

Full Length Research Paper

Sorghum and lentil-enriched wheat bread for enhancing nutrition and agricultural resilience in Kenya

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This study examines the nutritional quality and structural properties of bread made by partially substituting wheat flour with sorghum and lentil flour. While bread is a popular staple, wheat has high gluten, low nutrients, and low amylose to amylopectin ratio which can contribute to the prevalence of lifestyle diseases. Sorghum and lentil flour are promising due to their high antioxidants, micronutrients, and high amylose to amylopectin content. 8 loaves of bread with different wheat, sorghum, and lentil proportions were analyzed, and compared to control brands of bread from Kenyan supermarkets. Proximate analysis (protein, moisture, fiber, fat, ash, carbohydrates) and structural assessments (slice area, crumb sizes, amount of crumbling, pore size, and pore count) were conducted using standard methods and ImageJ, respectively. Statistical analyses were done using ANOVA and Tukey HSD tests. Composite bread with 7.5% sorghum and 6% lentil flours exhibited desirable nutritional quality and structural stability. Sorghum and lentils increased ($p < 0.05$) protein, moisture, and fiber content, and improved the structural integrity of the test bread compared to the control. This suggests sorghum-lentil-wheat bread could reduce lifestyle disease risks and promote climate-resilient agriculture. Further research should explore cereal-legume flour composite for baked food products and determine consumer preference.

Key words: Sorghum, lentil, wheat, bread, nutrition.

INTRODUCTION

As far back as four thousand years ago, people worldwide began to rely upon bread as a staple food. According to Dewettinck et al. (2008), bread can benefit the human diet as a source of carbohydrates and various nutrients, although some pieces of bread are healthier than others. They claimed that an ideal bread for healthy

diets should have low glycemic properties and provide dietary fiber, vitamins, magnesium, trace elements, and antioxidants. Foods that have high glycemic properties, due to starch content, increase blood glucose levels, contributing to increased risks of diabetes (Dewettinck et al., 2008). High fiber intake can reduce the risk of type 2

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Table 1. Proximate composition of wheat flour.

Nutrient	Percentage
Moisture	12.49 ± 0.03
Protein	11.27 ± 0.04
Fat	1.51 ± 0.03
Ash	0.69 ± 0.02
Carbohydrate	73.59 ± 0.10
Fiber	0.45 ± 0.02

Results are expressed as mean ± S.D, n=3

Source: Comparison of the nutritional profile of barley flour and refined wheat flour by Dobhal and Awasthi (2021).

Table 2. Starch compositions (%)

Flour type	Amylose	Amylopectin
Lentil	32.52	67.48
Sorghum	15.17-33.37	66.63-84.83
Wheat	10.23	89.77

The lentil ratio was determined using Joshi et al. (2015). The sorghum ratio was determined using Njuguna (2018). The wheat ratio was determined using Jamhari et al. (2019).

diabetes as well as the risk of cardiovascular disease, stroke, colorectal cancer, rectal cancer, and all-cause mortality (Gill et al., 2020). Antioxidants can protect against health issues such as premature aging, cancers, cardiovascular diseases, cataracts, and Alzheimer's disease (Rahaman et al., 2023). The United States Food and Drug Administration's (US FDA) daily reference values (DRVs) for macronutrient uptake by adults and children above four years of age should also be considered when making food. These DRVs include 275 g of carbohydrates, 28 g of fiber, 78 g of fat, and 50 g of protein (FDA, 2016a). Additionally, micronutrients must be considered. Common micronutrient deficiencies for Kenyans are vitamin A, iodine, folate, vitamin B12, and zinc (Wakoli et al., 2023). The US FDA's reference daily intakes (RDIs) suggest adults and children above four years of age should consume 1300 mg of iron, 900 µg of vitamin A, 150 µg of iodine, 400 µg of folate, 2.4 µg of vitamin B12, and 11 mg of zinc per day (FDA, 2016b). Overall, bread made with nutrient content in mind can help improve health and reduce risks for lifestyle diseases in Kenya.

Wheat (*Triticum aestivum*) is commonly used to make bread due to its popularity as a cereal crop and ideal bread-making properties. The downfalls of wheat are that it has low protein content (Table 1), high gluten content, and a high glycemic response in consumers due to low amylose to amylopectin ratio (Table 2) (Jamhari et al., 2019; Dobhal and Awasthi, 2021). This suggests that other cereals may be better for bread production, provided nutrition can be optimized. Instead of completely switching to another flour, adding different grains and

vegetables to wheat bread can increase the diversity of nutrients, fermentable soluble fibers, and overall health aspects of bread while retaining some of the ideal characteristics of wheat flour (Dewettinck et al., 2008).

The nutritional content of wheat-based bread can be improved by some possibly ideal additives that are becoming increasingly popular such as sorghum flour (*Sorghum bicolor* L.) and lentil flour (*Lens culinaris* Medik.). Sorghum flour is known to lack gluten, appealing to people with celiac disease and gluten intolerance (Ari Akin et al., 2022). Sorghum also contains high amylose relative to amylopectin (Table 2), which can help regulate the blood sugar level by slowing down starch digestion, thereby reducing risks for obesity, cardiovascular disease, and diabetes (Taylor and Duodu, 2022). Sorghum is also a good source of phenolics, resistant starch, phosphorus, zinc, iron, calcium, magnesium, potassium, sodium, vitamin B, vitamin E, and β-carotene (Ari Akin et al., 2022). Legumes, such as lentils, can significantly increase protein in bread. Lentils are also a good source of essential amino acids, and dietary fiber (Bayomy and Alamri, 2022). Another benefit of adding legumes is that they contain high amounts of phytochemicals and antioxidants (Dhull et al., 2023). In addition, lentils can also reduce blood glucose levels and insulin responses due to their beta-glucans, appealing especially to diabetic people (Tomar et al., 2024). Legumes also have high levels of fiber, which can lower cholesterol and blood pressure (Dhull et al., 2023).

The climate crisis is impacting agricultural productivity globally, causing increased climate volatility. This climate volatility contributes to decreases in arable land and water resources, and increased occurrences of floods, droughts, and temperatures (Mutiso and Kimtai, 2022). Sorghum is among a few crops adaptable to declining soil moisture deficit occasioned by reduced and irregular rainfall, frequent droughts, and high temperatures. Sorghum can also survive in high-salinity soils (Hossain et al., 2022). Due to its high tolerance and adaptation to abiotic stresses, sorghum is an ideal crop for improving food security through climate-resilient agriculture.

Supplementing wheat-based bread with sorghum and lentil flour may reduce risks of lifestyle diseases if the resultant bread contains sufficient nutrients. Additionally, if demand can be established for sorghum and lentil-enriched loaves of bread, then farmers will be incentivized to grow more sorghum and lentil, thus enhancing climate resilience in agriculture and improving food security. The current study was conducted to determine optimal ratios of sorghum, lentil, and wheat flour in producing marketable bread, and subsequently analyzing its nutritional contribution.

MATERIALS AND METHODS

Experimental design

The study employed eight different test mixtures of lentil flour,

Table 3. Bread treatments with their composite flour ratios.

Bread	Wheat (%)	Sorghum (%)	Lentil (%)
1	100	0	0
2	94	0	6
3	88	0	12
4	82	0	18
5	92	8	0
6	86.48	7.52	6
7	80.96	7.04	12
8	75.44	6.56	18

Each bread indicates a treatment group. For bread 1, 2, 3, and 4, the wheat to sorghum ratio was 100:0. For bread 5, 6, 7, and 8, the sorghum to wheat ratio was 92:8.

sorghum flour, and wheat flour. The eight treatments were laid out in a randomized complete block design (RCBD). The experimental treatments are shown in Table 3.

Bread formulation

The bread loaves were baked using the American Association of Cereal Chemists 10-10B method. 100.0 g of the flour mixtures, 1.5 g of salt, 6.0 g of sucrose, and 3.0 g of shortening, were added to 2 g of yeast suspended in the optimal amount of water. Water quantities were estimated by using the following equation: water absorption (%) = 1.5 (% protein) + 43.6 (Guan et al., 2009). Once mixed into dough, the loaves were placed in an aluminum pan and proofed for 1.5 h, uncovered. The loaves were then baked at conventional baking conditions, baking at 200°C for approximately 45 min as per the recommendations of Purna et al. (2011) and Akerberg et al. (2002).

After being removed from the oven, the loaves were removed from the pans and stored at room temperature for 24 h, then each loaf was sliced into approximately 1.0 cm thick slices. The loaves were then bagged in zip-lock bags and stored at room temperature. The slices from the middle were analyzed for proximate composition, starch composition, and sensory characteristics (Garimella Purna et al., 2011). These breads were also compared to three control bread brands from Kenyan supermarkets. These control groups consisted of two white wheat breads (Bread A and Bread B) and one sorghum-wheat bread (Bread C).

Proximate analysis

Three samples from each of the structurally stable loaves were analyzed for crude protein, moisture content, crude fiber, ash content, crude fat, and carbohydrate content.

Crude protein

The nitrogen conversion method was used to determine the crude protein content. The nitrogen content of the samples was determined via the Kjeldahl method (AACC 2010, 46–11), and the results used to calculate crude protein content as follows:

$$\%N = \text{NH}_4\text{Cl} \times (\text{Corrected acid volume/g of sample}) \times (14 \text{ g N/mole}) \times 100$$

where N=normality of HCl, in moles/1000 ml, corrected acid vol.= (ml std. acid for sample) - (ml std. acid for blank), 14=atomic weight

of nitrogen. The percentage protein is then determined using the formula: % PROTEIN = % N × 6.25 (nitrogen conversion factor for other legumes).

Moisture content

Moisture content was determined using the draft oven method (AOAC 2000, 934.01). Percentage moisture content was calculated using the formula:

$$\text{Percentage Moisture} = (\text{Weight of H}_2\text{O in Sample}) / (\text{Weight of wet sample}) \times 100$$

Crude fiber

Crude fiber content was determined according to AOAC (2000) method 978.10 and the percentage of a crude fiber expressed thus:

$$\text{Percentage of crude fiber} = ((W_1 - W_2)) / W \times 100$$

where W=initial weight of the sample, W₁=weight of the digested sample, and W₂=weight of ashed sample.

Ash content

Ash content was determined according to the AACC (2010) method 08-01. Percentage ash was determined thus:

$$\text{Percentage ash} = (\text{Weight after ashing} - \text{tare weight of crucible}) / (\text{Wt. of dry sample} - \text{tare crucible wt}) \times 100$$

Crude fat

The crude fat content was determined according to AOAC (2000) method 920.38, and the percent fat was determined thus:

$$\text{Percentage fat} = (\text{Wt. of extracted fat}) / (\text{Wt. of dried sample}) \times 100$$

Carbohydrate content determination

Carbohydrate content was determined mathematically by using the formula:

$$\text{Percentage carbs} = 100 - (\% \text{ moisture} + \% \text{ protein} + \% \text{ fat} + \% \text{ fiber} + \% \text{ ash})$$

Table 4. Nutritional and physical characteristics of test breads and commercial brands.

Bread	Moisture (%)	Protein (%)	Ash (%)	Fat (%)	Fiber (%)	Carbohydrate content	Slice area (cm ²)	Slice pore count	Pore area	Pore average size	Slice crumb count	Slice crumb average size
1	41.5	8.969	1.50	13.00	0.229	34.802	65.948	6028.00	91.405	0.00325	283.25	0.0035
5	44.7	18.156	1.83	14.50	0.729	20.085	50.068	3414.25	68.192	0.00525	201.5	0.00325
6	44.0	17.719	1.83	7.00	1.069	28.382	55.261	5043.25	91.263	0.0035	463.75	0.0045
7	43.2	17.719	0.67	7.25	0.374	30.787	56.307	5211.00	92.5466	0.00425	424.8	0.00425
8	44.3	20.125	1.50	6.75	0.837	26.488	57.697	5986.00	103.749	0.0035	410.75	0.00525
A	45.0	14.875	1.00	13.80	0.538	24.787	82.814	10103.00	121.996	0.0035	NC	0.0035
B	46.0	11.156	1.67	6.30	1.248	33.626	81.927	6364.50	77.685	0.0075	NC	0.0035
C	37.8	10.938	1.17	7.50	0.585	42.008	89.680	10240.50	114.190	0.003	NC	0.002

“NC” stands for “Not Comparable.”

Structural analysis

Crumbling, porosity, and slice area

Four slices of each bread were placed on a black surface with a ruler and were photographed. The surface was then wiped clean after the slices were removed. Then, one slice at a time, they were dropped from approximately 30 cm high, and photographs of the crumbs were taken after every drop. The crumbs were wiped away between each drop. All the images were then analyzed using *ImageJ*, the image processing and analysis software. The photographs were used to count and measure slice pores and crumbs as well as the sliced face area.

Data analysis

Using R version 4.3.2, ANOVA paired with Tukey HSD post-hoc tests were used to evaluate statistically significant differences. Significance was determined at a 95% confidence level ($p < 0.05$).

RESULTS AND DISCUSSION

Test breads two, three, and four existed only during pre-trials to determine the structural integrity of bread containing wheat, sorghum, and

lentils versus bread that only contained lentils and wheat (Table 3). The three trial groups were eliminated after it was determined that there was no significant difference in structure when combining both sorghum and lentil flour with the wheat-based bread. The moisture content of all the bread samples remained consistent, except for Bread 1 and Bread C. Specifically, the moisture content of Bread 1 was significantly lower than that of Bread B, and the moisture content of Bread C was significantly lower than that of all the other bread groups ($p < 0.05$) (Table 4 and Figure 1). The relatively lower moisture contents of Breads 1 and C can be partially attributed to their low fiber content as compared to the other breads hence trapping less moisture observed (Table 4). This observation is in tandem with findings by Carocho et al. (2020) and Rahman et al. (2021). The range of ash contents for Bread 6 reached higher values than the other breads, however, there were no significant differences ($p < 0.05$) (Table 4 and Figure 2). Bread 6, 7, 8, B, and C had the least fat on average, however, there were no statistically significant differences (Table 4 and Figure 3). Bread 1 had significantly lower fiber contents than Bread 5, 6,

8, A, B, and C ($p < 0.05$). Bread 6 had higher fiber contents than Bread 1, 5, 7, A, and C ($p < 0.05$) while Bread 7 had significantly lower fiber contents than 5, 6, 8, and B ($p < 0.05$). Bread B had higher fiber contents than Bread 1, 5, 7, 8, A, and C ($p < 0.05$) (Table 4 and Figure 4). The addition of 18% lentil flour in Bread 8 increased protein content, with significantly more protein than in Breads 1, B, and C ($p < 0.05$) (Table 4 and Figure 5). Bread C had significantly more crumbs than all of the other bread groups and Bread 5 had significantly less than only Bread B (Table 4 and Figure 6). The increased crumb count in Bread C shows increased instability and a sandy texture resulting from the lower gluten content (Mosca et al., 2022). Mosca et al. (2022) also found this crumbling texture to be unappealing for consumers. The pore count to surface area ratio was highest in Breads 8, A, and C and was lowest in Breads 5 and B (Table 4 and Figure 7). Bread C and 5 had much smaller crumbs on average, suggesting a decrease in cohesion in bread by high concentrations of sorghum and lower concentrations of wheat flour (Table 4 and Figure 8). There were no statistically significant differences in crumb size ($p < 0.05$). Bread 5 had the lowest carbohydrate content while

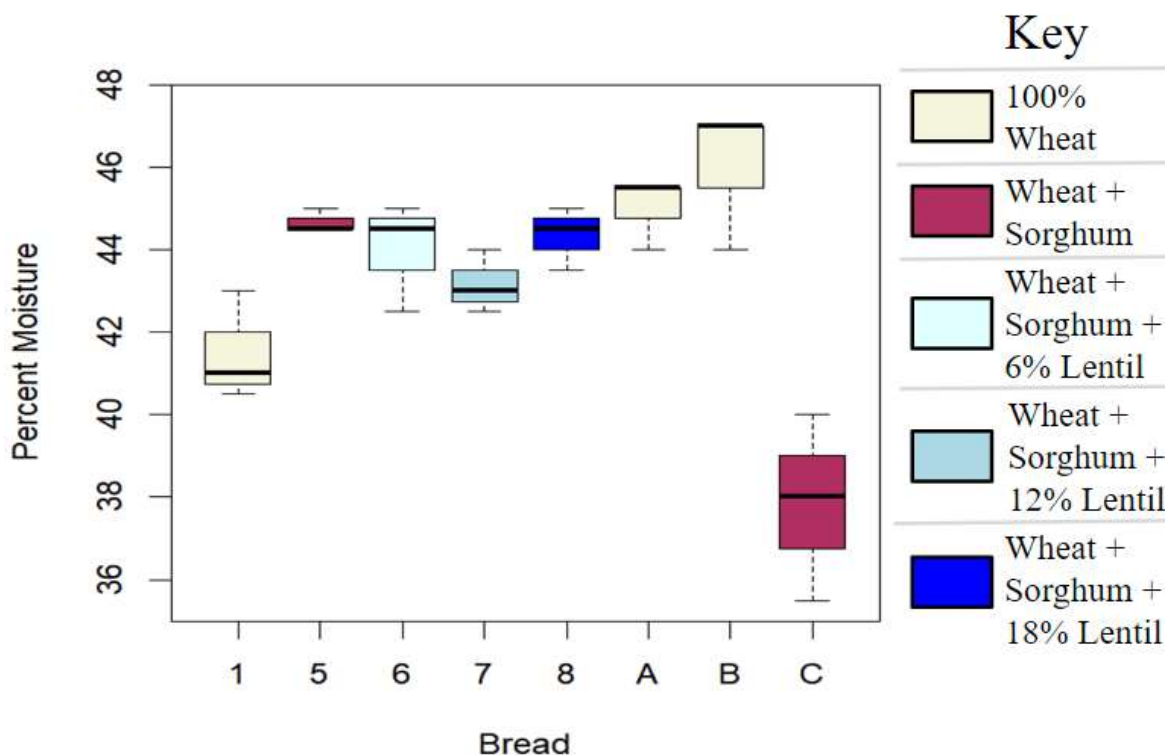


Figure 1. Percentage moisture content in the breads. Breads A, B, and C are market-purchased bread, and breads 1-6 are freshly baked breads.

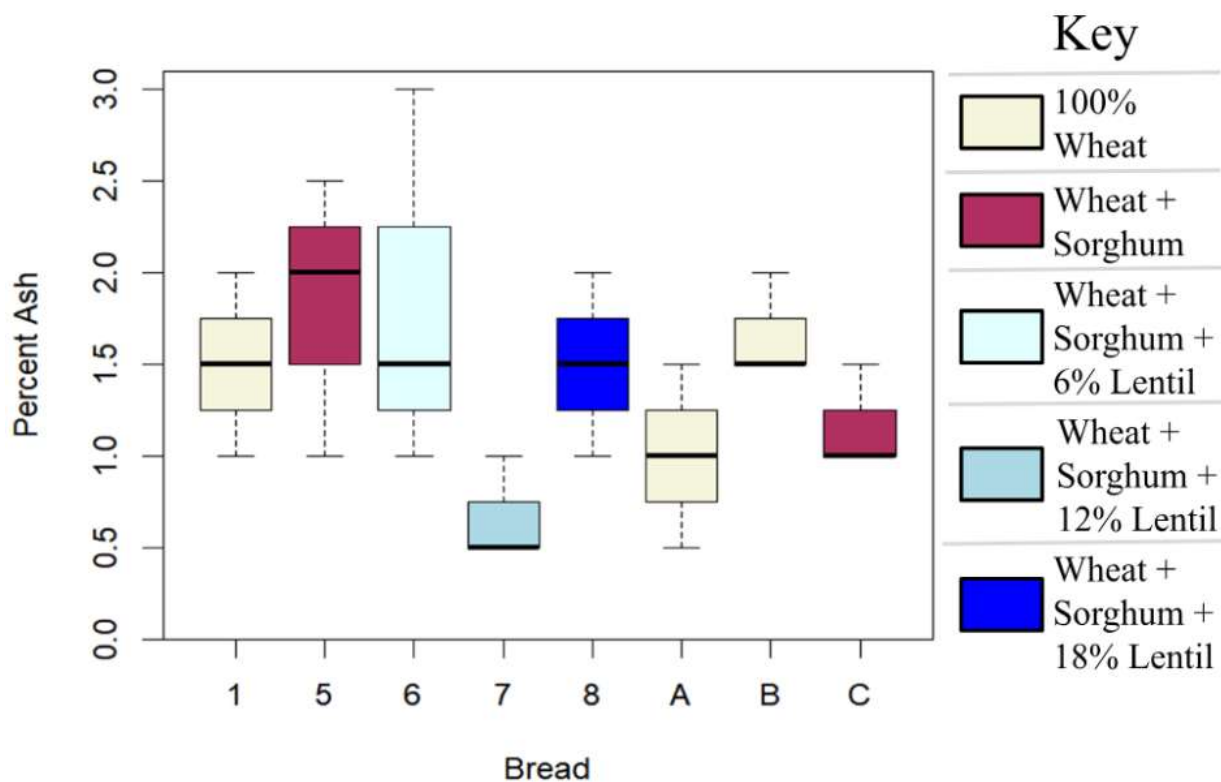


Figure 2. Percentage ash content in the bread. Breads A, B, and C are market-purchased bread, and breads 1-6 are freshly baked breads.

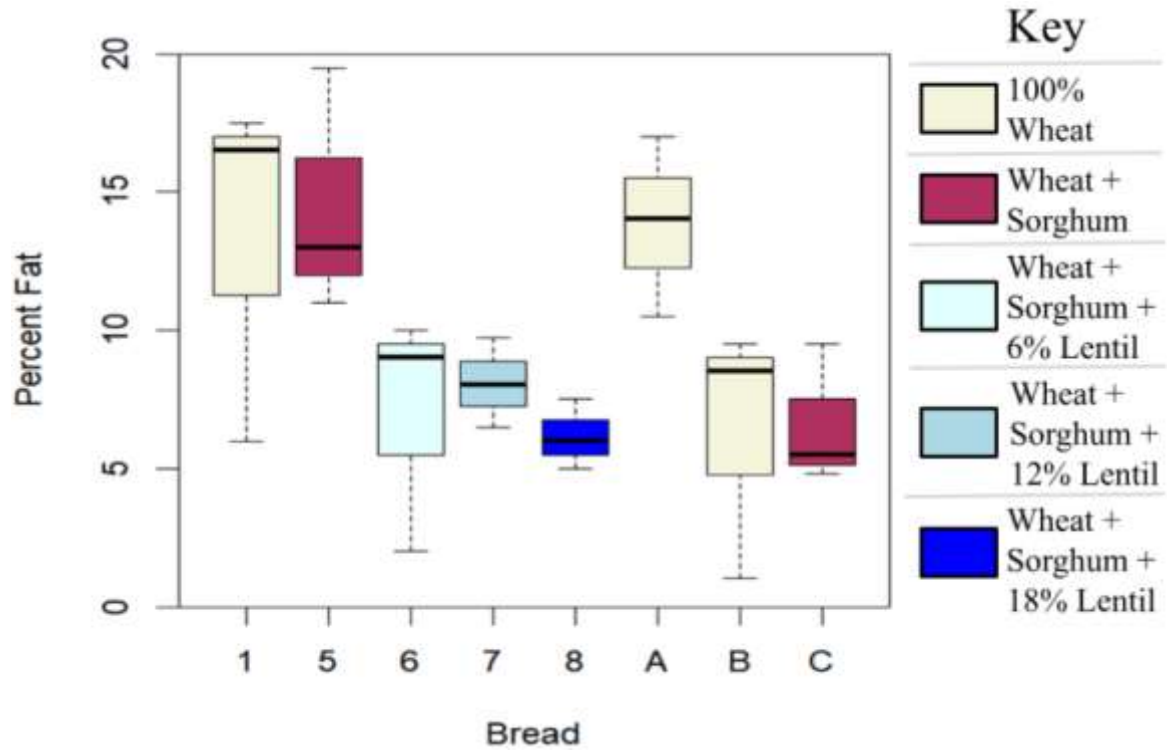


Figure 3. Percentage of crude fat in the bread. Breads A, B, and C are market-purchased bread, and breads 1-6 are freshly baked breads.

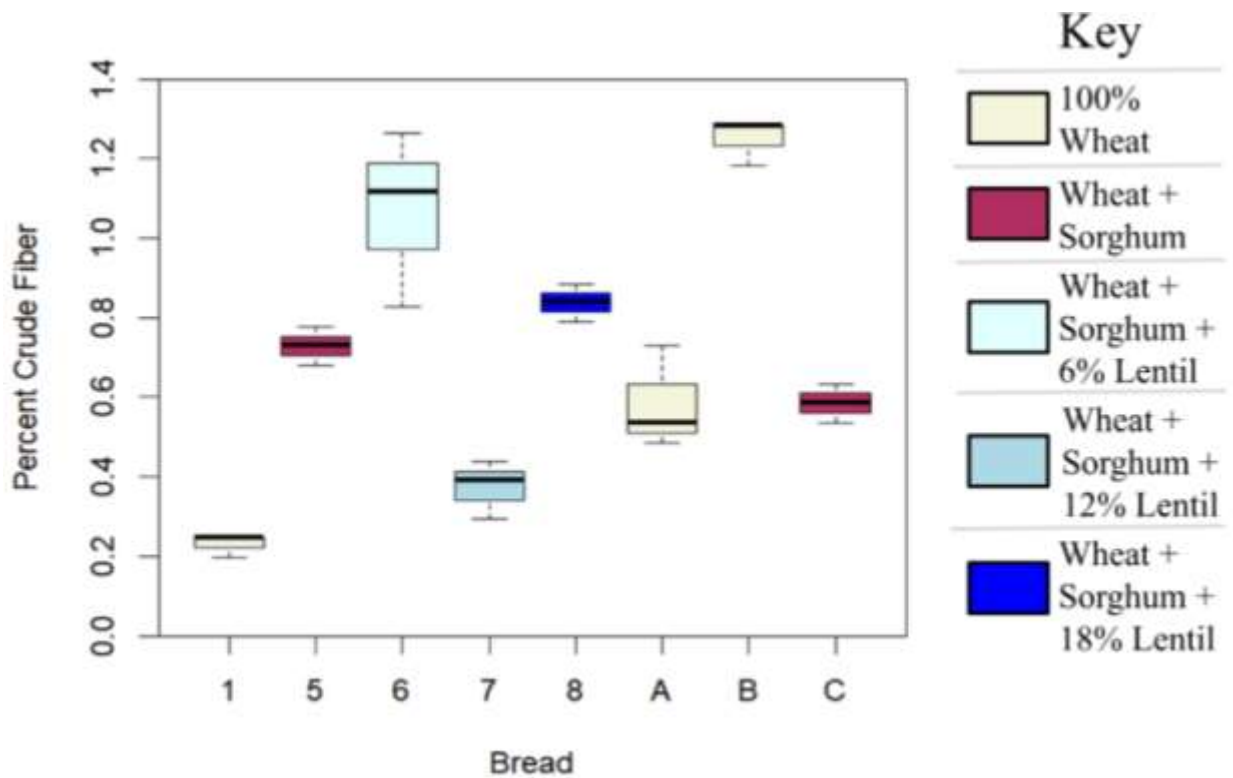


Figure 4. Percentage of crude fiber in the bread. Breads A, B, and C are market-purchased bread, and breads 1-6 are freshly baked breads.

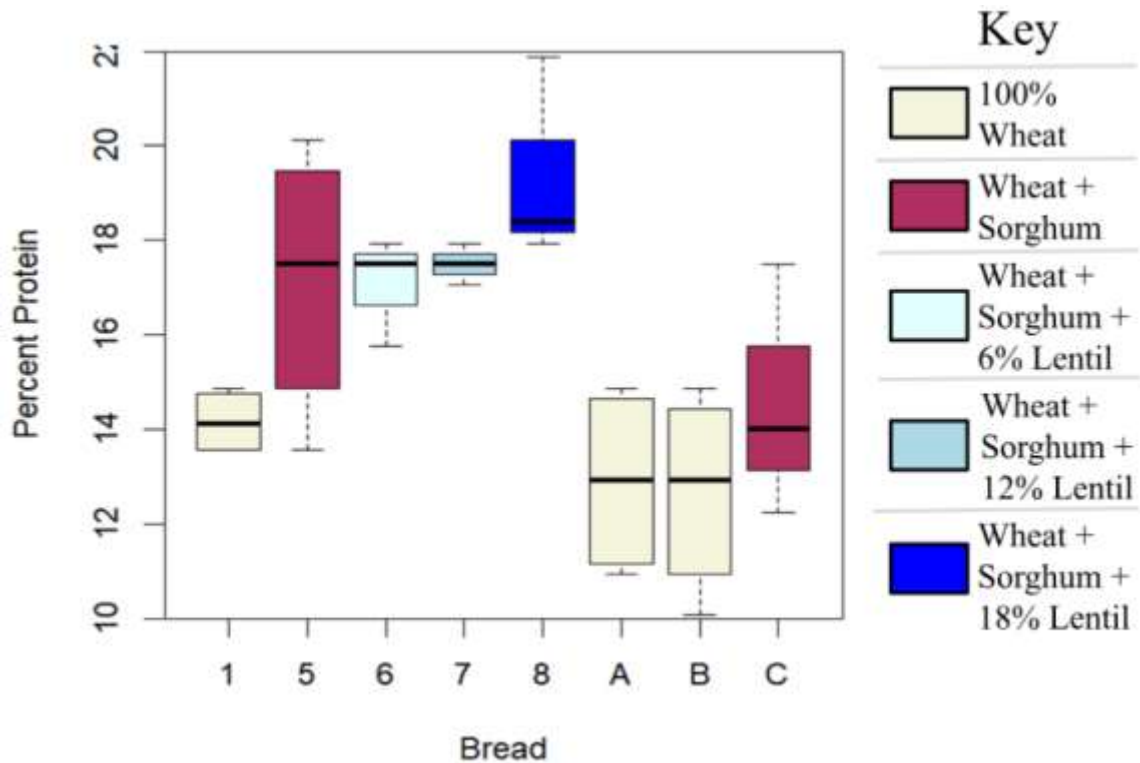


Figure 5. Percentage of crude protein content in the breads. Breads A, B, and C are market-purchased bread, and breads 1-6 are freshly baked breads.

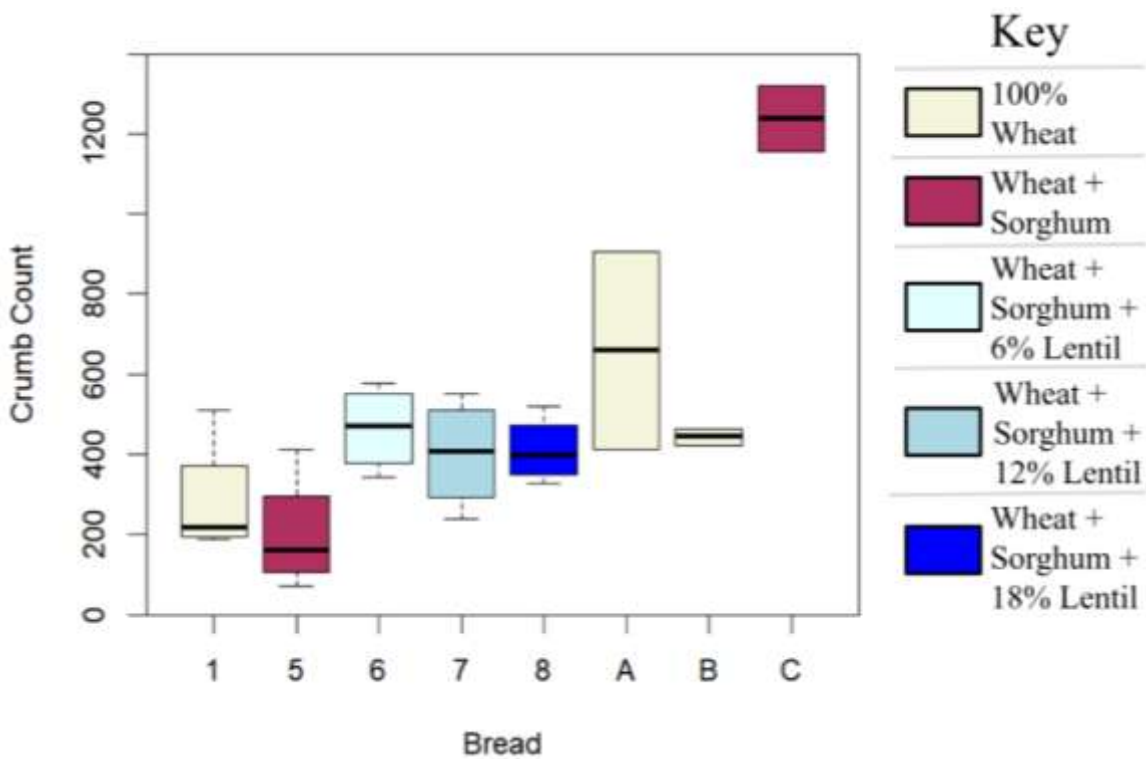


Figure 6. Average crumbs dropped from slices of bread. Breads A, B, and C are market-purchased bread, and breads 1-6 are freshly baked breads.

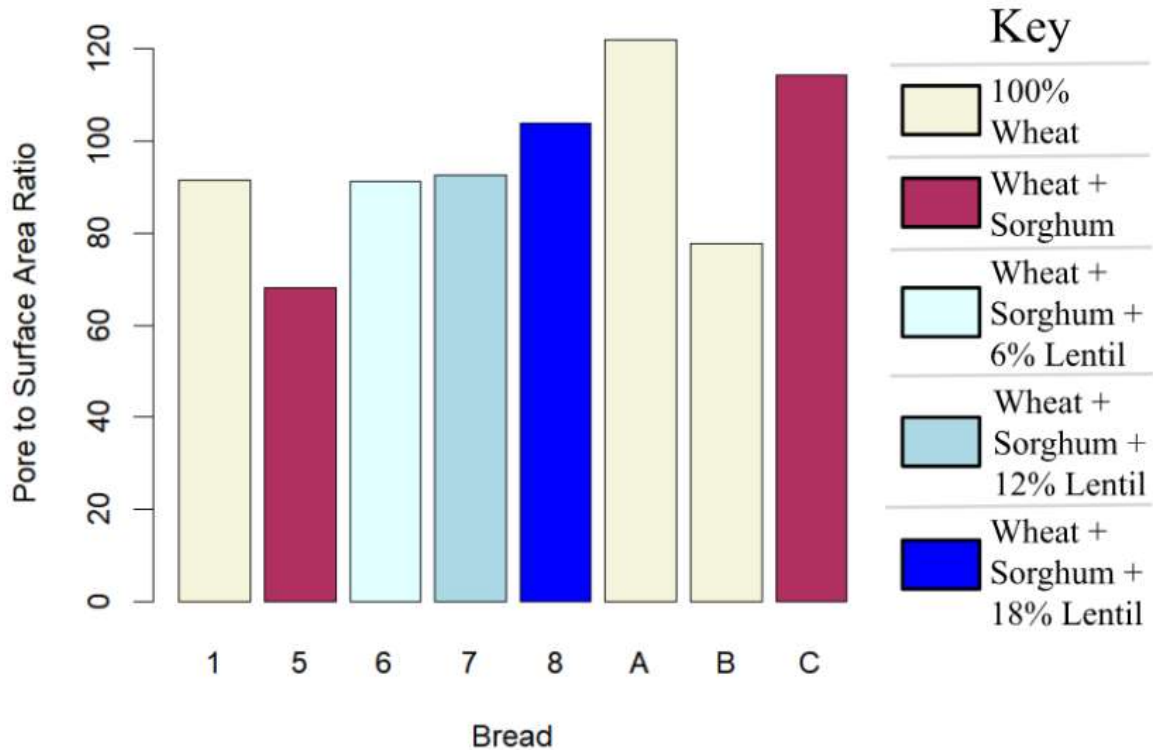


Figure 7. The pore counts to surface area ratio in breads. Breads A, B, and C are market-purchased bread, and breads 1-6 are freshly baked breads.

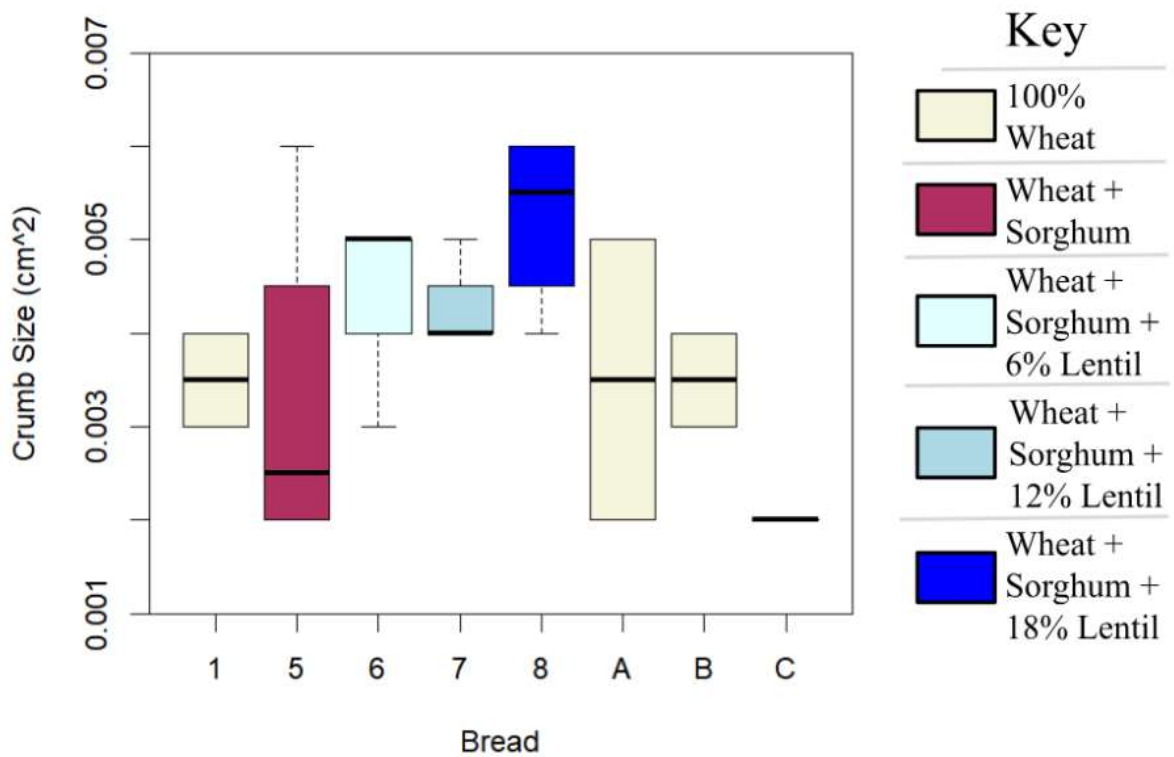


Figure 8. The average crumb size of bread. Breads A, B, and C are market-purchased bread, and breads 1-6 are freshly baked breads.

Bread C had the highest (Table 4).

The results from these experiments indicate that the bread recipe containing sorghum flour at 7.52% sorghum, lentil flour at 6%, and bread flour at 86.48% can best improve the nutritional quality of bread, resulting in bread with higher protein and fiber and similar structural properties compared to wheat bread. The new product reduces the amount of wheat flour by approximately 14%. It is necessary to compare the ratios of amylose to amylopectin in the bread products. Additional work is also needed to identify specific genotypes of both sorghum and lentil that will give adequate baked bread with desired optimum results. In the previous work, it was noted that not any sorghum could be used to bake bread. In an evaluation of over 130 sorghum genotypes, only 5 were identified as suitable for making the wheat-sorghum composite bread. It is also possible that with the different lentil genotypes, not all can give similar results. The incorporation of nutrient-packed cereals in baked food products as suggested in this article could lead to nutritional security while addressing climate change resilience with climate-smart crops.

CONCLUSION AND RECOMMENDATIONS

Partial substitution of wheat flour with approximately 7.5% sorghum flour and 6% lentil flour produces bread suitable for consumer markets with superior nutritional quality and structural stability. This study also established that the sorghum quantity in the current commercial Kenyan sorghum-wheat bread is slightly high, reducing moisture and structural stability. Similar experiments should be conducted with other types of lentils (green) and legumes. Sensory testing of the suggested bread formulation should be conducted to evaluate consumer acceptance and to obtain input for improvements. Further analysis should be done to conclusively determine amylose and amylopectin content in the test loaves of bread.

CONFLICT OF INTERESTS

The authors have not declared any conflicts of interests.

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