}	0.15±0.00^{e}
Porosity (%)	40.50±0.70^{bc}	45.40±0.20^{a}	39.75±0.31^{c}	41.1±0.41^{b}	37.75±0.35^{c}	41.65±0.39^{b}
PBD (g/mL)	0.45±.02^{b}	0.32±0.00^{e}	0.45±0.00^{b}	0.41±0.00^{c}	0.47±0.00^{a}	0.39±0.00^{d}
LBD (g/mL)	0.27±0.00^{a}	0.20±0.00^{d}	0.26±0.00^{ab}	0.25±0.00^{c}	0.26±0.00^{b}	0.25±0.00^{c}

Values are means of triplicate Determinations±Standard deviation. Mean values within each row bearing a different superscript are significantly ($p<0.05$) different. WF/SF: Wheat/soybean flour in equal proportion, WF/CF: Wheat/corn flour in equal proportion, WF/SF/CF: Wheat/corn/soybean flour in equal proportion, TTA: Total titratable acid, PBD: Packed bulk density and LBD: Loose bulk density increased significantly with the addition of corn flour. Compositing wheat, soybean and corn flours resulted in a significant decrease in PBD below those of all other samples except that of 100% soybean flour. The particle size and the density of the flour determine the PBD and LBD of a given flour. These properties of flour have been reported to aid in identifying suitable packaging requirements, material handling and its application in the food industry[7]. The result indicated a lesser package requirement with the incorporation of soybean flour. An increase in bulk density is desirable in that it offers a greater packaging advantage as a greater quantity may be packed within a constant volume[16].

Abioye *et al.*[7] reported a PBD of 0.46 g/mL for plantain flour and a range of 0.42-0.45 g/mL for plantain/soybean flour blends. Adebowale *et al.*[17] reported a PBD of 0.67-0.77 g/mL for sorghum-wheat composite flour. Mepba *et al.*[18] reported values of 0.57-0.62 g/mL for wheat-plantain composite. The variations may be attributed to the impact of geographical location on the compositions of the flour samples. The LBD of the blends ranged from 0.20-0.27 g/mL. The 100% wheat flour recorded the highest LBD (0.27g/mL) while 100% soybean flour had the lowest (0.20 g/mL).

The porosity of the blends in this study ranged from 37.75 to 45.40%. The wheat/corn flour composite had the highest porosity and was significantly ($p<0.05$) different from all other samples. The results obtained for porosity were in agreement with those of PBD and LBD. The higher the porosity, the lower the PBD. Porosity is a measure of void spaces in the flour particles[7].

Functional properties: The results of the functional properties of the composite flours are shown in Table 3. The functional attributes predict the application and use of food materials for various food products[7]. The GT of the composite flour ranged from 64.50-75°C. The composite of wheat and corn flours (50:50) recorded the highest value (75°C) while 100% wheat flour recorded the least 64.5°C. The GT obtained for wheat, corn, soybean and their blends were comparable to a similar report[11]. The GT is very important in the food system, it is relatively proportional to the energy required during food processing.

The WAC of the composite flours at ambient temperature ranged from 59.50 to 102.50%. Corn flour had the highest WAC (102.5%) while 100% wheat flour recorded the least. A similar trend was observed by Mepba *et al.*[18] for wheat/plantain composite. The WAC of wheat flour was enhanced significantly ($p<0.05$) by the addition of either corn flour or/and soybean flour. The WAC is important in the preparation of gravies, soup and dough, among others. The results showed that the composite flours would be useful in bakery products where hydration to improve handling is required as well as in comminuted meat, doughnuts and pancakes where good water absorption characteristic is required.

Table 3: Functional properties of wheat, soybean, corn flours and the composite flour

	Sample					
Parameter	WF	SF	CF	WF/SF	WF/CF	WF/CF/SF
WAC (%)	59.5±0.71^{f}	83.5±1.04^{c}	102.5±0.85^{a}	64.5±0.27^{e}	91.5±0.70^{b}	78.5±1.23^{d}
GT (°C)	64.5±0.71^{c}	71.0±1.41^{b}	67.5±0.71b^{c}	66.5±0.52^{c}	75.0±1.41^{a}	70.5±0.34^{b}
EC (%)	20.5±0.70b^{c}	10.1±1.41a	18.0±0.41^{b}	6.75±0.13^{d}	10.75±0.06^{d}	16.0±0.41^{c}
FC (%)	44.05±0.06^{a}	17.95±0.35^{d}	11.90±0.14^{e}	25.5±0.71^{b}	23.74±0.35^{c}	26.75±0.35^{b}
FS (%)	44.55±0.34^{a}	17.85±0.21^{e}	11.91±0.14^{f}	25.2±0.28^{c}	23.75±0.13^{d}	26.75±0.11^{b}
SI (%)	120.5±0.35^{e}	269±1.41^{a}	151.5±2.12^{c}	199.25±1.06^{b}	111.3±1.84^{f}	131.0±1.41^{b}
OAC (%)	385.5±1.72^{bc}	396.5±1.02^{a}	382.5±0.81^{d}	384.5±1.14^{cd}	382.5±1.83^{d}	387.5±0.97^{b}

Values are Means±SD of triplicate determinations. Mean values within each row bearing a different superscript are significantly ($p<0.05$) different. WF: Wheat flour, SF: Soybean flour, CF: Corn flour, WAC: Water absorption capacity, GT: Gelation temperature, EC: Emulsification capacity, FC: Foam capacity, FS: Foaming stability, SI: Swelling index and OAC: Oil absorption capacity

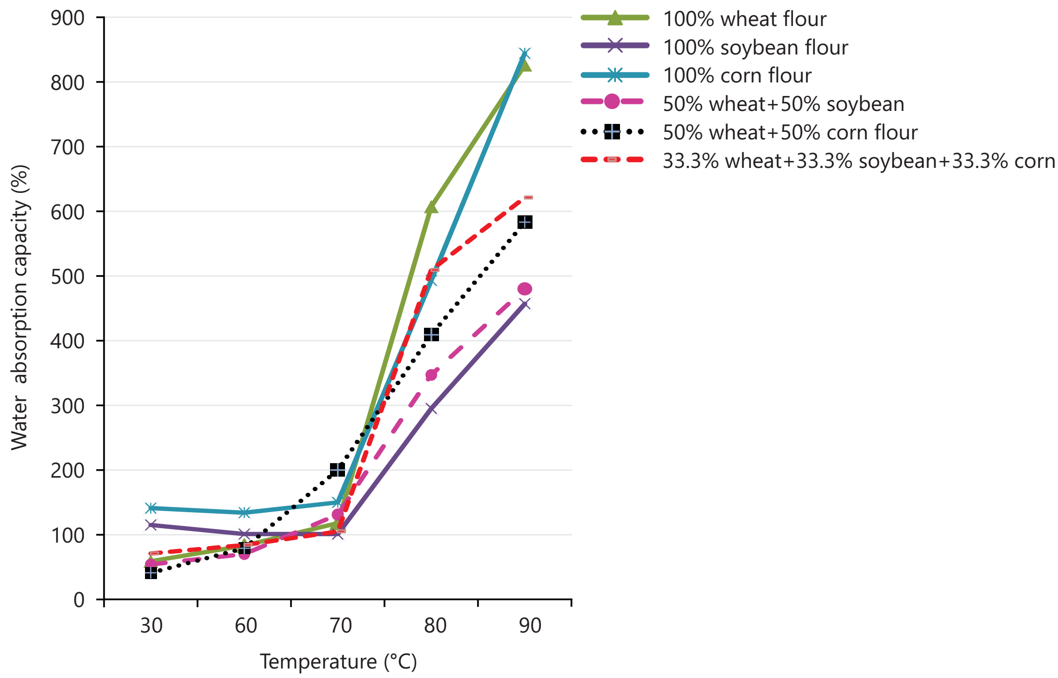

Fig. 2: Influence of temperature on water absorption capacity of composite flour of corn and wheat enriched with soybean

Abioye *et al.*[7] reported a WAC of 80.05% for plantain flour and a range of 82.46-86.50% for plantain-soybean flour composite. The influence of temperature on the WAC is shown in Fig. 2, which ranged from 70 to 844%, it increased rapidly at elevated temperatures. Accordingly, molecules are subject to random movement when there is an increase in temperature, which causes intermolecular and intramolecular forces to be broken and enables the material to absorb more water[19,20]. The high WAC of the composite flours shows that they can find application as a thickening agent and humectant in food formulation.

The OAC of the composite flours ranged from 382.5 to 396.5% (Table 3). The 100% soybean flour was observed to have the highest OAC (396.5%) while 100% corn flour and the composite of wheat-corn flour had the least (382.5%). The OAC of the composite flours were higher than the values reported by Fasasi *et al.*[21] in the fermented flour diet and lower than those reported by Odoemelam[22] in jackfruit flour but compared favourably with bambarra groundnut flour reported by Sirivongpaisal[15]. The OAC is an important property in food formulations because oil improves the flavor and mouth feel of foods[23]. The high OAC enhances the application as a thickening agent in food rich in oil such as soup, salad dressing and mayonnaise.

The EC of the composite flours ranged from 6.75 to 10.1% (Table 3). The emulsification properties of wheat flour decreased with the addition of soybean and/or corn flour. All the flour samples indicated relatively good EC[18] and could find applications in comminuted meat products, salad dressing, frozen desserts and mayonnaise. Mepba *et al.*[18] reported a range of 3.5 to 12.8% for wheat-plantain composite flours.

The FC of the composite flour ranged from 11.90 to 44.05%. The 100% wheat flour was observed to have the highest FC (44.05%) while 100% corn flour had the least (11.90%). It was reported that the ability of flour to foam is related to the rate of decrease in the surface tension of the air or water interface caused by the absorption of protein molecules[24].

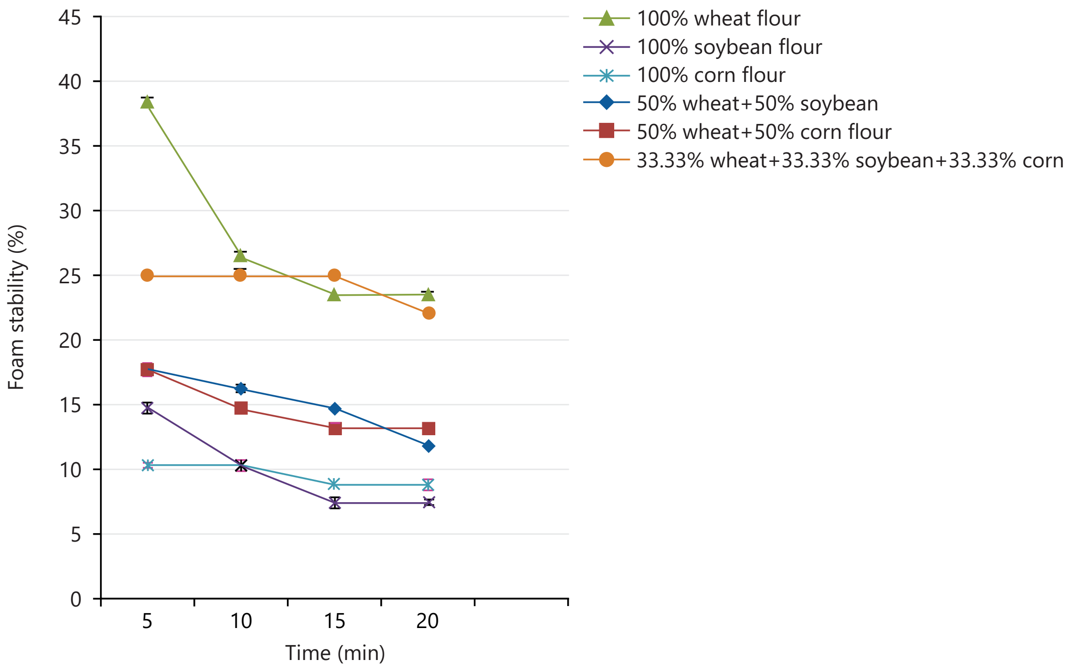

Fig. 3: Foam stability of composite flour of corn and wheat enriched with soybean

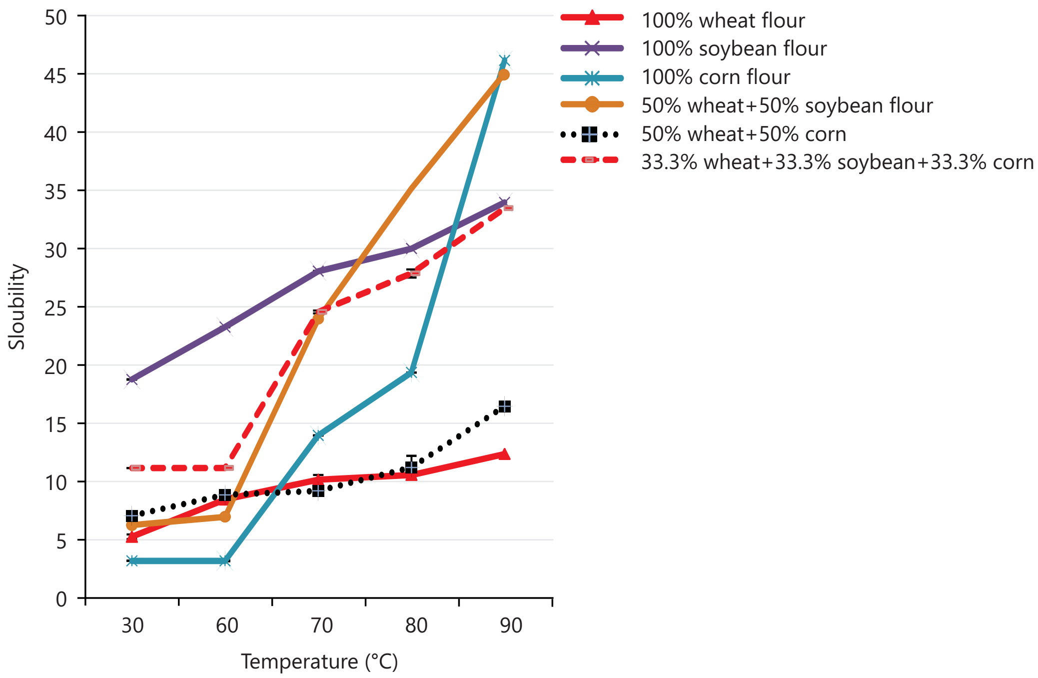

Fig. 4: Influence of temperature on solubility of composite flour of corn and wheat enriched with soybean

The FS ranged from 11.91 to 44.55% at 10 min (Table 3). The 100% wheat flour possessed the highest FS, 100% corn flour was observed to possess the lowest FS. The influence of time on the FS over 20 min is presented in Fig. 3. The results showed the most stable formulation was wheat/soybean/corn composite flour.

The SI of the composite flour ranged from 111.3 to 269% (Table 3). The 100% soybean flour recorded the highest SI of 269% and the composite of wheat and corn flour had the lowest value (111.3%). The SI of the composite flour was higher than the values reported by Odoemelam[22] but compared favorably with that of Fasasi *et al*.[21].

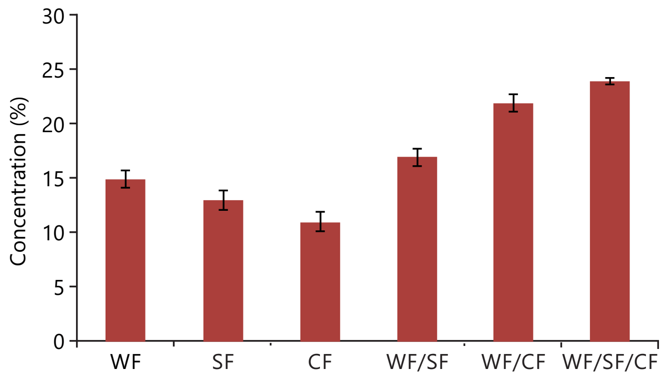

Fig. 5: Gelling concentration of composite flour of corn and wheat enriched with soybean
WF: 100% wheat flour, SF: 100% soybean flour, CF: 100% corn flour, WF/SF: 50% wheat+50% soybean flour. WF/CF: 50% wheat+50% corn flour and WF/SF/CF: 33.33% wheat flour+33.33% soybean flour+33.33% corn flour

The solubility of the flour samples at temperatures ranging from 30 to 90°C is presented in Fig. 4. Here, both the wheat/soybean blend and 100% corn flour recorded the highest solubility and had similar solubility patterns. The solubility of flour in water is governed by the mobility of its granules which in turn enhances its dispersion in water[5,20]. As can be seen in Fig. 4, there was an increase in solubility with a resultant increase in temperature. Water molecules can easily penetrate the intermolecular spaces of carbohydrate materials such as flour, this also enhances solubility[20].

The least gelling concentration of the flour samples (Fig. 5) shows that the highest concentration (24%, w/v) was recorded by wheat/soybean/corn composite flour. The gelling concentration is the minimum flour concentration at which gel remains in the inverted tube and this is used as an index of gelation capacity[25]. The low gelling concentration of wheat/soybean/corn composite flour can enhance its application as a bulky agent in the formulation of confectionery and pies.

CONCLUSION

This study provides a comprehensive evaluation of the quality attributes of a composite flour composed of wheat, corn and soybean. The physicochemical and functional properties assessed demonstrate its potential as a versatile ingredient in various food applications. The significant enhancement in water absorption capacity upon the addition of corn or/and soybean flour expands its utility in bakery and meat products, while the high oil absorption capacity enhances its suitability as a thickening agent for oil-rich foods. Additionally, the composite flour's low gelling concentration suggests its potential as a bulky agent in confectionery and pie formulations. These findings underscore the importance of composite flours in food processing and offer valuable insights for both domestic and industrial applications, contributing to advancements in product development and innovation within the food industry.

SIGNIFICANCE STATEMENT

This study on composite flour, blending wheat, corn and soybean, provides valuable insights into its functional and physicochemical properties. Understanding these attributes is crucial for optimizing its applications in various food products, including bakery items, comminuted meat and thickening agents. The findings offer practical implications for both domestic and industrial food processing, contributing to enhanced product development and innovation in the food industry.

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