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EFFECT OF PROCESSING ON PHYSICOCHEMICAL AND FUNCTIONAL PROPERTIES OF FOUR DIFFERENT IMPROVED VARIETIES OF WHOLE WHEAT (*TRITICUM AESTIVUM L.*) FLOUR.

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ABSTRACT

Wheat is consumed worldwide because of its high nutritional content and convenience to form different products. Whole wheat is an important source of dietary fiber and its consumption is known to lower the risk of colon cancer, diabetes mellitus and cardiovascular disease. Processing of agricultural products remain the most important food and nutrition security aspect in the modern world. Processing is done to improve consumer acceptability while retaining its nutritional values. The effects of fermentation singly, sprouting singly and combined sprouting-fermentation processes on various physicochemical and functional properties of four different varieties of whole wheat flour (*Triticum aestivum L.*) were investigated in this study. Standard methods were used to determine proximate, minerals, antinutrients as well as some functional characteristics in unprocessed (B100U, NU, IU and R28U), fermented (B100F, NF, IF and R28F), sprouted (B100S, NS, IS and R28S) and sprouted-fermented (B100C, NC, IC and R28C) samples of *Triticum aestivum L.* varieties. The results showed significant ($P<0.05$) increase between the processed and the unprocessed flours across the four wheat varieties in their nutrient contents, with the combined (sprouted-fermented) flours recording the highest value in terms of protein, fat and minerals followed by the sprouted and then fermented singly. Also, the percentage reduction in antinutrients was higher for the sprouted-fermented flours in phytic acid across all the four varieties. For tannins and saponins, sprouted and fermented flours showed higher percentage decrease respectively. All the processed flours showed desired functional characteristics. The findings in this research are in support of the body of literature that consumption of whole food products is likely to be more beneficial to consumers than the refined

products. Bioprocessing techniques such as sprouting and fermentation can be considered as a viable option towards improving nutritional value of food.

Keywords: *Whole Wheat flour, sprouting, fermentation and Mineral Composition.*

INTRODUCTION

Over time, various factors including modernity, emergence of diseases and prominence of ailments have led to deliberate lifestyle changes through conscious consumption of health benefitting foods. Whole grain (WG) cereals are one type of food with a wide range of nutritionally vital and healthy elements, including carotenoids, inulin, β-glucan, lignans, vitamin E-related compounds, tocols, phytosterols, and phenolic compounds, which are beneficial for human consumption (Oluwafemi and Gabriela, 2019). Whole grain products consumption has attracted increasing attention in recent years because they not only provide nutrition, but also confer health promoting effects in food, such as anti-carcinogenic, anti-diabetic, anti-microbial, and antioxidant properties. (Dykes and Rooney, 2007; Jiang *et al*., 2011; Okarter and Liu, 2010). Wheat, grown in many parts of the world, is a major contributor to food security in that it is a staple food in other countries (Shewry, 2009a). It has three main grain parts which are the bran, endosperm and the germ. The wheat grain as a whole comprises of nutritional and health beneficial components ranging from macronutrients, micronutrients, vitamins, phenolic compounds and other components at different levels across various grain parts (Shewry and Hey, 2015). Due to its regular consumption in various forms, the wheat grain is a major contributor to the daily dietary intake required by individuals. Thus, regular consumption of essential nutrients at adequate levels could largely contribute to the reduction of nutrient deficiency-related ailments such as aneamia, growth and development problems, cardiovascular diseases, cancer, diabetes, neurological disorders, etc. (FAO/WHO, 2000). Agricultural produce is processed to improve consumer acceptability while retaining its nutritional value. Different techniques are used for processing cereals and legumes that include fermentation, sprouting and germination (Hirawan *et al*., 2010). Fermentation, sprouting and malting facilitate the enzymatic breakdown of carbohydrates into simple sugars through activation of endogenous enzymes such as α-amylase thereby improving digestibility (Oghbaei and Prakash, 2016) as a result of degradation of starch to provide energy for the seed development (Wang *et al*., 2020). Thus, this study produced sprouted, fermented singly and a combined (sprouted-fermented) whole wheat flours from some improved whole wheat varieties and evaluated the effect of the employed processing techniques on their nutrient and physicochemical contents that will guide their use in the development of functional foods and nutraceuticals.

MATERIALS AND METHODS

Material Collection: Improved wheat varieties (LACRI WHIT 5, LACRI WHIT 6, LACRI WHIT 11 and LACRI WHIT 12) were purchased from a seed breeder at the Lake Chad Research Institute, Maiduguri, Borno State.
Chemicals and Reagents**:** Chemicals and reagents used were of available analytical grade and were purchased from the appropriate manufacturing company through Gabrous Nigeria Limited, Gombe.

Methods

Preparation of Samples:

Preparation of Whole Wheat Flour: One kilogram each of the four different improved wheat varieties were sorted to remove dirt and unwanted stones, they were then washed and sundried to constant moisture for 2 days and then milled into flour, sieved through 0.5mm fine mesh and then packaged in an air tight polythene bag for analysis (Chandra *et al*., 2015).

Production of Sprouted Whole Wheat Flour

Sprouting was carried out according to the method described by Kulkarni *et al*. (1991) with some modifications. One kilogram each of the four improved wheat varieties were sorted to remove dirt and unwanted stones, washed and then soaked in a plastic bucket containing 5 litres of distilled water for 6-12 hours until softened and then the water drained. The softened seeds were rinsed thoroughly and then spread over a woven cloth and kept in a dark place and water was sprinkled occasionally to keep them moist. Gently rinsing seeds at least once a day in hot weather helps prevent molds from growing. Tiny sprouts began to form in 2-3 days thereafter, were sun dried to constant weight for 2-3 days in a sterilized tray pan. The sprouted wheat grains were then milled using a disc attrition mill (Hunt No. 2A Premier Mill Hunt and Co, UK) to an average particle size of less than 0.3mm. The milled grains were sieved through a fine mesh (0.5mm) and the wheat flour was obtained. It was then packaged in an air tight polythene bag and stored for analysis.

Production of Fermented Whole Wheat Flour

Fermentation was carried out using the method described by Ariahu *et al*. (1991). One kilogram each of the four improved wheat varieties were sorted to remove dirt and unwanted stones, washed and then soaked in a plastic bucket containing distilled water 3 times its weight by volume for 72 hours. The fermented grains were thoroughly washed and sun dried for 3 days and then milled and sieved through a 0.5 mm mesh to obtain the fermented whole wheat flour. It was then packaged in an air tight polythene bag and stored for analysis.

Production of Combined (Sprouted-Fermented) Whole Wheat Flour

Combined whole wheat flour was produced using the method described by Falmata *et al*. (2014). One kilogram each of the four improved wheat varieties were sorted to remove dirt and unwanted stones, they were sprouted and then fermented. The sprouted-fermented grains were thoroughly washed and sun dried for 3 days and then milled and sieved through a 0.5 mm mesh to obtain the combined whole wheat flour. It was packaged in an air tight polythene bag and stored for analysis.

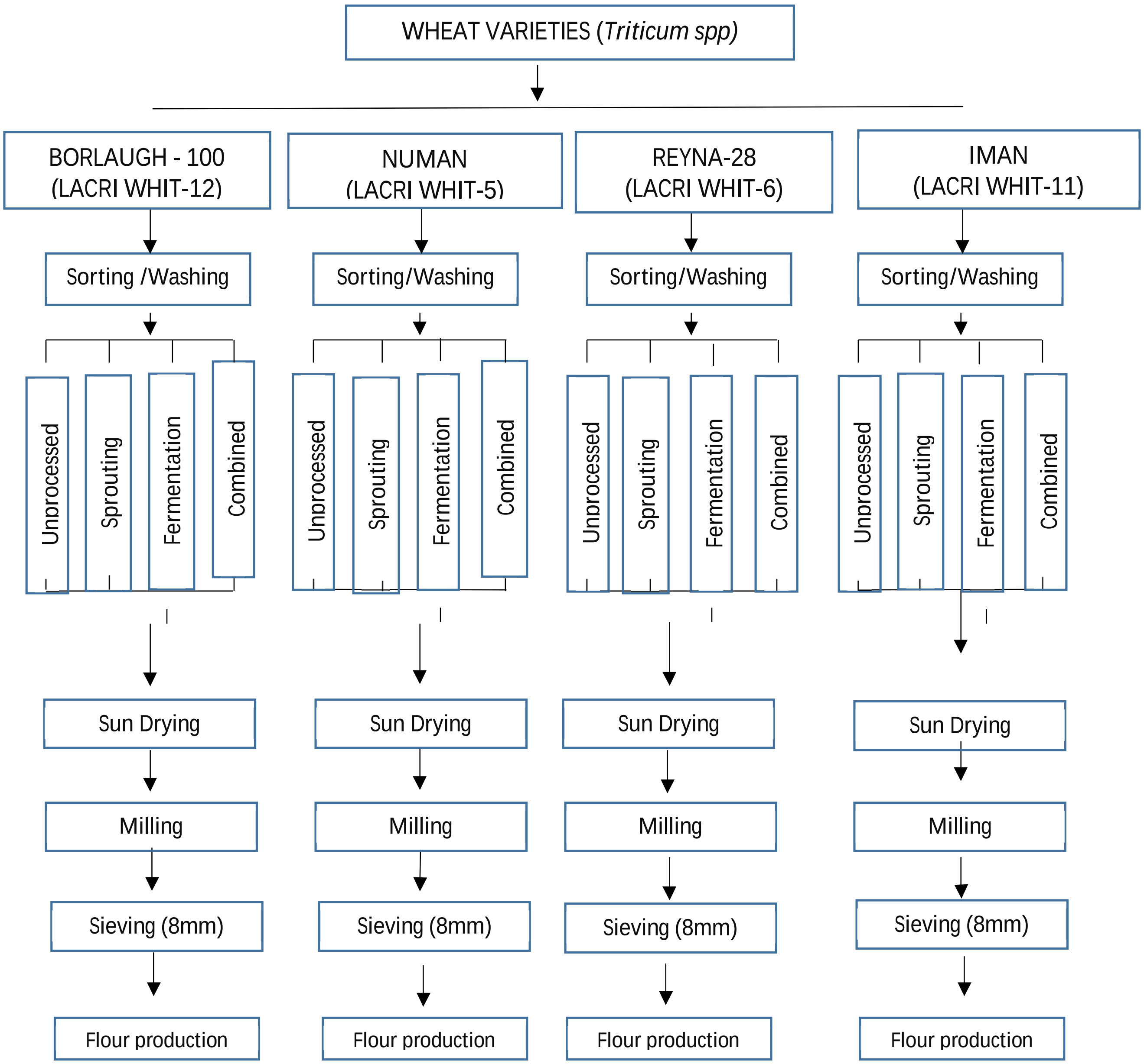

Figure 1: Flow Chart for the Processing of Sample
Source: Own Design

Proximate Analysis.

Proximate analysis was carried out using standard AOAC (2020) method to determine the moisture content, ash content, crude protein, crude fibre, fat content, dry matter as well as carbohydrate composition of the samples.

Determination of Mineral Elements (AOAC, 2020)

Atomic absorption spectrophotometer (AAS) AA 6800 series shimazocorp was used for the determination of Ca, K, Fe, Mn, Mg and Zn. Two grammes of sample was weighed into a crucible and incinerated at six hundred (600°C) in a muffle furnace for three (3) hours. To the ash sample and exactly ten (10.0mls) of 6NHCl was added to the ashed sample covered and was placed on a water bath and boil for ten minutes. The sample was removed and filtered into 100ml volumetric flask. The filter paper was washed down, and the volume was made up to 100 ml using de-ionized water. About 10 ml of the digested sample was transferred to the test tubes and was aspirated to the AAS. Reading was recorded in ppm. The appropriate lamps and correct wavelength for each element is specified in the instruction manual as follows: Fe=248.3nm, K=766.5nm, Zn=213.9nm, Mn=279.5nm, Ca=422.7nm, Mg=285.23nm

Determination of Antinutrients

Saponins (Mercy *et al.,* 2017).

Ten grams of the sample were dispersed in 100 ml of 20% ethanol and heated at 60°C with continuous stirring over a hot water bath for 4 hours. The mixture was filtered and the residue re-extracted with another 100ml of 20% ethanol. The combined extracts were pre-concentrated to 40 ml over water bath, and the concentrates were transferred into a 125 ml separator funnel. Diethyl ether (20 ml) were added and shaken vigorously. The aqueous layer was recovered while the ether layer was discarded. The purification process was repeated twice and then 60 ml of n-butanol was added. The combined n-butanol extracts were washed twice with 10 ml of 5% aqueous sodium chloride solution. The resulting solution was then heated in a water bath. Following evaporation, the samples were oven-dried until a constant weight was achieved. The saponin content was determined as a percentage.

Phytate (Francis, 2007)

Four grams (4g) of the sample was soaked in 100 cm^3 of 2% HCl for 3hrs and then filtered through two layers of filter paper. Twenty-five centimeter cube ($25cm^3$) of the filtrate was placed in $250cm^3$ conical flask and $5cm^3$ of 0.3 % NH_4SCN solution was added as an indicator. Fifty-three centimeter cube ($53.0cm^3$) of distilled water was added to reach the proper acidity. This mixture was titrated against $FeCl_3$ solution, which contains about 0.00195 g of Fe per cm^3 of $FeCl_3$ solution. The result was multiplied by a of factor 1.95 to obtain Phytate P. Phytate P result was multiplied by factor 3.55 to convert to Phyatate.

Tannins

Vanillin Hydrochloric Acid quantitative method was used as described by Burns (1971). Zero point two five (0.25g) of sample was weighed into Erlenmeyer flask and was pipette into 10ml of 4% HCl in methanol, the flask was closed with paraffin wax. The flask was shaken for twenty min (20 min) on a wrist action shaker and was centrifuged for ten min at 4500 rev/min.

One millilitre of the extract was pipetted and one ml of one % vannillin will be added, zero point five ml concentrated HCl phenol standard will be prepared and five different test tubes will be labelled as 1, 2, 3, 4 and 5; 0.1, 0.3, 0.5, 0.7 and 1.0 ml were pipetted respectively of phenol reagent into the tubes, the volume of the test tubes were made up to one ml with eight % HCl in methanol and 0.1ml of 1% vanillin and 0.5ml of concentrate and made up to volume to 5.5ml with 4% HCl in methanol. Blank sample was prepared using five mills of 4% HCl in methanol instead of the extract. The absorbance of standard solutions, sample extracts and sample blank was taken in the spectrophotometer at five hundred (500 nm) exactly for twenty minute into incubation.

Calculations;

$$AU/CU = Astd/Cstd$$

$$CU = \frac{Au \times Cstd}{Astd} = mg/g \quad \text{---} Eq(1)$$

Where AU = Absorbance of unknown

Astd = Absorbance of standard

CU = Concentration of unknown

Cstd = Concentration of standard

Determination of Functional Properties of the Whole Wheat Flour (AOAC, 2020)

pH: The pH was measured by making a 10% (w/v) flour suspension of each sample in distilled water. Each sample was mixed thoroughly in a plastic beaker, and the pH was recorded with an electronic pH meter (Model PHN-850, Villeur-Banne, France.

Water Absorption Capacity: Two grams (2g) of the sample was mixed with 20ml distilled water and allowed to stand at ambient temperature (32°C) for 30min, then centrifuged for 30min at 2000 x g. Excess water was decanted by inverting the tubes. Water absorption capacity was expressed as a percentage of water bound per gram;

$$\text{Water absorption capacity} = \frac{W2-W1}{W0} \quad \text{---------------------------------Eq(2)}$$

Where; W0 = weight of sample

W1 = weight of tube

W2 = weight of tube and sample

Bulk Density (BD): 50g sample was put into a 100 ml graduated cylinder. The cylinder was tapped 50 times and the bulk density was calculated as weight per unit volume of sample (g/ml).

$$BD = \frac{\text{Wt. of flour}}{\text{Volume of bulk flour}} \quad \text{--Eq(3)}$$

Foam Capacity (FC): Two grams (2g) of the sample was added to 50 ml distilled water at 30°C in a 100 ml measuring cylinder. The suspension was mixed and shaken for 5 min to foam. The volume of foam at 30s after whipping was expressed as FC using the formula;

$$FC = \frac{\text{Difference in Vol.}}{\text{Vol. before blending.}} \quad \text{----------------------------------Eq(4)}$$

Viscosity Determination (AOAC, 2020): Viscosity was determined by placing twenty grams of the sample in a measuring cylinder of 100 ml of water in a boiling water bath of 75-80°C.The slurry was constantly stirred and until boiling and was continued for five minutes. The slurry was cooled to room temperature 23-25°C and their viscosity was measured using canon viscometer.

Data Analysis: All analysis was carried out in triplicates. Data obtained were analyzed using Analysis of variance (ANOVA) using Statistical Package for the Social Sciences version 23.

RESULTS: The proximate compositions of unprocessed, fermented, sprouted and combined sprouted-fermented LACRI WHIT 5, LACRI WHIT 6, LACRI WHIT 11 and LACRI WHIT 12 whole wheat flour are presented in Table 1, 2, 3 and 4 respectively. In the unprocessed, there were variations within the four wheat varieties in their nutrient content compositions as follows; statistically significant ($P<0.05$) difference was observed in protein, fibre, fat, carbohydrate and energy contents among the four wheat varieties. However, the differences observed within LACRI WHIT 11 (IU 6.68^{b}±0.44), LACRI WHIT 6 (R28U 6.74^{b}±0.29) and LACRI WHIT 5 (NU 6.92^{b}±0.18) in terms of moisture contents, and, within LACRI WHIT 11 (IU 1.32^{b}±0.03) and LACRI WHIT 5 (NU 1.31^{b}±0.05) in ash contents were not statistically significant ($P>0.05$). Within the fermented varieties exhibited a significant ($P<0.05$) variation in moisture (B100F; 5.86^{a}±0.03, IF; 5.27^{b}±0.71, NF; 4.26^{d}±0.33 and R28F; 4.75^{c}±0.01), protein (B100F; 15.52±0.01^{a}, IF; 13.76±0.03^{b}, NF; 10.25±0.61^{d}, and R28F; 11.43±0.03^{c}), fat (B100F; 2.21^{d}±0.66, IF; 3.66^{a}±0.42, NF; 3.52^{b}±0.31, and R28F; 2.88^{c}±0.05) and carbohydrate (B100F; 62.06^{d}±0.07, IF; 63.33^{c}±0.31, NF; 66.44^{b}±0.82, and R28F; 67.41^{a}±0.45) contents. But, the differences recorded within NF (2.28^{b}±0.22) and R28F (2.29^{b}±0.07) in terms of ash content, B100F (11.25^{c}±0.09) and R28F (11.24^{c}±0.02) in fibre, and, IF (341.30^{a}±0.21) and R28F (341.28^{a}±0.28) in terms of energy were not statistically significant ($P>0.05$).

A significant ($P<0.05$) increase was observed in ash, protein and fibre contents within the four sprouted whole wheat varieties when compared to the unprocessed with B100S (2.30^{a}±0.04) having the highest ash content and R28S (1.32^{d}±0.70) having the least. B100S also had the highest crude protein (14.69^{a}±0.62) and IS (11.65^{d}±0.11) had the lowest. The total fibre content recorded for NS (12.71^{a}±0.17) was the highest while B100S (11.55^{d}±0.57) recorded the least. There was also a significant (P<0.05) decrease in moisture, fat and carbohydrate contents within the varieties. The reduced carbohydrate contents of the sprouted whole wheat flour resulted in a marked decline in energy. There was a significant (P<0.05) increase observed in fibre, fat, carbohydrate and energy contents in all the sprouted-fermented whole wheat flour. The moisture content of B100C ($5.89^{a}\pm0.31$) and NC ($5.87^{a}\pm0.14$), the ash content of IC ($2.52^{c}\pm0.34$) and NC ($2.54^{c}\pm0.61$), the protein content of B100C ($15.80^{a}\pm0.05$) and IC ($15.53^{a}\pm0.21$), and, the fibre content of IC ($11.78^{a}\pm1.01$) and NC ($11.73^{a}\pm0.85$) showed some slight variations even though they were not significant (P>0.05).

Table 1: Proximate Compositions of Unprocessed Whole Wheat Flour Varieties (%)

	Moisture	Ash	Protein	Fibre	Fat	CHO	Energy (Kcal/100g)
B100U	8.02^{a}±0.41	1.53^{a}±0.01	12.25^{a}±0.00	11.01^{c}±0.01	4.56^{a}±0.05	62.64^{d}±0.01	340.57^{b}±0.01
IU	6.68^{b}±0.44	1.32^{b}±0.03	10.50^{d}±0.11	11.65^{a}±0.00	3.53^{b}±0.02	66.34^{b}±0.01	339.04^{c}±0.11
NU	6.92^{b}±0.18	1.31^{b}±0.05	10.66^{c}±0.01	11.59^{b}±0.03	3.28^{d}±0.01	66.24^{c}±0.10	337.14^{d}±0.30
R28U	6.74^{b}±0.29	1.22^{c}±0.03	11.69^{b}±0.21	10.55^{d}±0.01	3.32^{c}±0.01	66.48^{a}±0.02	342.65^{a}±0.51
RDI(USDA) (g/100g)	<10	1.56	15.10	10.60	2.73	71.20	346(Kcal/100g)

Values are means ± SEM, n=3 Values with different superscripts along the column are significantly different ($p<0.05$)

Key:

B100U= Borlaugh 100 (LACRI WHIT 12) Unprocessed
IU= Iman (LACRI WHIT 11) Unprocessed
NU= Numan (LACRI WHIT 5) Unprocessed
R28U= Reyna 28 (LACRI WHIT 6) Unprocessed

Table 2: Proximate Compositions of Fermented Whole Wheat Flour Varieties (%)

	Moisture	Ash	Protein	Fibre	Fat	CHO (Kcal/100g)	Energy
B100F	$5.86^{a}\pm0.03$	$3.10^{a}\pm0.41$	$15.52^{a}\pm0.01$	$11.25^{c}\pm0.09$	$2.21^{d}\pm0.66$	$62.06^{d}\pm0.07$	$330.21^{c}\pm0.06$
IF	$5.27^{b}\pm0.71$	$2.16^{c}\pm0.16$	$13.76^{b}\pm0.03$	$11.82^{b}\pm0.23$	$3.66^{a}\pm0.42$	$63.33^{c}\pm0.31$	$341.30^{a}\pm0.21$
NF	$4.26^{d}\pm0.33$	$2.28^{b}\pm0.22$	$10.25^{d}\pm0.61$	$12.25^{a}\pm0.15$	$3.52^{b}\pm0.31$	$66.44^{b}\pm0.82$	$338.44^{b}\pm0.02$
R28F	$4.75^{c}\pm0.01$	$2.29^{b}\pm0.07$	$11.43^{c}\pm0.03$	$11.24^{c}\pm0.02$	$2.88^{c}\pm0.05$	$67.41^{a}\pm0.45$	$341.28^{a}\pm0.05$
RDI(USDA) (g/100g)	<10	1.56	15.10	10.60	2.73	71.20	346(Kcal/100g)

Values are means ± SEM, n=3 Values with different superscripts along the column are significantly different ($p<0.05$)

Key:

B100F= Borlaugh 100 Fermented
IF= Iman Fermented
NF= Numan Fermented
R28F= Reyna 28 Fermented

Table 3: Proximate Compositions of Sprouted Whole Wheat Flour from the Four Varieties (%)

	Moisture	Ash	Protein	Fibre	Fat	CHO	Energy
B100S	$7.31^{a}\pm0.81$	$2.30^{a}\pm0.04$	$14.69^{a}\pm0.62$	$11.55^{d}\pm0.57$	$2.71^{b}\pm0.45$	$61.45^{d}\pm0.24$	$328.93^{d}\pm0.02$
IS	$6.13^{b}\pm0.53$	$1.74^{b}\pm0.07$	$11.65^{d}\pm0.11$	$11.87^{c}\pm0.44$	$3.21^{a}\pm0.04$	$65.05^{c}\pm0.22$	$337.08^{a}\pm0.57$
NS	$5.50^{d}\pm0.51$	$1.55^{c}\pm0.26$	$12.30^{c}\pm0.01$	$12.71^{a}\pm0.17$	$2.67^{c}\pm0.31$	$65.27^{b}\pm0.65$	$334.33^{b}\pm0.11$
R28S	$5.97^{c}\pm0.24$	$1.32^{d}\pm0.70$	$13.05^{b}\pm0.33$	$12.23^{b}\pm0.21$	$2.10^{d}\pm0.41$	$65.34^{a}\pm0.13$	$332.37^{c}\pm0.32$
RDI(USDA) (g/100g)	<10	1.56	15.10	10.60	2.73	71.20	346(Kcal/100g

Values are means ± SEM, n=3 Values with different superscripts along the column are significantly different ($p<0.05$)

Key:

B100S= Borlaugh 100 Sprouted
IS= Iman Sprouted
NS= Numan Sprouted
R28S= Reyna 28 Sprouted

Table 4: Proximate Compositions of Combined (Sprouted-Fermented) Whole Wheat Flour Varieties (%)

	Moisture	Ash	Protein	Fibre	Fat	CHO	Energy(Kcal/100g)
B100C	$5.89^{a}\pm0.31$	$2.62^{a}\pm0.73$	$15.80^{a}\pm0.05$	$11.33^{b}\pm0.36$	$4.73^{b}\pm0.59$	$59.63^{d}\pm0.41$	$344.29^{c}\pm0.01$
IC	$5.10^{c}\pm0.06$	$2.52^{c}\pm0.34$	$15.53^{a}\pm0.21$	$11.78^{a}\pm1.01$	$4.67^{a}\pm0.88$	$63.40^{b}\pm0.32$	$345.75^{a}\pm0.02$
NC	$5.87^{a}\pm0.14$	$2.54^{c}\pm0.61$	$12.45^{c}\pm0.08$	$11.73^{a}\pm0.85$	$3.32^{c}\pm0.46$	$65.09^{a}\pm0.02$	$340.04^{b}\pm0.02$
R28C	$6.61^{b}\pm0.17$	$2.37^{b}\pm0.02$	$12.77^{b}\pm0.04$	$10.82^{c}\pm0.57$	$3.57^{d}\pm0.03$	$63.86^{c}\pm0.01$	$338.65^{d}\pm0.03$
RDI(USDA) (g/100g)	<10	1.56	15.10	10.60	2.73	71.20	346(Kcal/100g

Values are means ± SEM, n=3 Values with different superscripts along the column are significantly different ($p<0.05$)

Key:

B100C= Borlaugh 100 Combined (Sprouted-Fermented)
IC= Iman Combined (Sprouted-Fermented)
NC= Numan Combined (Sprouted-Fermented)
R28C= Reyna 28 Combined (Sprouted-Fermented)

Table 5, 6, 7 and 8 represents the phytic acid, tannin and saponin contents of the four wheat varieties. For LACRI WHIT 12, the percentage reductions were higher for phytic acids, followed by tannins and then saponins. Phytic acid values were reduced by 49.10%, 52.76% and 54.19%, for tannins, 24.70%, 21.18% and 32.94%, and, for saponins, 34.29%, 37.14% and 51.43% respectively after fermentation, sprouting and combined sprouting-fermentation processes. B100C recorded the highest percentage decrease (54.19%, 32.94% and 51.43% in phytic acid, tannin and saponins respectively). The differences were statistically significant ($p<0.0$). For LACRI WHIT 11, there were significant ($p<0.05$) reductions in the level of phytic acid (30.53%, 33.15% and 46.69%), tannins (10.53%, 52.63% and 21.05%) and saponins (16.67%, 43.33% and 26.67%) in fermented, sprouted and combined (sprouted-fermented) respectively. Percentage decrease was highest in IC (46.69%) for phytic acid and in IS (52.63%, 43.33% for tannins and saponins respectively). In LACRI WHIT 5, there were variations also in the percentage decrease between the fermented, sprouted and the combined (sprouted/fermented) whole wheat flours in phytic acid and tannin contents. The highest percentage decrease recorded was in phytic acid with the sprouted-fermented (NC 52.20%) flour having the highest value and the fermented (NF 29.19%) flour recording the lowest value. The variation was statistically significant ($p<0.05$). However, percentage reduction for saponin was higher in the fermented flour (NF 20.51%) while the sprouted (NS 17.95%) and combined flour (NC 17.95%) showed no significant ($p>0.05$) variation. For LACRI WHIT 6, the highest percentage decrease recorded was in the combined (sprouted-fermented) flour (R28C 61.45%) for phytic acid, and R28F (12.99%) recorded the lowest for tannin. All the variations were statistically significant ($p<0.05$).

Table 5: Antinutritional Contents of Unprocessed, Fermented, Sprouted and Combined (Sprouted-Fermented) LACRI WHIT 12 (g/100g)

	B100U	B100F	B100U	B100S	B100U	B100C
Phytic Acid	$16.83^{a}\pm0.05$	$8.55^{b}\pm0.06$	$16.83^{a}\pm0.05$	$7.95^{c}\pm0.03$	$16.83^{a}\pm0.05$	$4.71^{d}\pm0.17$
% Decrease	49.10%		52.76%		54.19%	
Tannin	$0.85^{a}\pm0.02$	$0.64^{c}\pm0.02$	$0.85^{a}\pm0.02$	$0.67^{b}\pm1.12$	$0.85^{a}\pm0.02$	$0.57^{d}\pm0.03$
% Decrease	24.70%		21.18%		32.94%	
Saponin	$0.35^{a}\pm0.13$	$0.23^{b}\pm0.01$	$0.35^{a}\pm0.20$	$0.22^{b}\pm0.02$	$0.35^{a}\pm0.00$	$0.17^{c}\pm0.01$
% Decrease	34.29%		37.14%		51.43%	

Values are mean ± SEM, n ═ 3 Values with different superscript along the row under the same heading are significantly different (P<0.05)
Key: B100U= Borlaugh 100 Unprocessed, B100F= Borlaugh 100 Fermented, B100C= Borlaugh 100 Combined (sprouted-fermented)

Table 6: Antinutritional Contents of Unprocessed, Fermented, Sprouted and Combined (Sprouted-Fermented) LACRI WHIT 11 (g/100g)

	IU	IF	IU	IS	IU	IC
Phytic Acid	$10.71^{a}\pm0.13$	$7.44^{b}\pm0.12$	$10.71^{a}\pm0.13$	$7.16^{c}\pm0.19$	$10.71^{a}\pm0.13$	$5.71^{d}\pm0.13$
% Decrease	30.53%		33.15%		46.69%	
Tannin	$0.57^{a}\pm0.01$	$0.51^{b}\pm0.01$	$0.57^{a}\pm0.01$	$0.27^{d}\pm0.02$	$0.57^{a}\pm0.01$	$0.45^{c}\pm0.01$
% Decrease	10.53%		52.63%		21.05%	
Saponin	$0.30^{a}\pm0.21$	$0.25^{b}\pm0.07$	$0.30^{a}\pm0.30$	$0.17^{d}\pm0.05$	$0.30^{a}\pm0.01$	$0.22^{c}\pm0.10$
% Decrease	16.67%		43.33%		26.67%	

Values are mean ± SEM, n = 3 Values with different superscript along the row under the same heading are significantly different (P<0.05). Key: IU= Iman unprocessed, IF= Iman Fermented, IC= Iman Combined (sprouted-fermented)

Table 7: Antinutritional Contents of Unprocessed, Fermented, Sprouted and Combined (Sprouted-Fermented) LACRI WHIT 5 (g/100g)

	NU	NF	NU	NS	NU	NC
Phytic Acid	$20.25^{a}\pm0.17$	$14.37^{c}\pm0.11$	$20.25^{a}\pm0.01$	$16.56^{b}\pm0.15$	$20.25^{a}\pm0.01$	$9.68^{d}\pm0.92$
% Decrease	29.19%		18.22%		52.20%	
Tannin	$0.95^{a}\pm0.01$	$0.77^{b}\pm0.01$	0.95 ± 0.01^{a}	0.75 ± 0.01^{b}	0.95 ± 0.01^{a}	0.76 ± 0.03^{b}
% Decrease	18.95%		21.05%		20.00%	
Saponin	$0.39^{a}\pm0.01$	$0.31^{b}\pm0.01$	$0.39^{a}\pm0.01$	$0.32^{b}\pm0.00$	$0.39^{a}\pm0.01$	$0.32^{b}\pm0.01$
% Decrease	20.51%		17.95%		17.95%	

Values are mean ± SEM,
n = 3 Values with different superscript along the row under the same heading are significantly different (P<0.05)
Key: NU= Numan Unprocessed, NF= Numan Fermented, NC= Numan Combined (sprouted-fermented)

Table 8: Antinutritional Contents of Unprocessed, Fermented, Sprouted and Combined (Sprouted/ Fermented) LACRI WHIT 6 (g/100g)

S	R28U	R28F	R28U	R28S	R28U	R28C
Phytic Acid	$18.73^{a}\pm0.07$	$12.15^{b}\pm0.04$	$18.73^{a}\pm0.07$	$11.14^{c}\pm0.13$	$18.73^{a}\pm0.07$	$7.23^{d}\pm0.03$
% Decrease	35.13%		40.52%		61.45%	
Tannin	$0.77^{a}\pm0.01$	$0.67^{b}\pm0.03$	$0.77^{a}\pm0.01$	$0.63^{b}\pm0.05$	$0.77^{a}\pm0.01$	$0.65^{b}\pm0.11$
% Decrease	12.99%		18.18%		15.58%	
Saponin	$0.33^{a}\pm0.66$	$0.22^{b}\pm0.08$	$0.33^{a}\pm0.50$	$0.23^{b}\pm0.03$	$0.33^{a}\pm0.21$	$0.27^{b}\pm0.01$
% Decrease	33.33%		30.30%		18.18%	

Values are mean ± SEM. n = 3 Values with different superscript along the row under the same heading are significantly different ($P<0.05$). Key: R28U= Reyna 28 Unprocessed, R28F= Reyna 28 Fermented, R28C= Reyna 28 Combined (sprouted-fermented).

Mineral element compositions of unprocessed, fermented, sprouted and combined (sprouted-fermented) four different whole wheat flour varieties is depicted in tables 9, 10, 11 and 12 respectively. Within the four varieties, minerals of relatively low levels were zinc ($1.18^{d}\pm0.04$ - $1.72^{a}\pm0.01$) and manganese ($0.12^{c}\pm0.02$ - $0.28^{a}\pm0.01$). Minerals of average levels were magnesium ($3.15^{d}\pm0.03$ - $5.11^{a}\pm0.07$) and iron ($2.30^{d}\pm0.05$ - $3.71^{a}\pm0.31$). The highest concentrated three minerals were calcium ($34.01^{d}\pm0.03$ - $51.20^{a}\pm0.45$), sodium ($24.51^{d}\pm0.18$ - $38.17^{a}\pm0.55$) and potassium ($50.39^{d}\pm0.04$ - $63.17^{a}\pm0.36$). A general significant ($p<0.05$) increase was observed across the processed varieties when compared to the unprocessed in all the elements analyzed with the exception of manganese which showed no significant ($p>0.05$) difference. The highest increase recorded was in the fermented flours, followed by the sprouted flours and then sprouted-fermented.

Table 9: Mineral Elements Composition of Unprocessed Whole Wheat Flour Varieties (ppm)

	Ca	Na	Mg	K	Fe	Zn	Mn
BIOOU	$34.01^{d}\pm0.03$	$38.17^{a}\pm0.55$	$5.11^{a}\pm0.07$	$57.17^{b}\pm0.09$	$3.71^{a}\pm0.31$	$1.72^{a}\pm0.01$	$0.18^{b}\pm0.02$
IU	$51.20^{a}\pm0.45$	$34.50^{b}\pm0.23$	$4.98^{b}\pm0.05$	$52.26^{c}\pm0.41$	$2.30^{d}\pm0.05$	$1.46^{b}\pm0.02$	$0.28^{a}\pm0.01$
NU	$38.01^{b}\pm0.60$	$25.51^{c}\pm0.07$	$3.15^{d}\pm0.03$	$63.17^{a}\pm0.36$	$2.48^{c}\pm0.02$	$1.30^{c}\pm0.11$	$0.14^{c}\pm0.02$
R28U	$37.40^{c}\pm0.02$	$24.51^{d}\pm0.18$	$3.52^{c}\pm0.22$	$50.39^{d}\pm0.04$	$3.38^{b}\pm0.04$	$1.18^{d}\pm0.04$	$0.12^{c}\pm0.02$

Values are means ± SEM, n=3

Values with different superscripts along the column are significantly different at p (<0.05)

Key:

B100U= Borlaugh 100 Unprocessed
IU= Iman Unprocessed
NU= Numan Unprocessed
R28U= Reyna 28 Unprocessed

Table 10: Mineral Elements Composition of Fermented Whole Wheat Flour Varieties (ppm)

	Ca	Na	Mg	K	Fe	Zn	Mn
B100F	$61.90^{c}\pm0.22$	$45.52^{b}\pm0.30$	$6.18^{b}\pm0.07$	$60.27^{c}\pm0.04$	$5.45^{c}\pm0.05$	$1.95^{b}\pm0.20$	$0.25^{a}\pm0.03$
IF	$92.01^{b}\pm0.35$	$58.10^{c}\pm0.61$	$6.11^{c}\pm0.44$	$58.40^{b}\pm0.23$	$4.28^{a}\pm0.02$	$1.96^{d}\pm0.06$	$0.35^{a}\pm0.01$
NF	$53.51^{d}\pm0.06$	$33.15^{d}\pm0.02$	$5.41^{d}\pm0.02$	$70.10^{d}\pm0.05$	$4.87^{b}\pm0.30$	$1.50^{a}\pm0.11$	$0.17^{b}\pm0.05$
R28F	$96.60^{a}\pm0.57$	$27.50^{a}\pm0.04$	$5.24^{a}\pm0.63$	$56.41^{a}\pm0.08$	$4.31^{d}\pm0.04$	$1.67^{c}\pm0.24$	$0.15^{a}\pm0.02$

Values are means ± SEM, n=3

Values with different superscripts along the column are significantly different at p (<0.05)

Key:

B100F= Borlaugh 100 Fermented
IF= Iman Fermented
NF= Numan Fermented
R28F= Reyna 28 Fermented

Table 11: Mineral Elements Composition of Sprouted Whole Wheat Flour Varieties (ppm)

	Ca	Na	Mg	K	Fe	Zn	Mn
B100S	$40.30^{d}\pm0.09$	$39.49^{a}\pm0.82$	$11.08^{b}\pm0.50$	$70.31^{a}\pm0.04$	$4.31^{a}\pm0.63$	$2.84^{a}\pm0.04$	$0.21^{b}\pm0.21$
IS	$62.01^{b}\pm0.04$	$36.10^{c}\pm0.11$	$9.13^{c}\pm0.66$	$58.41^{d}\pm0.02$	$2.83^{c}\pm0.70$	$2.45^{b}\pm0.51$	$0.30^{a}\pm0.12$
NS	$46.70^{c}\pm0.73$	$34.18^{d}\pm0.09$	$9.11^{c}\pm0.32$	$69.16^{b}\pm0.25$	$2.54^{d}\pm0.02$	$1.81^{d}\pm0.43$	$0.17^{c}\pm0.41$
R28S	$73.60^{a}\pm0.28$	$38.10^{b}\pm0.06$	$14.05^{a}\pm0.05$	$62.64^{c}\pm0.22$	$3.41^{b}\pm0.08$	$2.40^{c}\pm0.20$	$0.19^{c}\pm0.05$

Values are means ± SEM, n=3
Values with different superscripts along the column are significantly different at p (<0.05)
Key:

B100S= Borlaugh 100 Sprouted
IS= Sprouted
NS= Numan Sprouted
R28S= Reyna 28 Sprouted

Table 12: Mineral Elements Composition of Combined (Sprouted-Fermented) Whole Wheat Flour Varieties (ppm)

	Ca	Na	Mg	K	Fe	Zn	Mn
B100C	$61.90^{a}\pm0.31$	$45.15^{b}\pm0.60$	$7.06^{b}\pm0.08$	$90.11^{a}\pm0.42$	$5.91^{a}\pm0.05$	$3.22^{a}\pm0.09$	$0.24^{b}\pm0.07$
IC	$57.80^{b}\pm0.24$	$46.28^{a}\pm0.04$	$7.18^{a}\pm0.22$	$77.13^{c}\pm0.03$	$5.29^{b}\pm0.08$	$2.86^{c}\pm0.27$	$0.37^{a}\pm0.33$
NC	$48.30^{c}\pm0.02$	$33.31^{d}\pm0.10$	$6.11^{c}\pm0.05$	$70.11^{d}\pm0.06$	$4.12^{d}\pm0.13$	$2.11^{d}\pm0.52$	$0.26^{b}\pm0.08$
R28C	$47.60^{d}\pm0.50$	$38.10^{c}\pm0.01$	$6.10^{c}\pm0.43$	$79.29^{b}\pm0.20$	$4.21^{c}\pm0.01$	$2.90^{b}\pm0.06$	$0.21^{b}\pm0.31$

Values are means ± SEM, n=3
Values with different superscripts along the column are significantly different at p (<0.05)
Key:

- **B100C= Borlaugh 100 Combined (Sprouted-Fermented)**
- **IC= Combined (Sprouted-Fermented)**
- **NC= Numan Combined (Sprouted-Fermented)**
- **R28C= Reyna 28 Combined (Sprouted-Fermented)**

Functional characteristics (water absorption capacity, bulk density, viscosity, foam capacity, swelling power and pH) of four processed and unprocessed varieties of whole wheat flour were presented in table 13. Viscosity, bulk density, foaming capacity and pH values decrease significantly ($p<0.05$) with processing, the highest reduction recorded was in the sprouted-fermented flours. The values for water absorption capacity and swelling power on the other hand, increase significantly ($p<0.05$) with processing and the sprouted-fermented flours observed the highest increase as well followed by fermented flours and then sprouted.

Table 13: Determination of Functional Parameters

	Viscosity (cp)	WAC (g/ml)	BD (g/ml)	FC (g/ml)	SP (g/ml)	pH
B100U	$345.54^{d}\pm0.64$	$2.33^{ij}\pm0.08$	$0.64^{ab}\pm0.69$	$3.50^{h}\pm0.11$	$2.56^{j}\pm0.04$	$5.50^{ab}\pm0.23$
B100F	$294.78^{gh}\pm0.85$	$2.80^{ef}\pm0.01$	$0.50^{b}\pm0.52$	$1.95^{o}\pm0.04$	$3.10^{g}\pm0.02$	$5.00^{de}\pm0.87$
B100S	$272.31^{j}\pm0.93$	$2.69^{fg}\pm0.64$	$0.36^{b}\pm0.25$	$2.15^{m}\pm0.07$	$2.98^{h}\pm1.01$	$5.20^{cd}\pm0.43$
B100C	$264.37^{k}\pm1.16$	$2.99^{cd}\pm0.05$	$0.21^{b}\pm0.32$	$2.05^{n}\pm0.03$	$3.25^{e}\pm0.04$	$4.90^{ef}\pm0.06$
IU	$367.56^{c}\pm1.18$	$2.33^{ij}\pm0.09$	$0.68^{ab}\pm0.71$	$4.50^{d}\pm0.46$	$2.33^{l}\pm0.02$	$5.60^{a}\pm0.02$
IF	$298.16^{g}\pm0.92$	$2.52^{gh}\pm0.02$	$0.49^{b}\pm0.60$	$3.60^{g}\pm0.07$	$3.46^{d}\pm0.33$	$4.50^{g}\pm0.02$
IS	$318.87^{e}\pm1.18$	$2.50^{hi}\pm0.70$	$0.45^{b}\pm0.09$	$4.20^{e}\pm0.61$	$2.65^{i}\pm0.03$	$5.30^{bc}\pm0.04$
IC	$276.56^{i}\pm1.43$	$3.17^{b}\pm0.06$	$0.37^{b}\pm0.75$	$3.25^{i}\pm1.01$	$3.62^{c}\pm0.01$	$4.77^{ef}\pm0.34$
NU	$372.86^{b}\pm1.76$	$2.18^{j}\pm0.45$	$0.86^{ab}\pm0.03$	$5.50^{b}\pm0.08$	$3.10^{g}\pm0.03$	$5.60^{a}\pm0.01$
NF	$367.77^{c}\pm0.64$	$2.87^{de}\pm0.05$	$0.70^{ab}\pm0.03$	$4.00^{f}\pm0.03$	$3.27^{e}\pm0.81$	$4.70^{fg}\pm0.06$
NS	$312.55^{f}\pm1.16$	$2.66^{fgh}\pm0.08$	$0.67^{ab}\pm0.05$	$4.55^{c}\pm0.36$	$2.55^{j}\pm0.02$	$5.00^{de}\pm0.01$
NC	$292.08^{h}\pm1.44$	$2.91^{de}\pm0.11$	$0.50^{b}\pm0.18$	$3.50^{h}\pm0.06$	$3.60^{c}\pm0.03$	$4.90^{ef}\pm0.24$
R28U	$382.90^{a}\pm0.61$	$2.53^{gh}\pm0.22$	$0.63^{ab}\pm0.07$	$5.80^{a}\pm0.42$	$2.47^{k}\pm0.02$	$5.70^{a}\pm0.08$
R28F	$296.84^{g}\pm0.91$	$3.25^{b}\pm0.86$	$0.42^{b}\pm0.07$	$2.60^{k}\pm0.25$	$3.68^{b}\pm0.08$	$4.90^{ef}\pm0.51$
R28S	$312.45^{f}\pm1.14$	$3.12^{bc}\pm0.04$	$1.60^{a}\pm1.19$	$2.95^{j}\pm0.48$	$3.15^{f}\pm0.02$	$5.20^{cd}\pm0.01$

R28C	$266.24^{k}\pm1.33$	$3.68^{a}\pm0.55$	$0.26^{b}\pm0.06$	$2.45^{l}\pm0.03$	$3.72^{a}\pm0.07$	$5.00^{de}\pm0.24$

Values are mean ± SEM, n = 3 Values with different superscript along the column under the same heading, are significantly different (P<0.05)
Key: WAC= Water Absorption Capacity, FC= Foaming Capacity, SP= Swelling Power, BD= Bulk Density.

DISCUSSION

Proximate Compositions

The moisture content of the four unprocessed whole wheat flour varieties reported in this study were within the 10% acceptable limit for long term storage of flour (Hagos, 2018). Moisture content of foods is influenced by type, variety and storage condition. The differences observed in crude protein, fibre, fat, carbohydrates and energy content within the varieties can be attributed to the geographical location of soil fertility (for example soils with low nitrogen levels can influence protein levels as reported by Blumenthal *et al.* (2008), and varietal differences. Diets with high fat contents contribute significantly to the energy requirement for humans. High fat flours are also good for flavor enhancers and useful in improving palatability of foods in which it is incorporated (Azeez *et al*., 2022).

The protein content of the fermented whole wheat flour varieties observed in this study increased significantly in B100F and IF and decreased in NF and R28F when compared to the unprocessed. The increase in protein may partly be due to degradation of complex protein by microorganism thereby releasing peptides and amino acids. Similar increase was observed by Chiemela *et al.* (2023), who reported an increase in protein content of bioprocessed (fermented) wheat flour from 13.37 to 16.39. However, it is reported that fermenting microorganisms degrade amino acids into carbon, nitrogen and energy which could possibly be the reason for the lower protein content observed in NF and R28F (Food Fermentation, 2020). This agrees with the findings of Laminu *et al*. (2014). However, a decrease in fat content observed in fermented B100 and R28 is in line with the report of Chiemela *et al*. (2024) where he reported a reduction in fat content of fermented whole wheat flour from 1.65-1.27%. This decrease may be related to the activity of microorganisms utilizing glycerol and reducing its availability for lipid metabolism. Another reason could be as a result of oxidation of fatty acid into energy and other compounds (Azeez *et al*., 2022). The sprouted whole wheat flours were lower compared to the unprocessed flour in terms of moisture contents. Reduction in the moisture content of the sprouted grains could help to decrease microbial activity and consequently increase the shelf stability of sprouted grains and their value-added products. Saima *et al*. (2024) reported a decrease in moisture contents of sprouted whole wheat after 72hr. The increase observed in ash, protein, and fibre contents within the sprouted flours when compared to the unprocessed were also reported by Jribi *et al*. (2019) and Dhillon *et al*. (2020). During sprouting, the phytate content and cell wall of the seed are broken down by enzymes, which results in the release of mineral content. Therefore, the increase in the ash content of sprouted wheat flour could be linked to the longer soaking time and release of bound inorganic residues (Lemmens, De Brier, *et al*., 2019). The increased in ash content could also be ascribed to the release of bound mineral elements after the degradation of antinutritional factors following germination or fermentation of the whole wheat grains (Chinma *et al*., 2022). This also agrees with the findings of Chiemela *et al*. (2024) who reported an increase in ash content of germinated whole wheat from 1.72 to 2.25.

The observed increase in the protein content of the sprouted varieties is in agreement with other scientific findings that processing techniques such as germination, improved the nutritional quality of the food products in terms of protein content (Verma *et al*., 2021). Similar work by Dhillon *et al.* (2020) reported that the protein content of WWF in the germinated flour increased from 12.18% to 13.30%. Protein has been reported to increase upon germination depending on type of grains/seed (Laxmi *et al*., 2015; Otutu *et al*., 2014). The increase in protein levels may result from a reduction in dry weight, as carbohydrates and fats are utilised during respiration, along with the synthesis of amino acids during germination (Jan *et al*., 2017; Ongol *et al*., 2013). However, protein losses during germination are also linked to degradation by proteases. Consequently, the actual protein content reflects the balance between synthesis and breakdown. Overall, it appears that net protein synthesis exceeds degradation due to the critical demand for nucleic acid production required for growth, leading to an overall increase in protein levels (Moongngarm and Saetung, 2010). Zhang *et al.* (2015) reported that after germination of buckwheat for 72 hr, protein content increased significantly probably due to higher rate of protein synthesis compared to proteolysis. The decrease in fat content observed in all the sprouted flours could be due to hydrolysis and utilization of fats as an energy source for biochemical reactions during germination. Other studies have reported that germination reduces the fat content (Jan *et al.,* 2017; Wanasundara, and Shahidi, 1999) (Chinma *et al*., 2009; Jan *et al*., 2017; Moongngarm and Saetung, 2010).Earlier studies by Dhillon *et al*. (2020) have reported a significant ($p < 0.05$) increase in the fibre content of sprouted wheat grains by 25%, which could be linked to the breakdown of β-glucans by endogenous β-glucanases during the sprouting process. In the sprouting process, enzymes break the cell wall of the seed resulting in the release of bound fibre and increased fibre content (Guzmán-Ortiz *et al.,* 2019). A previous study by Benitez *et al.* (2013) attributed the production of cellulosic glucose to an increase in the dietary fibre constituents after germination resulting from the hydrolysis of endosperm starch. Therefore, results of total fibre content observed in this study was in line with the finding of Subaşı and Ercan (2023) wherein they reported that whole wheat flour contained 15% total fiber content. Also, a study by Ding *et al*. (2018) showed linearity to our results for soluble fibers wherein the researchers reported a significant ($p < 0.05$) increase in soluble fibers from 1.9 to 2.2% on wheat grain germination for 24 h at 28°C. Moreover, during sprouting α-amylase and β-amylase are activated, these enzymes convert starch into simple sugar (maltose and glucose) which is utilized by seed for germination (Ikram *et al.,* 2021). Therefore, the reduction in the calculated carbohydrate content of sprouted wheat flour observed in this research was in conformity with the report of Emmanuel (2024) where a decrease from 61.9-60.1is observed in germinated wheat. The reason for the decrease could be attributed to the partial breakdown of starch in the grains.

In addition, during sprouting soluble carbohydrates leached down in water which may be another reason for carbohydrate reduction (Ikram *et al.,* 2021). The reduction could also be due to the utilization of fat and carbohydrate for biochemical activities of the germinating seeds (Dhillon *et al.,* 2020). The highest increase in protein value was recorded in sprouted-fermented (combined) whole wheat flour B100C (15.80 ± 0.01^{a}) when compared to the control. This could be attributed to degradation of antinutrients and the synthesis of enzymes during germination and fermentation of whole wheat, releasing bound proteins (Nkhata *et al*., 2018). Chiemela *et al*. (2024) also reported an increased in germinated-fermented whole wheat flour from 13.39-16.84%.The increased in fat content observed in the sprouted-fermented flour could be as a result of the fermenting microorganisms synthesizing lipids as byproducts of metabolism. It may also be related to the activity of lipase enzyme during fermentation, which breaks the triglycerides in the aleurone layer and releases free fatty acids, glycerol, and aldehydes (Dhillon *et al.* (2020); Benincasa *et al.*, 2019).

Mineral Elements Composition

Cereals and legumes are the major source of minerals in developing countries where they are widely consumed. Minerals from plant sources have very low bioavailability because they are found complexed with non-digestible materials such as cell wall polysaccharides (Emmanuel, 2024) as well as phytate. The complex matrices in which these minerals are entrapped and bonded are largely responsible for their low bioavailability.

The reduction in anti-nutritional factors following sprouting, fermentation, and combined sprouting and fermentation of whole wheat grains may be the reasons for the increase in mineral content of the bioprocessed flours compared to the unprocessed. Most of the antinutrients (phytic acids, tannins, oxalates, etc) are bound by forming a complex with the minerals in grains (Sharma *et al*., 2023). Fermentation and germination breakdown the complexes, thereby releasing the minerals (Arbab *et al*., 2023). Azeez *et al*. (2022) and Chiemela *et al*. (2024) also reported an increase in minerals of bioprocessed (germinated, fermented, and germinated-fermented) finger millet flour and bioprocessed whole wheat flour respectively. The increase in mineral content may also be attributed to a reduction in dry matter during fermentation, as microbes break down carbohydrates and proteins (Day and Morawicki, 2018), as documented in the literature. Higher mineral content of the processed wheat flours would be beneficial for maintaining and promoting physical well-being as a functional flour when used in food formulation (Chiemela *et al*., 2024).

Antinutritional Contents

Phytic acid in grains represents a serious problem in human diets. It blocks the absorption of not only phosphorous but also other minerals such as calcium, magnesium, iron and zinc. It also negatively affects the absorption of proteins and lipids because by inhibiting the activities of the digestive enzymes like pepsin, amylases and trypsin (Abdoulaye *et al*., 2011). Therefore, the reduction in phytic acid contents during fermentation, sprouting and combined sprouting-fermentation processes may be attributed to the increase in hydrolytic activity of the phytase enzyme converting phosphorus phytate into inositol monophosphate (Ohanenye *et al.,* 2021; Kumari *et al*., 2023). Also, the reduction during fermentation has been previously ascribed to the activities of microbial enzymes that caused the reduction in phytic acid content (Sharma *et al*., 2023). The reduction in tannin contents during germination could be attributed to the use of tannin compounds as precursors or intermediates in the biosynthesis of different flavan-3-ols and phenolic acids via the shikimate pathway (Bhinder *et al*., 2021). Reduction in tannin content during fermentation has previously been attributed to the increased activity of polyphenol oxidase and other catabolic enzymes (Ram *et al*., 2020). Generally, it was observed in this study that a combination of sprouting and fermentation facilitated more reduction in antinutrients in whole wheat flours than a single processing method, thus in agreement with a previous report on bioprocessing of finger millet grains by Azeez *et al*. (2022) and bioprocessed whole wheat flour by Chiemela *et al*. (2024).

Functional Properties

According to Dehnad *et al.* (2016), functional properties contribute to the overall behavior of foods during processing, storage, and consumption of food product. The changes recorded in the functional properties of the processed whole wheat flours could suggest the potential of these bioprocessing methods as a natural means of modification of their functional properties, which could be explored in food formulation.

pH

The pH of the processed whole wheat flours was observed to be lower than the unprocessed whole wheat flour. pH reduced due to secretion of enzymes which results in hydrolysis of complex molecules into simpler acidic compounds (Adedeji *et al.,* 2014).

Water Absorption Capacity (WAC)

Water absorption capacity is an indication of the maximum amount of water that a food product would absorb and hold. The WAC observed in this study is within the lower acceptable range of flours approved by USDA (2020). The increase in water absorption capacity after processing could be attributed to the higher protein content, as hydrophilic proteins can readily absorb water molecules. Additionally, the breakdown of starch contributes to improved flour hydration (Elkhalifa and Bernhardt, 2010). Similar findings were reported by Hussain and Uddin (2012), who observed a rise in water absorption capacity in wheat flour germinated for varying durations at different temperatures, ranging from 2.0 to 2.4 g/g. Research has also indicated that food products with lower water absorption capacity tend to exhibit reduced microbial activity. Hence the shelf-life of sprouted and fermented flour could be extended by product development. The increased WAC may be attributed to modification of macro-constituents, such as breakdown of polysaccharide molecules during germination or fermentation to produce maltose and glucose, which are simple sugars (Xu *et al.,* 2019)

Bulk Density

The bulk density of the sprouted wheat flour sample in this study was lower than the value (0.71 g/ml) reported by Akubor and Badifu (2004) for wheat flour. Bulk density plays a significant role in packaging, with lower values facilitating better digestibility of food products, especially for children with underdeveloped digestive systems (Gopaldas and John, 1992). The reduction in bulk density in bioprocessed flours can be attributed to the breakdown of complex carbohydrates, such as polysaccharides and oligosaccharides, into simpler sugars (monosaccharides) during germination or fermentation. Nutritionally, a lower bulk density supports easier digestion, particularly for young children (Gopaldas and John, 1991). Additionally, bulk density is crucial for efficient packaging, transportation, and mixing of flours. High bulk density flours are employed as thickeners in food products [Akubor and Badifu,2004] while low bulk density flours can find use in baby food formulations where high nutrient density to bulk is required (Mepba *et al*., 2007). Therefore, the combined sprouted-fermented whole wheat flours in this study with low bulk densities will be useful for infant food products.

Foam Capacity

The decreased FC have previously been attributed to decreased amphiphilic properties of protein molecules after hydrolysis, resulting in a decrease in their capacity for adsorbing and forming stable protein films around the bubble (Du *et al.,* 2014).

CONCLUSION

This study affirmed that processing of whole wheat represent valuable strategies for modifying the physicochemical and functional properties of whole wheat flour. Processed whole wheat flour had better nutritional parameters like protein, fiber, mineral elements and desirable functional properties that could be used in food products formulation.

RECOMMENDATION

It is recommended that studies on the stability of the fermented singly, sprouted singly and combined sprouted-fermented whole wheat flour be carried out. Also, the effects of these processing methods on antioxidants and the phenolic contents needs to be investigated.

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