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ORIGINAL RESEARCH ARTICLE

Effects of Sprouting Duration on the Physicochemical, Nutritional, Functional, and Pasting Properties of Obatanpa and Honampa Maize Flours

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ABSTRACT

Maize is an important staple crop with potential to contribute to improved nutrition. This study evaluated the effects of sprouting duration on the physicochemical, nutritional, functional, and pasting properties of Obatanpa and Honampa maize flours. With prolonged sprouting, titratable acidity (0.81–3.81%), total soluble solids (0.53–1.28 °Brix), and redness (0.62–2.48) increased, whereas pH (7.20–6.11), lightness (16.53–7.40), and yellowness (13.90–6.27) decreased in both varieties. Color difference ranged from 0.00 to 6.42, whiteness index from 6.03 to 15.01, hue angle from 0.26 to 1.51, saturation index from 6.52 to 13.98, and browning index from 82.39 to 165.72. Sprouting reduced fat (9.70–1.46%), fiber (1.98–1.50%), carbohydrate (79.42–73.91%), and energy value (1759.38–1494.14 kJ/100 g), while increasing moisture (0.66–3.82%), ash (0.60–4.03%), and protein (8.53–14.20%). Water- and oil-absorption capacities, dispersibility, and emulsion stability generally increased, whereas bulk density, loose bulk density, water absorption index, and swelling power decreased. Peak, trough, breakdown, final, and setback viscosities and peak time also declined. No pasting temperature was detected, probably because increased α-amylase activity degraded starch during heating and suppressed the viscosity response. Sprouting is therefore a low-cost approach for improving selected nutritional and functional attributes of these maize varieties.

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1. INTRODUCTION

Maize (*Zea mays* L.), commonly referred to as corn, is a cereal crop classified under the Poaceae family. It ranks third globally in cereal crop production, following rice and wheat, due to its wide range of applications. As a major staple crop cultivated worldwide, maize occupies approximately 197 million hectares of farmland, with substantial cultivation occurring in regions such as Asia (notably China), Latin America (including Brazil and Argentina), and Sub-Saharan Africa (SSA) (FAOStat, 2021). Although Africa contributes around 6.5% to global maize output, countries such as Nigeria, South Africa, Ethiopia, Tanzania, and Kenya are among the continent's top producers (Kamara et al., 2020). According to Kaur et al. (2021) nutritionally, maize is a rich source of carbohydrates, dietary fiber, lipids, and essential vitamins (A, B1, B3, B9, and C), as well as minerals (iron, magnesium, and potassium). Moreover, regular intake of whole-grain maize products decreased risk of chronic conditions, including type 2 diabetes, cardiovascular diseases, and various forms of cancer, primarily due to their high dietary fiber content and antioxidant capacity (Siyuan et al., 2018).

In Ghana, maize plays a pivotal role in the national food system, serving as a principal dietary component across diverse ethnic groups and cultural practices. It has largely supplanted traditional staples like sorghum and millet, particularly in the northern regions (SRID-MoFA, 2011). The versatility of maize in Ghanaian cuisine is reflected in its various traditional and modern uses, such as in the preparation of *banku*, *kenkey*, *tuo-zaafi*, *akple*, *koko*, breakfast cereals, snack items, and brewing applications, as well as in its consumption in boiled or roasted forms (Eli-Cophie et al., 2017; Serna-Saldivar, 2023). As of 2020, maize cultivation involved approximately 70% of Ghanaian farmers, contributing to over half of the country's total cereal production and resulting in a per capita consumption of 75.91 kg (Akramov & Malek, 2012; MoFA, 2018; Wongnaa & Awunyo-Vitor, 2019; MoFA, 2020). Given its importance to household food security and economic well-being, there has been a concerted effort across many African nations, including Ghana, to develop improved maize varieties characterized by high yields and enhanced resistance to drought and diseases (Ragasa et al., 2014). Among the most widely cultivated are the open-pollinated varieties *Obatanpa* and *Honampa,* developed in 1992 and 2012, respectively, by the Crop Research Institute of the Council for Scientific and Industrial Research (CSIR-CRI), which now account for more than 40% of national maize production (Anthony, 2017; Tripp & Ragasa, 2015).

Sprouting (germination) is a traditional, low-cost processing approach that has gained recognition for its role in improving the nutritional attributes of cereal-based foods (Adu et al., 2024; Singh et al., 2015). During this biological process, seeds absorb water, leading to the disruption of dormancy and triggering metabolic pathways that stimulate enzyme production (amylase), which degrade starch into simpler sugars, enhance digestibility and provide energy for seedling development (Nkhata et al., 2018; Guzmán-Ortiz et al., 2019; Ikram et al., 2021). Concurrently, proteolytic enzymes hydrolyze storage proteins into amino acids, thereby improving nutrient absorption and contributing to better gut health (do Nascimento et al., 2022). Furthermore, previous studies have also reported that germination reduce anti-nutritional components such as tannins and phytic acid, which interfere with nutrient bioavailability, while enhancing antioxidant compounds like phenolics and flavonoids which are key agents in the mitigation of oxidative stress and prevention of chronic illnesses (Nelson et al., 2013).

Despite these advantages, limited research exists regarding the influence of sprouting on the nutritional and functional properties of locally adapted maize varieties prevalent in Ghana. This gap in knowledge restricts the ability to maximize the potential of these improved cultivars and hampers the development of nutrient-rich, value-added food products. Consequently, this study was undertaken to evaluate the impact of sprouting duration on the nutritional composition and functional characteristics of two maize varieties cultivated in Ghana.

2. MATERIALS AND METHODS

2.1 Source of Materials

Two-kilogram (2 kg) of maize grains (*Obatanpa* OPV orange maize and *Honampa* OPV white maize) were obtained from UVEC Farms Enterprise, a certified Ministry of Food and Agriculture (MoFA) seed breeders in Somanya, Eastern Region of Ghana. These varieties were chosen not only for their wide cultivation and consumption in Ghana but also for their nutritional and agronomic relevance in various regions, offering versatility for processing into a diverse range of food products.

2.2 Production of Maize Flour

Maize flour was prepared following the procedure outlined by Birhane (2012), with slight modifications. The procured maize grains were initially sorted to remove impurities, The seeds were thoroughly washed, and all floating seeds were removed by decantation and remained seed were stored in clean plastic containers before processing. For each maize variety, three sanitized plastic containers (3 L capacity) were used. The containers were half-filled with maize grains of biological replicates and chlorinated water was added to sanitized seeds for 30 min followed by multiple rinsing with distilled water. Afterwards, the seed in the container was filled with water until nearly full, then left undisturbed for 24 h to initiate soaking. After the soaking period, water was decanted, and the grains were retained in the containers to undergo germination at 75–80 % Relative Humidity and 25–30 °C for three days in a cool dark room. To prevent microbial growth, particularly mold, the samples were rinsed at 12-hour intervals throughout the sprouting phase. Sprouted samples were collected for each maize variety at three time points: Day 1, Day 2, and Day 3. Unsprouted samples served as the control (D0). Post-sprouting, the grains were dried in an oven at 150 °C for 2.5 h, ground using a high-powered kitchen blender (Sinbo, 2 L, 2200 W), and then passed through a 0.2 mm sieve to produce fine flour. The final flour samples were stored in ziplock bags for subsequent analysis.

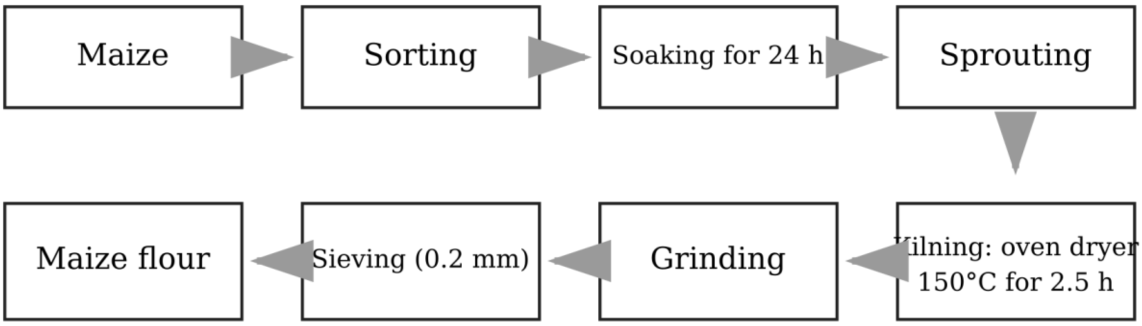

Figure 1. Flow Diagram for Maize Flour Preparation

2.2.1 Experimental Design

The experiment was conducted using two maize variety with each sample subjected to three independent sprouting batches (biological replicates). Each biological replicate was analyzed in triplicate and the average of the three analytical measurements was calculated. Statistical analyses were performed using the mean values obtained from the three independent biological replicates.

2.3 Physicochemical Properties

The pH, Total Soluble Solids (TSS), and Titratable Acidity (TTA) of the malted flour were measured using standard methods outlined by AOAC (2010). pH was determined using a Digital Hanna pH meter (Orion 2 Star, UK), TSS was measured with a Hanna digital refractometer (HI 96801, UK), and TTA assessed using standard titration techniques. Sample (10 g) of each flour sample of an independent biological replicate from separate sprouting batches was used and average mean was calculated.

2.4 Color Properties

Color measurement method outlined by de Matos et al. (2021) was adopted using a colorimeter (Model WR-10QC, China). The instrument provided values for L* (lightness, ranging from 0 = black to 100 = white), a* (representing the green [−] to red [+] spectrum), and b* (indicating the blue [−] to yellow [+] axis). The color difference (ΔE) between the germinated and control (ungerminated) maize flours, along with the whiteness index (WI), was computed using the equations reported by Choque-Quispe et al. (2022), Ligarda-Samanez et al. (2023), and Ramos-Pacheco et al. (2024). Furthermore, the saturation index (SI), hue angle, redness index (RI), and browning index (BI) were derived based on the formula described by Maskan (2001), Saricoban & Yilmaz (2010), and Rajkumar et al. (2022).

$$\text{Colour Change } (\Delta E = [\,(\Delta L*)2 + (\Delta a*)2 + (\Delta b*)2\,]^{1/2}$$

$$\text{Whitening Index (WI)} = 100 - \sqrt{(100 - L*)2 + a*2 + b*}$$

$$\text{Saturation Index (SI)} = \sqrt{a*^2 + b*^2}$$

$$\text{Hue Angle (H)} = \tan-^1 (b*/a*) \times 57.29$$

$$BI = \frac{[100\times(x-0.310]}{0.17}, \text{ where, } x = \frac{(a* + 1.75\times L*)}{(5.645\times L* + a* - 3.012\times b*}$$

$$\text{Redness Index (RI)} = a*/b*$$

2.5 Proximate Composition

The maize flours were analyzed for moisture, ash, crude fat, protein, and crude fiber using the methods outlined by AOAC (2016) in dry basis. Carbohydrate and energy contents were determined by difference and Atwater factor respectively (AOAC, 2012; Nwachoko et al., 2023) using the formula below;

$$\boldsymbol{Carbohydrate} = 100 - (Moisture + Ash + Protein + Fat + Crude\ fiber)$$

$$\boldsymbol{Energy} = 4 \times Protein + 4 \times Carbohydrate + 9 \times Fat$$

2.6 Functional Properties

2.6.1 Bulk Density and Loose Bulk Density

The Bulk Density (BD) and Loose Bulk Density (LBD) were assessed using a modified protocol from Hamid et al. (2015). A 10 g portion of each sample was carefully transferred into a 50 mL graduated measuring cylinder. For LBD determination, the volume was recorded prior to any compaction. Subsequently, the cylinder was tapped gently on a laboratory bench 10 times to facilitate packing of the particles. The BD was then measured based on the volume occupied post-tapping. Both densities were calculated using the corresponding volume measurements and expressed in g/mL.

$$\boldsymbol{Bulk\ density}\ (g/ml) = \frac{Weight\ of\ the\ sample}{Volume\ of\ the\ sample\ after\ tapping}$$

$$\boldsymbol{Loose\ Bulk\ density}\ (g/ml) = \frac{Weight\ of\ the\ sample}{Volume\ of\ the\ sample\ before\ tapping}$$

2.6.2 Water- and Oil-Absorption Capacities

Water Absorption Capacity (WAC) and Oil Absorption Capacity (OAC) were determined using a modified method of (Zhou et al. (2023). About 0.5 g of each sample was weighed into pre-weighed 1.5 mL centrifuge tubes. Then, 1 mL of distilled water (WAC) and refined oil (OAC) was added, and the contents were mixed thoroughly. The samples were then centrifuged at 3,000 × g for 10 minutes using an Eppendorf 5810R centrifuge (Hamburg, Germany). After removing the supernatant, the tubes were weighed again, and WAC and OAC were calculated.

$$\boldsymbol{Oil\ Absorption\ capacity}(\%) = \frac{Wet\ sample\ weight\ -\ Dry\ sample\ weight}{Dry\ sample\ weight.} \times 100$$

$$\boldsymbol{Water\ absorption\ capacity}(\%) = \frac{Wet\ sample\ weight\ -\ Dry\ sample\ weight}{Dry\ sample\ weight.} \times 100$$

2.6.3 Dispersibility

The dispersibility of the flour samples was assessed by Eke-Ejiofor et al. (2021) method. 10 g portion of each sample was transferred into a 100 mL graduated measuring cylinder, after which distilled, water was added to reach the 50 mL mark. The contents were stirred thoroughly to ensure uniform dispersion and subsequently left undisturbed for 3 hours to allow sedimentation. After settling, the volume of the sediment was measured, and the percentage dispersibility was determined.

$$\boldsymbol{Dispersibility}\ (\%) = \frac{(50 - volume\ of\ settled\ particle)}{50} \times 100$$

2.6.4 Water Absorption Index, Water Solubility Index, and Swelling Power

Water Absorption Index (WAI) and Water Solubility Index (WSI) of the maize flour were assessed by Deriu et al. (2022) with minor adjustments. Precisely 0.8 g of flour (Wo) was mixed with 10 mL of distilled water in pre-weighed centrifuge tubes using a glass stirring rod. The suspension was heated at 90 °C for 10 minutes, then cooled to ambient temperature and centrifuged at 3000 × g for 10 minutes. The supernatant was poured into a pre-weighed evaporating dish for solids analysis, while the remaining residue was weighed (Wss). The supernatant was then dried overnight at 110 °C to determine the dry solids (Wds).

$$\boldsymbol{WAI}\ (\boldsymbol{g/g}) = \frac{WSS}{Wo}$$

$$\boldsymbol{WSI}\ (\boldsymbol{g/100g}) = \frac{Wds}{Wo} \times 100$$

$$\boldsymbol{SP}\ (\boldsymbol{g/g}) = \frac{Wss}{Wo - Wds}$$

2.6.5 Emulsifying Properties

The emulsifying properties of the samples were evaluated by Sibian et al. (2017) with slight modifications. Flour suspension (1%) was homogenized in 5 mL of refined oil. The resulting emulsion was centrifuged at 1100 × g for 5 min using a FLC-04S centrifuge (4000 RPM, China). After centrifugation, the heights of both the emulsified layer and the entire mixture in the tube were measured.

$$\boldsymbol{Emulsifying\ capacity}\ (\%) = \frac{Height\ of\ the\ emulsified\ layer}{Total\ height\ of\ tube\ content} \times 100$$

Emulsion stability was evaluated by heating the emulsion for 30 min at 80°C and centrifuged at 1100 x g for 5 min.

$$\boldsymbol{Emulsifying\ stability}\ (\%) = \frac{Height\ of\ the\ emulsified\ layer\ after\ heating}{Height\ of\ the\ emulsified\ layer\ before\ heating} \times 100$$

2.7 Pasting Properties

Pasting properties of the maize flour samples were analyzed using a Rapid Visco Analyzer (RVA 4500-Perten Instruments, NSW211, Australia), procedure by Aidoo et al. (2022). Based on the flour moisture content computed int the software (TCW3), a slurry was prepared by combining approximately 3 grams of the flour with 25 mL of water in the RVA canister. The canister was then placed into the tower and engaged with the system. The slurry underwent a controlled heating and cooling cycle, rising from 50 °C to 95 °C and then cooling back to 50 °C for 12 min. During this time, the mixture was stirred continuously at 160 rpm using a plastic paddle. The software (TCW3) recorded parameters, including peak viscosity, trough viscosity, final viscosity, setback viscosity, pasting temperature, and pasting time from the resulting pasting curve with a moisture of 12%.

2.8 Statistical Analysis

Data obtained from the experiment were subjected to one-way analysis of variance (ANOVA) using SPSS software version 27.0. Differences between sample means were assessed using the Least Significant Difference (LSD) test at a 95% confidence interval.

3. RESULTS AND DISCUSSION

3.1 Physicochemical Properties

Physicochemical properties are important to flour due to their influence on shelf life, flavour and taste (Tene et al., 2022). pH, titratable acidity, and total soluble solid were determined for both sprouted maize flours on various days (**Table 1**). pH is a critical property that determines protein behaviour and possible applications in food processing. pH recorded for the maize flour samples was 6.19-6.81 and 6.11-7.20 for *Obatanpa* and *Honampa,* respectively, with significant differences (p<0.05) among all *Honampa* samples. Both sample pH increases at day one and decreases progressively as sprouting period progresses. The pH of the samples generally declined throughout the sprouting process, a trend consistent with findings by Akonor et al. (2014) and Ojewumi et al. (2018), who reported decreases in pH from 5.21 to 5.16 and 6.85 to 5.93, respectively, in maize sprouted for 96 h and 168 h. While the lowest pH was recorded in the samples sprouted for three days, the observed variation between the two maize varieties suggests differences in their genetic composition, which may influence acid-producing metabolic pathways. Similar trends have been observed in various cereal grains (Yenasew & Urga, 2022; Owheruo et al., 2019; Udeh et al., 2018; Derbew & Moges, 2017). The decrease in pH observed during sprouting may be attributed to the accumulation of organic acids formed during germination, which has also been reported in previous studies (Agume Ntso et al., 2017). In addition, natural biochemical changes during germination may contribute to the accumulation of organic acids, resulting in a reduction in pH. Sharma & Garg (2023) explained that low pH could also result from enzymes that hydrolyze phytin and proteins into simpler acidic compounds (phosphate and amino acids). Although previous studies have suggested that limited microbial activity may occur during soaking and sprouting, this was not investigated in the present study and therefore cannot be confirmed. This reduction in pH may help inhibit the growth of pathogenic microorganisms and enhance mineral absorption, as organic acids can form soluble complexes with iron and zinc (Gernah et al., 2011).

Titratable acidity (TTA), which reflects the total acid content in food, increased over the sprouting period for both maize varieties, with *Obatanpa* (0.81-2.24%) and *Honampa* (0.91-3.81%) exhibiting p<0.05 significant differences among all samples (**Table 1**). *Honampa* consistently demonstrated higher TTA than *Obatanpa*, with the highest values recorded on day three (D3) for both varieties. Guo et al. (2017) suggested that differences in enzyme activity associated with organic acid metabolism could explain the variations between the two maize varieties. Moreover, *Honampa's* genetic makeup may enhance its flavor profile, resulting in a greater production of acids during sprouting. The TTA values for both varieties were higher than those reported for fermented maize flour (0.06-0.70%) by Agume Ntso et al. (2017), but lower than those observed in malted maize (Dongmo et al., 2020) and maize sprouted for six days (Bedel et al., 2022). These discrepancies could be due to differences in maize variety, steeping duration, and processing methods. Ferreira et al. (2019) suggested that increased TTA could also be linked to lipase activity, which breaks down triacylglycerols into free fatty acids. The increase in titratable acidity may also be associated with the formation of organic acids during germination. Although previous studies by Bedel et al. (2022), have suggested possible microbial activity during sprouting this was not investigated in the present study.

Total Soluble Solids (TSS), which measures the concentration of dissolved solids like sugars and acids in a food matrix, increased during sprouting for both *Obatanpa* (0.53-0.83 °Brix) and *Honampa* (0.86-1.28 °Brix), with the highest values observed on day three (D3) (**Table 1**). Sprouted Obatampa samples recorded the lowest TSS compared to Honampa as sprouting period progressed. The increase in TSS could be due to the breakdown of polysaccharides into simpler sugars through the activity of natural enzymes. This trend has also been observed in fermented maize (Xolo et al., 2024) as well as malted millet and sorghum (Adu et al., 2024). Rungpichayapichet et al. (2016) noted that drying after sprouting further facilitates the breakdown of carbohydrate chains, likely leading to the production of more sugars. The rise in sugar content during sprouting enhances the potential of malted maize flour for brewing applications, as yeasts ferment these sugars to produce alcohol (Oseguera-Toledo et al., 2020). Additionally, the hygroscopic nature of sugars facilitates water absorption, contributing to a more liquid paste and accelerating the starch gelatinization process, which increases viscosity (Wang & Hartel, 2021).

3.2 Color Properties

Color is a critical quality attribute in the food processing industry, significantly influencing consumer preferences, and sprouting has a notable impact on the color of flour. The color attributes evaluated for both maize varieties included Lightness (L*), Redness (a*), Yellowness (b*), Total color difference (ΔE), Whiteness Index (WI), Hue angle (Hue), Saturation Index (SI), and Browning Index (BI), were measured for both maize varieties (**Table 2**).

The Lightness (L*) values for *Obatanpa* and *Honampa* flour ranged from 11.49-16.40 and 7.40-16.53 respectively, with significant differences (p<0.05) observed across all samples (**Table 2**). A general decline in lightness was observed as the sprouting duration increased. The variation in color during sprouting is influenced by factors such as the type of raw material, germination conditions, starch and protein content, and the activity of bioactive compounds (Sharma et al., 2019). A similar decreasing trend in lightness was reported for malted maize (Xolo et al., 2024), as well as millet and sorghum (Yenasew & Urga, 2022). According to Yang et al. (2025), as sprouting progresses, starch and protein hydrolysates are produced, leading to Maillard reactions between the hydrolysates during the drying process. The marked reduction in L* values indicate progressive darkening of the flour during sprouting. This also explains the lower whiteness index observed in both maize varieties.

The redness (a*) values range from 1.25-2.48 for *Obatanpa* and 0.62-1.79 for *Honampa*. While *Obatanpa* increased after a decrease on day one, *Honampa* generally increased as the

Table 1. Physicochemical Properties of Sprouted Maize Flours

Parameter	Obatanpa				Honampa			
	D0	D1	D2	D3	D0	D1	D2	D3
pH	6.69±0.23[a]	6.81±0.01[a]	6.55±0.01[a]	6.19±0.02[b]	6.90±0.02[a]	7.20±0.02[b]	6.78±0.02[c]	6.11±0.10[d]
TTA (%)	0.81±0.06[a]	1.52±0.02[b]	1.53±0.02[c]	2.24±0.02[d]	0.91±0.01[a]	1.34±0.01[b]	1.91±0.01[c]	3.81±0.01[d]
TSS (°Brix)	0.53±0.02[a]	0.62±0.01[b]	0.82±0.01[c]	0.83±0.01[c]	0.86±0.05[a]	1.04±0.06[ab]	1.18±0.06[bc]	1.28±0.15[cb]

The values are expressed as mean ± standard deviation. Means within a row sharing the same superscript letter are not significantly different (P > 0.05), while those with differing superscripts indicate significant differences (P < 0.05). The designations D0, D1, D2, and D3 correspond to sprouting on day zero, day one, day two, and day three, respectively. Abbreviations used include: TTA for Titratable Acidity, TSS for Total Soluble Solids, L for lightness, a* for redness/greenness, and b* for yellowness/blueness.*

Table 2. Color Properties of Sprouted Maize Flours

Parameter	Obatanpa				Honampa			
	D0	D1	D2	D3	D0	D1	D2	D3
L*	16.40±0.01[a]	15.79±0.01[b]	11.62±0.01[c]	11.49±0.02[d]	16.53±0.01[a]	14.54±0.02[b]	12.19±1.30[c]	7.40±0.30[d]
a*	1.61±0.01[a]	1.25±0.01[b]	2.48±0.02[c]	2.48±0.02[c]	0.62±0.02[a]	0.90±0.01[b]	1.16±0.01[c]	1.79±0.02[d]
b*	13.87±0.02[a]	13.90±0.02[a]	10.07±0.02[b]	9.84±0.01[b]	9.59±0.05[a]	8.10±0.02[b]	7.72±0.01[c]	6.27±0.02[d]
ΔE	0.00±0.00[a]	0.68±0.06[b]	6.18±0.01[c]	6.42±0.01[d]	0.00±0.00[a]	2.45±0.01[b]	3.01±0.01[c]	4.57±0.01[d]
WI	15.01±0.01[a]	14.65±0.01[b]	11.02±0.01[c]	10.92±0.01[d]	9.60±0.010[a]	7.22±0.02[b]	6.76±0.01[c]	6.03±0.01[d]
Hue	1.48±0.01[a]	1.46±0.01[a]	1.46±0.01[a]	0.26±0.01[b]	1.51±0.01[a]	1.47±0.01[b]	1.43±0.01[c]	1.31±0.01[d]
SI	13.94±0.01[ab]	13.98±0.01[ab]	10.14±0.01[cd]	10.15±0.01de	9.66±0.01[a]	8.14±0.01[b]	7.81±0.01[c]	6.52±0.01[d]
BI	147.07±0.01[a]	158.83±0.01[b]	100.06±0.06[c]	164.73±0.02[d]	82.39±0.04[a]	82.72±0.10[b]	123.55±0.02[c]	165.72±0.02[d]

The data are mean ± standard deviation. Within each row, means sharing the same superscript letter are not significantly different (P>0.05), while those with different superscript letters are significantly different (P<0.05). D0, D1, D2, and D3 correspond to sprouting at day zero, day one, day two, and day three, respectively. The color parameters evaluated include L (lightness), a* (redness/greenness), b* (yellowness/blueness), ΔE (color difference), WI (whiteness index), Hue (hue angle), SI (saturation index), and BI (browning index).*

sprouting period extended, with significant differences ($p<0.05$) observed particularly in the *Honampa* samples (**Table 2**). This increase in redness can be attributed to the extent of germination, which influences the formation of starch and protein hydrolysates. These components can participate in the Maillard reaction during drying, leading to color changes. Additionally, the migration and diffusion of bran pigments into the endosperm during soaking and heating may also contribute to the observed increase in redness (Murungweni et al., 2024). The redness values for both varieties were higher than the values for fermented maize (0.22-0.28) found by Xolo et al. (2024).

Yellowness (b*) decreased from 13.87 to 9.84 for *Obatanpa* and from 9.59 to 6.27 for *Honampa* as sprouting days increased, with *Obatanpa* consistently showing higher values compared to *Honampa* (**Table 2**). The lowest yellowness was observed in samples sprouted for three days (D3), with significant differences ($p<0.05$) noted in the *Honampa* flour, particularly between D0 and D1, and D2 and D3. Similar trends in yellowness reduction were reported by Chauhan et al. (2015) for germinated amaranth flour (ranging from 63.25 to 61.70) and by Kumari et al. (2023) for foxtail millet malt flour (ranging from 52.79 to 48.86), with the decline attributed to the breakdown of carotenoids and tannins during steeping and sprouting. Xolo et al. (2024) suggested that these changes could be linked to steeping, temperature, or kilning processes, as well as oxidation of polyphenols.The color difference (ΔE) ranged from 0.00 to 6.42 for *Obatanpa* and from 0.00 to 4.57 for *Honampa*, both showing an increasing trend as sprouting days increased (**Table 2**). All sprouted samples, except for *Obatanpa* and *Honampa* at D2, met the visible threshold of three units ($\Delta E > 3$), as outlined by De Flaviis & Sacchetti (2025). Sprouting for three days (D3) produced the greatest measurable color changes (6.42) for *Obatanpa* and (4.57) for *Honampa*. Similar trends were reported by Ramos-Pacheco et al. (2024), and Xolo et al. (2024), with increasing color differences due to the formation of starch and protein hydrolysates during sprouting, which undergo maillard reactions during drying, resulting in deeper color changes.

Whiteness index (WI) which is a critical factor for product end-use quality, decreased from 15.01 to 9.60 for *Obatanpa* and from 9.60 to 6.03 for *Honampa* as sprouting days increased, with significant differences ($p<0.05$) observed among all the samples (**Table 2**). This trend aligns with the findings of Ramos-Pacheco et al. (2024) for white, red, and black quinoa, where WI values decreased from 81.30 to 75.31, 72.95 to 71.43, and 72.15 to 69.47 respectively. These results suggest that color pigments are mainly concentrated in the coat, which are leached out during soaking and drying (Pedrali et al., 2023). The decrease in whiteness index corresponded with the reduction in L* values, indicating that the flour became progressively darker as sprouting advanced. This may be due to enzymatic reactions and pigment oxidation during sprouting and drying (Ji et al., 2021).

Hue angle (h0) indicates the qualitative quality of color based on various hues, and ranged from 0.26 to 1.48 for *Obatanpa* and 1.31 to 1.57 for *Honampa* (**Table 2**). As sprouting days increased, a general decline in the hue angle was noted, with significant differences ($p<0.05$) observed among the samples. These results suggest that the hue of the samples was most pronounced on day 0, indicating that sprouting significantly affected the color. The values reported here were lower than those reported by Ramashia et al. (2018) and Afify et al. (2015), which could be attributed to differences in maize variety and processing methods.

The saturation index (SI) indicates the degree of color saturation, which ranged from 10.14 to 13.98 for *Obatanpa* and from 1.31 to 1.51 for *Honampa* (**Table 2**). Similar trends were observed by Olamiti et al. (2022) with values ranging from 13.10 to 14.00. A decreasing trend in the saturation index was observed as sprouting days increased, with significant differences ($p<0.05$) noted between *Honampa* samples. No significant differences were observed between *Obatanpa* samples at D0 and D1, and between D2 and D3, suggesting a reduction in pigment concentration as the sprouting period lengthened. This decrease in saturation could be due to the degradation of pigment concentration, resulting in darker colors as sprouting progressed. Variations may also arise from biochemical processes, polyphenol leaching during malting, and varietal differences (Taylor & Duodu, 2015). Higher saturation values indicate more intense color in flour, which can be more readily detected by humans (Pathare et al., 2013).

The browning index (BI) which is used to characterize the overall changes in browning color, ranged from 100.06 to 164 for *Obatanpa* and from 82.39 to 165.72 for *Honampa*, with significant differences ($p<0.05$) observed across the samples (**Table 2**). These values were higher than the range of 4.15 to 23.16 reported by Udoro et al. (2020), but lower than the values of 166.25 to 231.68 reported by Rajkumar et al. (2022). The rise in the browning index observed during sprouting could be linked to the enzymatic oxidation of phenolic compounds, a process that intensifies as the integrity of cell walls and membranes deteriorates. Non-enzymatic browning reactions, influenced by reducing sugar content and temperature, may also contribute to the observed changes (Pathare et al., 2013).

3.3 Proximate Composition

Moisture content plays a crucial role in determining product freshness and shelf life. Higher moisture levels promote microbial growth, leading to shorter shelf life and potential product deterioration (Ejim et al., 2019). The moisture content of the *Obatanpa* and *Honampa* samples showed an increasing trend, ranging from 0.66% to 3.25% for *Obatanpa* and from 0.76% to 3.82% for *Honampa* (**Table 3**), with significant differences ($p<0.05$) observed. This trend is likely due to changes in the dry matter content of the maize samples during germination (Hamadina, 2015). Additionally, the rapid absorption of water by the seeds at the beginning of germination may further contribute to the rise in moisture content.

Proteins being hydrophilic tend to bind water (Monroe et al., 2020), whereas lipids are hydrophobic (Ramos-Martín & D'Amelio, 2022). Therefore, maize varieties with higher protein content are expected to retain more moisture, while

Table 3. Proximate Composition of Sprouted Maize Flours

Parameter	Obatanpa				Honampa			
	D0	D1	D2	D3	D0	D1	D2	D3
Moisture	0.66±0.02^{a}	0.72±0.02^{b}	1.47±0.02^{c}	3.25±0.02^{d}	0.76±0.02^{a}	1.40±0.02^{b}	2.94±0.01^{c}	3.82±0.02^{d}
Total Ash	0.60±0.10^{a}	1.03±0.01^{b}	1.52±0.02^{c}	2.53±0.03^{d}	1.03±0.02^{a}	3.02±0.01^{b}	3.52±0.02^{c}	4.03±0.06^{d}
Crude Fat	9.70±0.61^{a}	7.92±0.08^{b}	7.90±0.10^{cb}	4.33±0.15^{d}	8.46±0.06^{a}	6.96±0.06^{b}	3.97±0.06^{c}	1.46±0.06^{d}
Total Fiber	1.98±0.01^{a}	1.89±0.02^{b}	1.79±0.01^{c}	1.67±0.01^{d}	1.92±0.05^{a}	1.84±0.05^{ab}	1.78±0.05^{b}	1.50±0.02^{c}
Protein	10.17±0.06^{a}	11.23±0.08^{b}	12.15±0.05^{c}	14.20±0.10^{d}	8.53±0.15^{a}	10.70±0.10^{b}	12.14±0.05^{c}	12.67±0.28^{d}
Total CHO	76.68±0.02^{a}	77.13±0.06^{b}	75.13±0.06^{c}	73.91±0.02^{d}	79.42±0.07^{a}	75.88±0.07^{b}	75.61±0.03^{c}	76.74±0.12^{d}
Energy (kJ/100g)	1759.38±0.62^{a}	1721.09±1.01^{b}	1700.56±0.47^{c}	1591.39±0.88^{d}	1729.78±0.10^{a}	1624.86±1.32^{b}	1564.47±0.55^{c}	1494.14±0.52^{d}

values are mean ± standard deviation. Values in the same row that share the same letter superscript do not differ significantly (P > 0.05), while those with different superscripts indicate a significant difference (P < 0.05). Sample was Obatanpa (orange maize) and Honampa (white maize). D0, D1, D2, D3 represent samples sprouted for day zero, day one, day two, and day three respectively. CHO-carbohydrate. All values are in dry basis.

those with higher lipid content may retain less. The observed difference in moisture content between *Obatanpa* and *Honampa* may be attributed to their genetic differences. The moisture content values recorded in this study were lower than those reported by Ikujenlola et al. (2013) and Salami et al. (2018) for various malted maize varieties, which ranged from 7.07% to 8.62% and 7.23% to 8.99%, respectively. The moisture levels in the malted flours from *Obatanpa* and *Honampa* are considered safe for extended storage, as moisture content below 10% is generally recommended for maintaining the freshness of flour-based products (Zambrano et al., 2019; Chinma et al., 2021).

Ash content refers to the inorganic residue left after the complete combustion or oxidation of organic matter in food products (Marshall, 2010). In this study, the ash content in *Obatanpa* (0.60-2.53%) and *Honampa* (1.03-4.03%) exhibited significant variability (p<0.05), with *Honampa* showing the highest levels. These findings were notably higher than the 1.34-1.54% range reported by Ajayi & Makanjuola (2017) for maize malted over 48 h. Such discrepancies are likely due to differences in maize varieties and sprouting durations. As the sprouting period progressed, a corresponding increase in ash content was observed, with the highest levels noted in samples sprouted for three days (D3). This trend aligns with similar results reported by Adebayo (2017) for yellow maize and Guzmán-Ortiz et al. (2019) for cereals. The rise in ash content during malting can be attributed to the breakdown of carbohydrates, which releases inorganic minerals previously bound within the grain, thereby increasing the ash content (Maldonado-Alvarado et al., 2023). Malama et al. (2020) also observed that extended sprouting enhances the solubility of minerals, further contributing to higher ash content, a point also highlighted by Shah & Smith (2020), who noted that increased enzymatic activity during sprouting alters the mineral composition of grains. Fat content serves as an energy source and facilitates the transport of fat-soluble vitamins, while supporting body tissues and cellular processes. The fat content in *Obatanpa* (9.70% to 4.33%) and *Honampa* (1.46% to 8.46%) declined with increasing sprouting duration, with the highest fat content recorded in the ungerminated samples (D0) (Table 3). Notably, significant differences (p<0.05) were found in the *Honampa* samples.

This decrease in fat content is consistent with previous research by Kunle et al. (2023), who reported a reduction from 11.38% to 9.34% for maize malted for 24 to 72 hours, respectively, and Adebayo (2017), who noted a reduction from 4.45% to 3.51% for sprouted maize. The decrease in fat is likely due to its utilization by fermenting microorganisms, which oxidize the fat to generate energy, and its consumption as an energy source for the developing embryo. Additionally, the increased activity of lipolytic enzymes during fermentation likely contributes to the breakdown of lipids into fatty acids and glycerol, thus reducing fat content (Naraharasetti et al., 2025; Kassegn et al., 2018). Furthermore, malted grains may have a longer shelf life than non-malted grains due to their reduced fat content, which decreases oxidative rancidity and moisture retention, preventing microbial spoilage (Ikram et al., 2021; Pérez-Díaz et al., 2017).

Crude fiber content, indicative of the presence of lignin and indigestible carbohydrates in food, decreased with longer sprouting periods in both *Obatanpa* (1.98% to 1.67%) and *Honampa* (1.92% to 1.50%) (**Table 3**). Significant differences (p<0.05) were observed in the *Obatanpa* samples. The fiber content in this study was higher than the 1.20% to 1.41% range reported by Dhliwayo et al. (2023) for germinated orange maize. Variations in fiber could be due to maize variety and the extent of seed coat removal (Zhong et al., 2018). The decrease may be due to the enzymatic breakdown of structural carbohydrates such as cellulose and hemicelluloses by enzymes like cellulase and hemicellulose. Shin (2022) also noted that fiber content within the 1.50% to 1.98% range supports digestive health by facilitating regular bowel movements and helping to prevent constipation.

Protein content is a critical determinant of the nutritional value and functional characteristics of maize, especially during malting (Fox & Bettenhausen, 2023). In this study, the protein content of *Obatanpa* (10.17% to 14.20%) and *Honampa* (8.53% to 12.67%) showed significant variation (p<0.05), as presented in **Table 3**. A clear increase in protein content was noted as the sprouting period lengthened, with the highest levels occurring in samples sprouting for three days (D3). This increase suggests that the malting process facilitates the breakdown of complex proteins into more digestible forms, thus improving protein availability (Reddy et al., 2015). Similar findings were observed by Makanjuola & Makanjuola (2018) and Adebayo (2017) for various malted maize varieties, although Agume Ntso et al. (2017) reported lower protein content (4.90 g/100g at 24 h and 4.00 g/100g at 48 h). The increase is likely due to enhanced enzymatic activity during sprouting, which hydrolyzes proteins into soluble forms.

Carbohydrate content decreased with increasing sprouting time, from 76.68% to 73.91% in *Obatanpa* and from 79.42% to 76.74% in *Honampa* (**Table 3**), with significant differences (p<0.05) between the samples. This reduction aligns with findings by Guzmán-Ortiz et al. (2019) and Aguirre et al. (2018), primarily due to enzymatic conversion of starches into fermentable sugars and maltodextrins (Kumar et al., 2023; Adu et al., 2024). This transformation increases the availability of these nutrients for fermentation processes, which is particularly important in brewing, where yeast utilizes sugars for alcohol production. The carbohydrate content in this study (ranging from 70% to 80%) is consistent with previous studies (Haug et al., 2017), indicating that these maize varieties could contribute significantly to the energy content of food products made from the flour.

Energy content in *Obatanpa* (1759.38–1591.39 kJ/100g) and *Honampa* (1789.78–1494.14 kJ/100g) exhibited significant differences (p<0.05), with both showing a decreasing trend as the germination period increased. This decrease is likely due to the conversion of complex carbohydrates into simpler sugars, as well as energy consumption by enzymes during the malting process (Kumar et al., 2023). The higher energy content in *Honampa* is attributed to its higher starch content, which typically provides more calories (Adebayo, 2017). Similar results were reported by Haug et al. (2017) and Ejim et al. (2019), who noted a decrease in energy content due to enzymatic starch breakdown. This suggests that the flour samples could provide sufficient energy when incorporated into food products, which is essential for maintaining bodily functions and supporting physical activity.

3.4 Functional Properties

Functional properties describe how a food's composition and molecular structure influence its behavior during processing and storage (Dereje et al., 2020). Bulk density (BD) plays a significant role in determining the texture and porosity of flour-based products, which affects their packaging and handling (Bala et al., 2020). In this study, the BD of *Obatanpa* (0.72–0.53 g/mL) and *Honampa* (0.72–0.52 g/mL) decreased with longer sprouting periods, with values similar between the two maize varieties (Table 4). These BD values were lower than those reported by Murungweni et al. (2024) (0.74 g/mL to 0.81 g/mL) and others (Anosike et al., 2020; Iwe et al., 2015; Gnanwa et al., 2021). The observed difference could be attributed to particle size, as smaller particles typically lead to lower BD (Sun et al., 2019). Finer flour fractions are often associated with reduced protein content and slightly higher ash, which could contribute to lower BD (Ahmed et al., 2015). The low BD observed in the flours suggests they are suitable for producing products with consistent, well-packed textures (Bala et al., 2020).

Loose density measures the lowest achievable density under compression, and reflects how much load the samples can support when stacked (Kumar & Saini, 2016). The loose density of *Obatanpa* (0.50–0.70 g/mL) and *Honampa* (0.50–0.60 g/mL) decreased with longer sprouting periods (**Table 3**). This reduction is consistent with findings for malted millets by Murungweni et al. (2024), and can be attributed to starch breakdown and molecular changes during malting, which reduce interparticle attraction and overall density (Ojha et al., 2018; Ocheme et al., 2015). Foods with lower loose density tend to have lower energy density, which can be beneficial for calorie-conscious diets. The low loose density in the present study suggests that the flours would maintain their volume during storage, making them suitable for efficient packing (Kumar & Saini, 2016).

Water Absorption Capacity (WAC) quantifies the amount of moisture absorbed by flour during processing, influencing product consistency and quality. Both inadequate and excessive water absorption can adversely affect food product quality (Awuchi et al., 2019). The WAC of *Obatanpa* and *Honampa* flours increased from 114.11% to 123.20% and from 126.70% to 142.17%, respectively, from day 0 to day 2. However, a decline was observed on day 3, with WAC values of 104.10% for *Obatanpa* and 96.10% for *Honampa* in both samples (**Table 4**). The higher WAC in *Honampa* suggests a greater starch (amylopectin) content, which has a more branched structure and thus a higher capacity for water retention.

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Table 4. Functional Properties of Sprouted Maize Flours

Parameter	Obatanpa				Honampa			
	D0	D1	D2	D3	D0	D1	D2	D3
BD (g/mL)	0.72±0.01^{a}	0.64±0.02^{b}	0.55±0.01^{c}	0.53±0.01^{cd}	0.72±0.01^{a}	0.66±0.02^{b}	0.55±0.02^{c}	0.52±0.02^{dc}
LBD (g/mL)	0.70±0.01^{a}	0.60±0.01^{b}	0.52±0.02^{c}	0.50±0.01^{cd}	0.63±0.02^{a}	0.60±0.01^{b}	0.51±0.02^{c}	0.50±0.01^{dc}
WAC (%)	114.11±0.10^{a}	122.10±0.10^{b}	123.20±0.20^{c}	104.10±0.10^{d}	126.70±1.12^{a}	128.10±0.10^{a}	142.17±0.15^{b}	96.10±0.10^{c}
OAC (%)	68.17±0.15^{a}	70.10±0.10^{b}	74.10±0.10^{c}	96.10±0.10^{d}	74.10±0.10^{a}	98.07±0.12^{b}	122.10±0.10^{c}	94.10±0.10^{d}
Disp (%)	50.10±0.10^{a}	59.10±0.05^{b}	59.50±0.10^{c}	60.20±0.10^{d}	54.13±0.15^{a}	58.25±0.05^{b}	59.50±0.10^{c}	60.10±0.10^{d}
WAI (g/g)	4.10±0.10^{a}	5.10±0.05^{b}	3.35±0.05^{c}	2.25±0.05^{d}	4.69±0.01^{a}	4.40±0.02^{b}	3.50±0.01^{c}	2.41±0.10^{d}
WSI(g/100g)	8.82±0.08^{a}	6.58±0.08^{b}	6.60±0.10^{cb}	6.10±0.10^{d}	6.25±0.02^{a}	4.53±0.15^{b}	8.72±0.10^{c}	11.26±0.01^{d}
SP (g/g)	4.39±0.01^{a}	5.50±0.10^{b}	3.63±0.06^{c}	2.82±0.08^{d}	4.98±0.01^{a}	4.68±0.07^{b}	3.92±0.07^{c}	2.87±0.21^{d}
EC (%)	85.80±0.10^{a}	75.31±0.08^{b}	74.35±0.10^{c}	63.85±0.05^{d}	72.40±0.02^{a}	69.57±0.06^{b}	73.35±0.02^{c}	76.21±0.03^{d}
ES (%)	79.56±0.03^{a}	97.58±0.08^{b}	97.52±0.07^{cb}	98.62±0.08^{d}	97.38±0.01^{a}	95.89±0.02^{b}	98.72±0.08^{c}	96.35±0.05^{d}

values are mean ± standard deviation. Values in the same row that share the same letter superscript do not differ significantly (P > 0.05), while those with different superscripts indicate a significant difference (P < 0.05). Sample was Obatanpa (orange maize) and Honampa (white maize). D0, D1, D2, D3 represent samples sprouted for day zero, day one, day two, and day three respectively. BD=Bulk Density, LD=Loose Density, WAC=Water Absorption Capacity, OAC=Oil Absorption Capacity, DISP=Dispersibility%, WAI=Water Absorption Index, WSI=Water Solubility Index, SP=Swelling Power, EC=Emulsifying capacity, ES=Emulsifying stability.

The increase in WAC until day 2 reflects seed physiological activity, which involves water absorption to support enzymatic processes and cellular functions essential for sprouting (Atudorei & Codină, 2020). Additionally, the breakdown of starch crystalline structures, along with increased amylose leaching and solubility, contributes to higher WAC (Rathore et al., 2019). The decline in WAC on day 3 indicates the stabilization of water absorption as the germination process reaches its peak (Kapoor et al., 2020). The findings show significant differences (p<0.05) in WAC across all samples, except between *Honampa* malted at D2 and D3. The observed WAC was lower than the 205.36% to 304.90% range reported for raw and sprouted maize by Gnanwa et al. (2021). Variations in WAC between samples may be attributed to differences in maize varieties, affecting protein degradation, water interactions, and starch conformational properties. Such differences might stem from variations in amylose and amylopectin release from starch granules, as well as weaker associative forces in some samples (Iwe et al., 2016). A higher WAC is advantageous for baking, as it often indicates a greater presence of hydrophilic components like polysaccharides (Abah et al., 2020). Conversely, lower WAC could result in poorer dough performance, negatively affecting the quality of baked goods. According to Murray et al. (2017), flours with a WAC below 50% produce drier, less elastic doughs, leading to baked products with diminished volume and texture. Thus, the WAC results in this study suggest the flour samples are suitable for bakery applications.

Oil Absorption Capacity (OAC) is a key functional characteristic affecting flavor, mouthfeel, and overall food quality. It describes the flour's ability to absorb fat via the non-polar side chains of proteins (Iwe et al., 2016). Foods with higher protein content, amino acids, and surface polarity typically exhibit greater oil absorption (Awuchi et al., 2019). The results (**Table 4**) indicate that *Obatanpa* exhibited a steady increase in OAC from 68.17% (D0) to 96.10% (D3) over the sprouting period. In contrast, *Honampa* showed an initial increase from 74.10% (D0) to 122.10% at D2, followed by a decrease to 94.10% at D3, with significant differences (p<0.05) observed across all samples. The OAC values for both *Obatanpa* and *Honampa* were consistent with the range (63%-82%) reported for various maize flours (Oladapo et al., 2017).

Oil absorption is largely attributed to the physical trapping of lipids by proteins (Kumar & Saini, 2016). The observed increase in OAC during sprouting may be due to hydrolyzed starch's high oil retention capacity and its ability to bind oil to non-polar protein side chains. The subsequent decrease in OAC at D3 is likely due to the breakdown of hydrolyzed starches into simpler sugars, which are less efficient at absorbing oil. Moreover, the changes in grain structure and protein denaturation during sprouting may also affect oil retention, contributing to the reduction in OAC after the initial increase (Kumar et al., 2022). These findings indicate that the flour samples, with their oil absorption properties, are suitable for use in food products where flavor retention and palatability are crucial, particularly in bakery products and other items requiring oil absorption.

Dispersibility refers to how easily flour particles disperse in water, forming a uniform mixture (Anosike et al., 2020). In this study, *Obatanpa's* dispersibility increased from 50.10% at D0 to 60.20% at D3, while *Honampa's* increased from 54.13% at D0 to 60.10% at D3, with significant differences ($p<0.05$) between the samples. These results are consistent with the dispersibility values (59%-71.83%) reported for malted wheat flours (Baranwal & Sankhla, 2019). Several factors influence dispersibility, including temperature, pH, ionic composition, and mixing intensity (Kushwaha & Said, 2020). The observed increase in dispersibility for both maize varieties can be attributed to enhanced water absorption capacity, which facilitates better rehydration and dispersion in water. This suggests that the samples can be easily reconstituted into smooth and consistent dough during mixing, indicating their potential for applications requiring easy dispersion, such as in baking or dough preparation (Alabi et al., 2025).

The Water Absorption Index (WAI) quantifies the volume occupied by starch after swelling in excess water, which reflects its ability to absorb water and expand, thereby influencing its processing behavior (Deriu et al., 2022). The WAI values for *Obatanpa* (5.10-2.25 g/g) and *Honampa* (4.69-2.41 g/g) exhibited a declining trend as the sprouting period advanced, with significant differences ($p<0.05$) observed among samples (**Table 3**). These values are comparable to the 3.03 g/g to 4.18 g/g range reported for popped maize by Sharma et al. (2015). The observed decline in WAI is likely due to the malting process, which alters the crystalline structure of starch, rendering it more soluble and less able to retain water (Bhandari et al., 2016). Furthermore, the enzymatic breakdown of starch by α-amylase during sprouting likely contributes to the reduction in water absorption (Sanni & Fatoki, 2017). The relatively high WAI values suggest that these maize varieties may be appropriate for instant mix formulations, such as weaning or dessert mixes, where reconstitution capacity is critical (Sharma et al., 2015).

The Water Solubility Index (WSI) measures the starch's ability to absorb water and swell, providing insight into the structural integrity of starch granules, with amylopectin playing a significant role (Awuchi, 2019). The WSI for *Obatanpa* ranged from 6.10 to 8.82 g/100g, and for *Honampa*, from 4.53 to 11.21 g/100g, with significant differences ($p<0.05$) between samples (**Table 4**). The malting process typically reduces peak temperatures, resulting in lower WSI values, as enzymes like α-amylase break down starch granules, decreasing their ability to absorb water and swell (Aidoo et al., 2022). Flours with lower WSI values are preferred for pasta production, as they reduce water solubility and shorten cooking times, thereby minimizing solids loss (Fideles et al., 2019). Higher WSI values are associated with greater water absorption and swelling, which contributes to softer, more gel-like textures in food products (Wani et al., 2020).

Swelling Power (SP) measures the starch or flour's ability to absorb water and expand under specific cooking conditions, influenced by the amylose/amylopectin ratio and other molecular factors (Jamal et al., 2016; Bikila et al., 2022). In this study, *Obatanpa* exhibited a decrease in SP from 4.39 g/g at D0 to 2.82 g/g at D3, while *Honampa* showed a similar decline from 4.98 g/g at D0 to 2.87 g/g at D3 (**Table 4**). This reduction in SP is likely due to the enzymatic activity of amylase, which breaks down starch into simpler sugars, thus lowering its expansion capacity (Kok et al., 2019). The higher amylopectin content in *Honampa* may also contribute to superior swelling properties. Comparably, other studies have reported swelling power ranges of 2.94–3.8 g/g and 0.76–3.45 g/g for different flours (Nwosu et al., 2014; Yenasew & Urga, 2023). The decrease in SP can be attributed to stronger associative forces within the granules, which restrict their ability to absorb water and swell (Hedayati et al., 2020).

Emulsifying Capacity (EC) refers to the ability of proteins and other compounds to form stable emulsions by interacting with oil and water. This property is influenced by factors such as non-polar amino acids, oil, water, starch, and fiber, which stabilize emulsions (Gupta et al., 2018; Lin & Fernández-Fraguas, 2020; Bento et al., 2021). *Obatanpa* exhibited a decline in EC, ranging from 85.80% to 63.85%, while *Honampa* demonstrated an increase from 69.57% to 76.21%, with significant differences ($p<0.05$) observed. This trend in *Honampa* may result from the partial unfolding of polypeptides during sprouting, which exposes hydrophobic amino acid residues, enhancing protein-lipid interactions. Additionally, increased protein content and greater protein interactions during germination likely improve EC. The EC observed in this study was higher than those reported for other sprouted grains (Gnanwa et al., 2021).

Emulsion Stability (ES) refers to a product's ability to maintain a stable emulsion by resisting droplet aggregation. Smaller particle sizes typically enhance emulsifiers' ability to stabilize emulsions (Zhang et al., 2023). The ES for *Obatanpa* (79.56–98.62%) and *Honampa* (97.38–96.35%) showed a general decrease as sprouting progressed, with the highest stability observed on day 3 (D3). This increase in ES is likely due to the protein layer's ability to adsorb, along with enhanced starch and fiber viscosity, which prevents droplet aggregation (Lin & Fernández-Fraguas, 2020). These findings were superior to those reported for sprouting yellow

Table 5. Pasting Properties of Sprouted Maize Flours

Parameter	Obatanpa				Honampa			
	D0	D1	D2	D3	D0	D1	D2	D3
Peak Viscosity	204.50±6.36[a]	196.50±2.12[a]	109.50±3.54[b]	81.50±0.71[c]	219.00±1.41[a]	198.50±0.71[b]	120.50±0.71[c]	42.50±0.71[d]
Trough Viscosity	173.50±4.95[a]	181.00±2.83[a]	107.50±3.54[b]	27.50±0.71[c]	187.00±2.83[a]	172.50±0.71[b]	115.50±0.71[c]	13.50±0.71[d]
Breakdown Viscosity	31.50±0.71[a]	15.50±0.71[b]	20.50±0.71[c]	54.50±0.71[d]	32.00±1.41[a]	25.50±0.71[a]	7.50±3.54[b]	31.00±1.41[a]
Final Viscosity	448.50±0.71[a]	434.00±1.41[b]	167.50±2.12[c]	39.50±0.71[d]	400.50±6.36[a]	393.50±0.71[a]	197.00±1.41[b]	21.50±0.70[c]
Setback Viscosity	271.00±1.41[a]	253.00±1.41[b]	113.00± 4.24[c]	12.50±0.71[d]	213.50±3.53[a]	220.50±0.71[a]	92.00±12.73[b]	8.50±0.71[c]
Peak Time (Min)	7.00±0.00[a]	8.43±2.12[ab]	6.87±0.19[a]	4.09±0.02[ac]	7.00±0.00[a]	7.00±0.00[a]	6.83±0.14[a]	6.94±0.01[a]
Pasting Temperature (oC)	ND	ND	ND	ND	ND	ND	ND	ND

The values are expressed as the mean ± standard deviation. Means within a row sharing the same superscript letter do not differ significantly (P > 0.05), while those with distinct superscript letters exhibit statistically significant differences (P < 0.05). The samples included in the study were Obatanpa orange maize and Honampa white maize, with ND indicating the parameter was not detected. The designations D0, D1, D2, and D3 refer to maize samples malted for zero, one, two, and three days, respectively.

maize and other grains (Gnanwa et al., 2021; Sibian et al., 2017). According to McClements (2004), the drying stage during malting enhances emulsifying properties by denaturing proteins, which exposes hydrophobic sites, thus improving emulsion stability through better protein-lipid interactions.

3.5 Pasting Properties

Pasting properties are important characteristics of starches that describe their behaviour when heated and are vital to the food industry because they impact the texture, viscosity, and overall quality of food products (Donmez et al., 2021). The distribution of branch chain lengths in amylopectin, lipid levels, and amylose levels all influence the pasting properties, while amylose and lipids typically prevent swelling, amylopectin promotes swelling and helps with pasting of starch granules (Thitisaksakul et al., 2021). Furthermore, the chain length of amylopectin and the molecular size of amylose interact synergistically to influence the flour pasting properties. Sprouting can alter the starch composition of flour, leading to changes in pasting properties (Gui et al., 2021). The result of pasting properties is shown in **Table 5**.

Peak Viscosity (PV) is the maximum viscosity of gelatinized starch when heated in water, and also depicts the water-binding capacity of the starch (Shimelis et al., 2006). The PV of the samples generally declined with increasing malting days from 204.50 to 81.50 RVU and 219.00 to 42.50 RVU for *Obatanpa* and *Honampa* with noted significant differences ($p<0.05$) between the samples except Obatanpa D0 and D1 (**Table 5**). Similar decreasing trend in PV was observed by Li et al. (2024) in sorghum. As malting days increase, more starch is converted into sugars, leading to a reduction in the amount of starch available to form a viscous paste (Haug et al., 2017). Also, higher peak viscosity in ingredients has been linked to weak molecular interactions between starch granules, making them more prone to disintegration, as well as factors such as varietal differences, processing methods, and starch-hydrocolloid interactions (Musah-Bawa et al., 2020; Vela et al., 2024). The result reveals that the spouted flour would have less cooking time than an unsprouted flour.

Viscosity (TV) is a critical parameter that gauges the resilience of flour granules to sustained high temperatures and mechanical shear forces, reflecting the paste's stability and its influence on sensory characteristics, such as texture and mouthfeel. Generally, higher viscosity results in a creamier texture, while lower viscosity imparts a lighter sensation (Mouritsen & Styrbæk, 2017).

In this study, trough viscosity varied between 173.50 RVU and 13.50 RVU, with the highest values of 173.50 RVU and 187.00 RVU recorded for samples sprouted for one day (D1), and the lowest values of 27.50 RVU and 13.50 RVU for *Obatanpa* and *Honampa*, respectively, sprouted for three days (D3). For *Obatanpa*, no significant difference ($p>0.05$) was observed between D0 and D1, while *Honampa* samples exhibited significant differences ($p<0.05$). The general trend showed a decline in trough viscosity as the sprouting period extended, consistent with the findings of Onwurafor et al. (2020). The viscosity values observed here were generally higher than those reported by Adebayo (2017). The increase in trough viscosity for both *Obatanpa* and *Honampa* may be attributed to enzymatic activity during sprouting, which degrades starch components (Han et al., 2021). Furthermore, the increase in protein content during sprouting likely contributes to the formation of a network that retains water, thereby enhancing the viscosity of the dough or slurry (Prasadi & Joye, 2023). Conversely, the decrease in viscosity at later sprouting stages might result from the higher moisture content in malted maize flours (Onwurafor et al., 2020). Trough viscosity is a key factor in paste stability, significantly affecting food texture, where higher viscosity typically results in a creamier texture, while lower viscosity offers a lighter feel (Mouritsen & Styrbæk, 2017).

Breakdown Viscosity (BV) measures the extent to which flour resists enzymatic breakdown during cooking, which impacts both its texture and digestibility. Higher breakdown viscosity signifies reduced ability to withstand heating and shear stress (Byarugaba et al., 2023). In this study, breakdown viscosity ranged from 15.50 to 54.50 RVU for *Obatanpa* and 32.00 to 7.50 RVU for *Honampa* (**Table 5**). A declining trend in breakdown viscosity was observed from D0 to D2, followed by an increase at D3 for both *Obatanpa* and *Honampa*. This initial decrease is likely due to pre-gelatinization effects during malting, which make starch less susceptible to breakdown during heating (Qi et al., 2023). Enzymes such as α-amylase and β-amylase are activated during malting, breaking down starch molecules into simpler sugars like maltose and glucose (Sammartino, 2015). The breakdown viscosity values observed in this study were lower than those reported by Ocheme et al. (2018) for wheat and groundnut blends (672–377 RVU) but higher than those recorded by Adebayo (2017) for germinated yellow maize (15.00–32.00 RVU). Higher breakdown viscosity indicates that the sample has less ability to endure heating and shear stress, thus affecting both its texture and digestibility (Asaam et al., 2018).

Final Viscosity (FV), assessed at 50°C, reflects the starch's capacity to form a viscous paste after cooking and cooling, as starch granules undergo molecular restructuring and retrogradation (Shafie et al., 2016). FV is influenced by factors like protein content, which binds water and decreases water availability, as well as the re-association of starch molecules (especially amylose) during cooling, forming a gel structure. In this study, *Obatanpa* (448.50–39.50 RVU) and *Honampa* (400.50–21.50 RVU) displayed a decrease in FV as sprouting duration increased, with the lowest values recorded in the samples sprouted for three days (D3) (**Table 5**). These values were lower than those reported for sprouted sorghum (901.00–49.00 RVU) and maize (603.00–453 RVU) by Adebayo (2017). The reduction in FV can likely be attributed to the heightened enzymatic activity during sprouting, which breaks down starch and proteins, leading to a decrease in final viscosity (Kumar et al., 2023). Lower final viscosity indicates improved resistance to shear stress during stirring (Liu et al., 2021). Despite this decrease, both *Obatanpa* and *Honampa* still exhibited sufficient viscosity to form acceptable gels during processing.

Setback Viscosity (SV) gauges the changes in texture and viscosity as starch molecules retrograde or re-associate upon cooling, providing an indicator of starch stability and its potential for retrogradation (Ratnawati et al., 2019; Yan et al., 2021). In this study, samples sprouted for one day (D1) recorded the highest SV values (271.00 RVU and 213.50 RVU), while those sprouted for three days (D3) showed the lowest values (12.50 RVU and 8.50 RVU) for *Obatanpa* and *Honampa*, respectively. No significant differences were observed between D0 and D1 (**Table 5**). Overall, SV decreased as sprouting duration increased, a trend consistent with previous studies (Sibanda et al., 2024; Okoye et al., 2023; Adebayo, 2017). This decline may be linked to changes in the amylose-to-amylopectin ratio during sprouting, which influences setback viscosity (Onyango et al., 2021). The lower setback values at D2 and D3 suggest reduced starch retrogradation and syneresis, making these samples suitable for low-viscosity foods, particularly those intended for infants. Conversely, the higher setback viscosity observed at D1 indicates that starch granules are less prone to retrogradation after cooling.

Peak Time (PTmin) refers to the duration required for each sample to reach its peak viscosity, serving as an indicator of the necessary cooking time (Majzoobi & Farahnaky, 2021). For *Obatanpa*, peak times were 7.00 min, 8.3 min, 6.87 min, and 4.09 min for sprouting days D0, D1, D2, and D3, respectively. For *Honampa*, peak times were 7.00 min, 7.00 min, 6.83 min, and 6.94 min across the same sprouting days, with no significant differences ($p>0.05$). These results indicate that *Honampa* maize flour maintains a more stable gelatinization profile across varying malting durations compared to *Obatanpa*. The reduction in peak time, particularly for *Obatanpa*, can be attributed to increased enzymatic activity during malting, which breaks down starch granules and promotes faster gelatinization (Kumar et al., 2023). Additionally, the malting process produces amylases that facilitate starch hydrolysis, thereby decreasing the time needed to reach peak viscosity (Gui et al., 2021; Han et al., 2021). The relatively stable peak time in *Honampa* suggests greater resistance to gelatinization, potentially due to differences in starch composition or structural properties during malting. Monitoring peak time can serve as an effective quality control tool to ensure consistent starch performance in various applications.

Pasting Temperature (PT °C) represents the minimum temperature required for cooking a food product, influencing the energy needed for cooking. In this study, pasting temperature was not detected in either *Obatanpa* or *Honampa* malted flours (**Table 4**). Muñoz-Llandes et al. (2023) suggested that malting leads to the degradation of starch granules, reducing their ability to swell and gelatinize. These findings also align with observations by Oyeyinka et al. (2020), who noted an inverse relationship between peak viscosity, pasting time, and temperature. Specifically, higher peak viscosities were associated with shorter pasting times and lower temperatures. Similar results were found in studies of malted pearl millet, potato starch, chickpea starch, and other beans, where pasting temperatures were undetectable when peak viscosities were below 250 RVU (Sibanda et al., 2024; Bento et al., 2021; Reddy et al., 2015). Hua & Yang (2016) explained that enzymes such as amylases break down starch into smaller polysaccharides and sugars, leading to the absence or reduction of pasting temperatures. Also, the viscosity profiles did not reach the instrument's criterion for identifying the onset of pasting as well as the lower moisture output (12%) after determination could account for the undetected pasting temperature. Again, germination substantially increases α-amylase activity, which degrades starch molecules during heating and suppresses viscosity development.

4. CONCLUSION

Sprouting significantly influenced the physicochemical, nutritional, functional, and pasting properties of Obatanpa and Honampa maize flours. Increasing sprouting duration reduced pH, lightness, yellowness, fat, fiber, carbohydrate, energy value, bulk density, loose bulk density, water absorption index, swelling power, and most pasting parameters. In contrast, titratable acidity, total soluble solids, redness, moisture, ash, protein, water- and oil-absorption capacities, dispersibility, and emulsion stability generally increased. The absence of a detectable pasting temperature in the sprouted samples may reflect increased α-amylase activity and the associated degradation of starch during heating. These findings show that controlled sprouting can serve as a low-cost means of improving selected nutritional and functional attributes of locally available maize. The resulting flours may be useful in composite foods, weaning foods, bakery products, and other applications that benefit from improved hydration and reduced paste viscosity. Further studies should optimize sprouting and kilning conditions and evaluate micronutrient bioavailability, antinutritional factors, sensory quality, shelf stability, and performance in specific food products.

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CONFLICT OF INTEREST

The authors declare no conflict of interest

DATA AVAILABILITY STATEMENT

Data is available upon reasonable request from the corresponding author

AUTHOR CONTRIBUTIONS

M.A: Writing-original draft, formal analysis, data curation, and conceptualization. **W.O**: Writing – review & editing, Supervision, Conceptualization. **S.O.A**: Writing – original draft, Formal analysis, Data curation, Conceptualization. **F. A**: Writing – original draft, Formal analysis, Data curation. **S.G.O**: Writing – original draft, Formal analysis, Data curation.

REFERENCES

Abah, C. R., Ishiwu, C. N., Obiegbuna, J. E., & Oladejo, A. A. (2020). Nutritional composition, functional properties and food applications of millet grains. *Asian Food Science Journal*, *14*(2), 9-19. https://doi.org/10.9734/AFSJ/2020/v14i230124

Adebayo, S. F. (2017). Physicochemical, antioxidants and pasting properties of some grains as affected by germination. *Research Journal of Food Science and Quality Control*, *3*(2), 2504-6145.

Adu, M., Anim, S. O., Odoom, W., Adomako, C., & Osei-Asibey, R. K. (2024). Sprouting days: Its influence on quality characteristics of millet and sorghum flour. *Applied Food Research*, *4*(2), 100518. https://doi.org/10.1016/j.afres.2024.100518

Afify, A. E. M. M., El-Beltagi, H. S., Abd El-Salam, S. M., & Omran, A. A. (2015). Effect of soaking, cooking, germination and fermentation processing on physical properties and sensory evaluation of sorghum biscuits. *Notulae Scientia Biologicae*, *7*(1), 129-135. https://doi.org/10.15835/nsb719428

Afoakwa, E. O., Adjonu, R., & Asomaning, J. (2010). Viscoelastic properties and pasting characteristics of fermented maize: influence of the addition of malted cereals. *International journal of food science & technology*, 45(2), 380-386. https://doi.org/10.1111/j.1365-2621.2009.02160.x

Aguirre, M., Kiegle, E., Leo, G., & Ezquer, I. (2018). Carbohydrate reserves and seed development: An overview. *Plant reproduction*, *31*, 263-290. https://doi.org/10.1007/s00497-018-0336-3

Agume Ntso, A. S., Njintang, Y. N., & Mbofung, C. M. F. (2017). Physicochemical and pasting properties of maize flour as a function of the interactive effect of natural-fermentation and roasting. *Journal of Food Measurement and Characterization,* 11, 451-459. https://doi.org/10.1007/s11694-016-9413-1

Ahmed, J., Al-Jassar, S., & Thomas, L. (2015). A comparison in rheological, thermal, and structural properties between Indian Basmati and Egyptian Giza rice flour dispersions as influenced by particle size. *Food Hydrocolloids*, 48, 72-83. https://doi.org/10.1016/j.foodhyd.2015.02.012

Aidoo, R., Oduro, I. N., Agbenorhevi, J. K., Ellis, W. O., & Pepra-Ameyaw, N. B. (2022). Physicochemical and pasting properties of flour and starch from two new cassava accessions. *International Journal of Food Properties*, *25*(1), 561-569. https://doi.org/10.1080/10942912.2022.2052087

Ajayi, A., & Makanjuola, O. M. (2017). Effect of Sprouting Periods on the Proximate Composition, Functional

Properties and Mineral Content of Malted Sorghum Flour. *The International Journal of Science & Technoledge*, *5*(11), 68-71.

Akonor, P. T., Tortoe, C., & Oduro-Yeboah, C. (2014). Physicochemical characterization of non-alcoholic beverages produced from malted roasted varieties of maize (Zea mays). *Food and Nutrition Sciences, 4*(1), 28-35. https://doi.org/10.5923/j.food.20140401.04

Akramov, K., & Malek, M. (2012). Analyzing profitability of maize, rice, and soybean production in Ghana: Results of PAM and DEA analysis. *Ghana Strategy Support Program (GSSP) Working*, *28*.

Alabi, S. O., Okeji, M. A., Ajewole, D. S., Foluso, O. E., & Enujiugha, V. N. (2025). Enhancing the Techno-Functional Properties of Sorghum Ogi via Starter Culture Fermentation and Mixed-Spice Incorporation. *IPS Journal of Nutrition and Food Science*, *4*(2), 444-455.https://doi.org/10.54117/ijnfs.v4i2.103

Anosike, F. C., Nwagu, K. E., Nwalo, N. F., Ikegwu, O. J., Onyeji, G. N., Enwere, E. N., & Nwoba, S. T. (2020). Functional and pasting properties of fortified complementary foods formulated from maize (Zea mays) and African yam bean (Sphenostylis stenocarpa) flours. *Legume Science*, *2*(4), e62. https://doi.org/10.1002/leg3.62

Anthony, A. (2017). *Relative susceptibility of selected maize seed varieties to the maize weevil (Sitophilus zeamais Motschulsky) in Ghana* (Master's thesis). University of Ghana.

Association of Official Analytical Chemists. (2010). *Official methods of analysis* (18th ed.). AOAC.

Association of Official Analytical Chemists. (2012). *Official methods of analysis* (19th ed.). AOAC.

Association of Official Analytical Chemists. (2016). *Official methods of analysis* (20th ed.). AOAC.

Asaam, E. S., Adubofuor, J., Amoah, I., & Apeku, O. J. D. (2018). Functional and pasting properties of yellow maize–soya bean–pumpkin composite flours and acceptability study on their breakfast cereals. *Cogent Food & Agriculture*, *4*(1), 1501932. https://doi.org/10.1080/23311932.2018.1501932

Atudorei, D., & Codină, G. G. (2020). Perspectives on the use of germinated legumes in the bread making process: A review. *Applied Sciences, 10*(18), 6244. https://doi.org/10.3390/app10186244

Awuchi, C. G., Igwe, V. S., & Echeta, C. K. (2019). The functional properties of foods and flours. *International Journal of Advanced Academic Research*, *5*(11), 139-160.

Bala, M., Handa, S., Mridula, D., & Singh, R. K. (2020). Physicochemical, functional, and rheological properties of grass pea *(Lathyrus sativus* L.) flour as influenced by particle size. *Heliyon, 6*(11), e05471. https://doi.org/10.1016/j.heliyon.2020.e05471

Baranwal, D., & Sankhla, A. (2019). Physical and functional properties of malted composite flour for biscuit production. *Journal of Pharmacognosy and Phytochemistry, 8*(2), 959-965.

Bedel, F. J., Hyacinthe, A. A., Ouolouho, C. S., & Patrice, K. L. (2022). Physicochemical Characterisation and Determination of the Effect of Temperature on the Amylase Activities of Germinated Sorghum and Maize Grains. *Asian Journal of Research in Biochemistry*, *11*(2), 23-33.https://doi.org/10.9734/ajrb/2022/v11i2213

Bento, J. A. C., Bassinello, P. Z., Carvalho, R. N., Souza Neto, M. A. D., Caliari, M., & Soares Junior, M. S. (2021). Functional and pasting properties of colorful bean (Phaseolus vulgaris L) flours: Influence of the cooking method. *Journal of Food Processing and Preservation*, *45*(11), e15899. https://doi.org/10.1111/jfpp.15899

Bhandari, L., Sodhi, N. S., & Chawla, P. (2016). Effect of acidified methanol modification on physico chemical properties of black-eyed pea (Vigna unguiculata) starch. *International Journal of Food Properties,* 19(12), 2635-2648. https://doi.org/10.1080/10942912.2016.1171236

Bikila, A. M., Tola, Y. B., Esho, T. B., Forsido, S. F., & Mijena, D. F. (2022). Starch composition and functional properties of raw and pretreated anchote (Coccinia abyssinica (Lam.) Cogn.) tuber flours dried at different temperatures. *Food Science & Nutrition*, *10*(3), 645-660. https://doi.org/10.1002/fsn3.2687

Birhane, G. (2012). *Effect of processing on phytochemicals and nutrients composition of fenugreek (Trigonella foenum-graecum L.), and development of value-added products* (Doctoral dissertation, University of Mysore).

Byarugaba, R., Nabubuya, A., Muyonga, J., & Mwakha, A. (2023). Effects of roasting conditions on the proximate composition and functional properties of common bean (Phaseolus vulgaris) flours. *Tanzania Journal of Science*, *49*(2), 546-558. https://doi.org/10.4314/tjs.v49i2.23

Chauhan, A., Saxena, D. C., & Singh, S. (2015). Total dietary fibre and antioxidant activity of gluten-free cookies made from raw and germinated amaranth *(Amaranthus* spp.) flour. *LWT - Food Science and Technology, 63*(2), 939–945. https://doi.org/10.1016/j.lwt.2015.03.115

Chinma, C. E., Abu, J. O., Asikwe, B. N., Sunday, T., & Adebo, O. A. (2021). Effect of germination on the physicochemical, nutritional, functional, thermal properties and in vitro digestibility of Bambara groundnut flours. *LWT-Food Science and Technology*, *140*, 110749. 10.1016/j.lwt.2020.110749

Choque-Quispe, D., Choque-Quispe, Y., Ligarda-Samanez, C. A., Peralta-Guevara, D. E., Solano-Reynoso, A. M., Ramos-Pacheco, B. S., & Quispe-Quispe, Y. (2022). Effect of the addition of corn husk cellulose nanocrystals in the development of a novel edible film. *Nanomaterials*, *12*(19), 3421. https://doi.org/10.3390/nano12193421

De Flaviis, R., & Sacchetti, G. (2025). A 50-Year Theoretical Gap on Color Difference in Food Science: Critical Insights and New Perspectives. *Journal of Food Science*, *90*(6), e70317. https://doi.org/10.1111/1750-3841.70317

de Matos, M. F. R., Bezerra, P. Q. M., Correia, L. C. A., Viola, D. N., de Oliveira Rios, A., Druzian, J. I., & Nunes, I. L. (2021). Innovative methodological approach using CIELab and dye screening for chemometric classification and HPLC for the confirmation of dyes in cassava flour: A contribution to product quality control. *Food Chemistry, 365*, 130446. https://doi.org/10.1016/j.foodchem.2021.130446

Derbew, H., & Moges, D. (2017). Effect of germination duration on nutritional and functional properties of sorghum (Sorghum bicolor): The case of Girana and Miskr varieties. *Ethiopian Journal of Science and Technology, 10*(3), 165–180. https://doi.org/10.4314/ejst.v10i3.2

Dereje, B., Girma, A., Mamo, D., & Chalchisa, T. (2020). Functional properties of sweet potato flour and its role in product development: a review. *International Journal of Food Properties*, 23(1), 1639-1662. https://doi.org/10.1080/10942912.2020.1818776

Deriu, A. G., Vela, A. J., & Ronda, F. (2022). Techno-functional and gelling properties of Acha (Fonio)(Digitaria exilis stapf) flour: a study of its potential as a new Gluten-free starch source in industrial applications. *Foods*, *11*(2), 183. https://doi.org/10.3390/foods11020183

Dhliwayo, T., Chopera, P., Matsungo, T. M., Chidewe, C., Mukanganyama, S., Nyakudya, E., & Nyanga, L. K. (2023). Effect of germination and roasting on the proximate, mineral and anti-nutritional factors in finger millet (Eleucine coracana), cowpeas. *African Journal of Food, Agriculture, Nutrition and Development,* 23(8), 24346-24362. https://doi.org/10.22004/ag.econ.340751

do Nascimento, L. Á., Abhilasha, A., Singh, J., Elias, M. C., & Colussi, R. (2022). Rice germination and its impact on technological and nutritional properties: A review. *Rice Science*, *29*(3), 201-215. https://doi.org/10.1016/j.rsci.2022.01.009

Dongmo, H., Tambo, S. T., Teboukeu, G. B., Mboukap, A. N., Fotso, B. S., Djuidje, M. C. T., & Klang, J. M. (2020). Effect of process and variety on physico-chemical and rheological properties of two corn flour varieties (Atp and Kassaï). *Journal of Agriculture and Food Research*, *2*, 100075. https://doi.org/10.1016/j.jafr.2020.100075

Donmez, D., Pinho, L., Patel, B., Desam, P., & Campanella, O. H. (2021). Characterization of starch–water interactions and their effects on two key functional properties: Starch gelatinization and retrogradation. *Current Opinion in Food Science*, *39*, 103-109. https://doi.org/10.1016/j.cofs.2020.12.018

Ejim, M. N., Omachi, A. B., Odor, C. B., Abiodun, M. A., & Obafemi, J. K. (2019). Proximate composition and sensory properties of bread produced from malted maize–soy flour blends. *International Journal of Pure and Applied Science, 17*(9), 145–155. https://doi.org/10.70382/hijcisr.v10i9.033

Eke-Ejiofor, J. N., Ojimadu, A. E., Wordu, G. O., & Ofoedu, C. E. (2021). Functional properties of complementary food from millet (Pennisetum glaucum), African yam bean (Sphenostylis stenocarpa), and Jackfruit (Artocarpus heterophyllus) flour blends: A comparative study. *Asian Food Science Journal*, *20*(9), 45-62.https://doi.org/10.9734/afsj/2021/v20i930342

Eli-Cophie, D., Agbenorhevi, J. K., & Annan, R. A. (2017). Glycemic index of some local staples in Ghana. *Food Science & Nutrition,* *5*(1), 131–138. https://doi.org/10.1002/fsn3.372

Food and Agriculture Organization of the United Nations. (2021). *FAOSTAT statistical database*. https://www.fao.org/faostat

Ferreira, C. D., Bubolz, V. K., da Silva, J., Dittgen, C. L., Ziegler, V., de Oliveira Raphaelli, C., & de Oliveira, M. (2019). Changes in the chemical composition and bioactive compounds of chickpea (*Cicer arietinum* L.) fortified by germination. *LWT, 111*, 363–369. https://doi.org/10.1016/j.lwt.2019.05.049

Fideles, M. C., Bento, J. A. C., Ferreira, K. C., Oliveira, A. L. M. D., Caliari, M., & Soares, M. S. (2019). Physicochemical and technological characteristics of arrowroot flour modified by ultrasound and low-temperature heat treatment. *Ciência Rural, 49*(10), e20181037**.** https://doi.org/10.1590/0103-8478cr20181037

Fox, G. P., & Bettenhausen, H. M. (2023). Variation in quality of grains used in malting and brewing. *Frontiers in Plant Science*, *14*, 1172028. https://doi.org/10.3389/fpls.2023.1172028

Gernah, D. I., Ariahu, C. C., & Ingbian, E. K. (2011). Effects of malting and lactic fermentation on some chemical and functional properties of maize (Zea mays). *American Journal of Food Technology, 6*(5), 404-412. https://doi.org/10.3923/ajft.2011.404.412

Gnanwa, M. J., Fagbohoun, J. B., Ya, K. C., Blei, S. H., & Kouame, L. P. (2021). Assessment of minerals, vitamins and functional properties of flours from germinated yellow maize (*Zea mays* L.) seeds from Daloa (Côte D'Ivoire). *International Journal of Food Science and Nutrition Engineering, 11*(2), 35-42. https://doi.org/10.5923/j.food.20211102.01

Gui, Y., Zou, F., Li, J., Zhu, Y., Guo, L., & Cui, B. (2021). The structural and functional properties of corn starch treated with endogenous malt amylases. *Food Hydrocolloids, 117,* 106722. https://doi.org/10.1016/j.foodhyd.2021.106722

Guo, R., Shi, L., Yan, C., Zhong, X., Gu, F., Liu, Q., & Li, H. (2017). Ionomic and metabolic responses to neutral salt or alkaline salt stresses in maize (*Zea mays* L.) seedlings. *BMC Plant Biology, 17,* 41. https://doi.org/10.1186/s12870-017-0994-6

Gupta, S., Chhabra, G. S., Liu, C., Bakshi, J. S., & Sathe, S. K. (2018). Functional properties of select dry bean seeds and flours. *Journal of Food Science, 83*(8), 2052–2061. https://doi.org/10.1111/1750-3841.14213

Guzmán-Ortiz, F. A., Castro-Rosas, J., Gómez-Aldapa, C. A., Mora-Escobedo, R., Rojas-León, A., Rodríguez-Marín, M. L., & Román-Gutiérrez, A. D. (2019). Enzyme activity during germination of different cereals: A review. *Food Reviews International*, *35*(3), 177-200. https://doi.org/10.1080/87559129.2018.1514623

Hamadina, E. I., & Asiedu, R. (2015). Dry matter, free sugar, and starch changes in tuber regions of white yam *(Dioscorea rotundata Poir*.), and the effect of storage environment. *Journal of Advances in Agriculture, 4*(1), 303–309. https://doi.org/10.24297/jaa.v4i1.4298

Hamid, S., Muzzafar, S., Wani, I. A., & Masoodi, F. A. (2015). Physicochemical and functional properties of two cowpea cultivars grown in temperate Indian climate. *Cogent Food & Agriculture, 1*(1), 1099418**.** https://doi.org/10.1080/23311932.2015.10994

Han, X., Wen, H., Luo, Y., Yang, J., Xiao, W., Ji, X., & Xie, J. (2021). Effects of α-amylase and glucoamylase on the characterization and function of maize porous starches. *Food Hydrocolloids*, *116*, 106661. https://doi.org/10.1016/j.foodhyd.2021.106661

Haug, W., Lantzsch, H. J., & Schmidtlein, H. (2017). The effects of malting on the protein content and quality of maize. *Journal of Cereal Science*, 75, 56-63. https://doi.org/10.1002/jsfa.2740341217

Hedayati, S., Shahidi, F., Majzoobi, M., Koocheki, A., & Farahnaky, A. (2020). Structural, rheological, pasting and textural properties of granular cold water swelling maize starch: Effect of NaCl and CaCl2. *Carbohydrate polymers*, *242*, 116406. https://doi.org/10.1016/j.carbpol.2020.116406

Hua, X., & Yang, R. (2016). Enzymes in starch processing. *Enzymes in food and beverage processing*, 139-170.

Ikram, A., Saeed, F., Afzaal, M., Imran, A., Niaz, B., Tufail, T., & Anjum, F. M. (2021). Nutritional and end-use perspectives of sprouted grains: A comprehensive review. *Food science & nutrition*, *9*(8), 4617-4628. https://doi.org/10.1002/fsn3.2408

Ikujenlola, A. V., Oguntuase, S. O., & Omosuli, S. V. (2013). Physico-chemical properties of complementary food from malted quality protein maize (*Zea mays* L.) and defatted fluted pumpkin flour (*Telfairia occidentalis* Hook, f.). *Food and Public Health, 3*(6), 283–288. https://doi.org/10.5923/j.fph.20130306.09

Iwe, M. O., Onyeukwu, U., & Agiriga, A. N. (2016). Proximate, functional and pasting properties of FARO 44 rice, African yam bean and brown cowpea seeds composite flour. *Cogent Food & Agriculture*, *2*(1), 1142409. https://doi.org/10.1080/23311932.2016.1142409

Jamal, S., Qazi, I. M., & Ahmed, I. (2016). Comparative studies on flour proximate compositions and functional properties of selected Pakistani rice varieties: Comparative studies on flour proximate compositions and functional properties. *Proceedings of the Pakistan Academy of Sciences: B. Life and Environmental Sciences*, *53*(1), 47-56.

Ji, M., Fang, W., Li, W., Zhao, Y., Guo, Y., Wang, W., Chen, G., Tian, J., & Deng, Z. (2021). *Genome wide association study of the whiteness and colour related traits of flour and dough sheets in common wheat. Scientific Reports, 11*, 8790. https://doi.org/10.1038/s41598-021-88241-4

Kamara, A. Y., Sanginga, P. C., & Menkir, A. (2020). Maize production in Africa: Status, challenges and the future. *Agriculture & Food Security*, 9(1), 1-13.

Kapoor, D., Bhardwaj, S., Landi, M., Sharma, A., Ramakrishnan, M., & Sharma, A. (2020). The impact of drought in plant metabolism: How to exploit tolerance mechanisms to increase crop production. *Applied Sciences*, *10*(16), 5692. https://doi.org/10.3390/app10165692

Kassegn, H. H., Atsbha, T. W., & Weldeabezgi, L. T. (2018). Effect of germination process on nutrients and phytochemicals contents of faba bean (Vicia faba L.) for weaning food preparation. *Cogent Food & Agriculture*, *4*(1), 1545738. https://doi.org/10.1080/23311932.2018.1545738

Kaur, R., Pahwa, A. A., & Bhise, S. H. (2021). Maize: A potential grain for functional and nutritional properties. In *Cereals and -Based Foods* (pp. 65-80). *Apple Academic Press*

Kaushal, P., Kumar, V., & Sharma, H. K. (2012). Comparative study of physicochemical, functional, antinutritional, and pasting properties of taro (*Colocasia esculenta*), rice (*Oryza sativa*) flour, pigeonpea (*Cajanus cajan*) flour, and their blends. *LWT - Food Science and Technology, 48*(1), 59–68. https://doi.org/10.1016/j.lwt.2012.02.028

Kok, Y. J., Ye, L., Muller, J., Ow, D. S. W., & Bi, X. (2019). Brewing with malted barley or raw barley: What makes the difference in the processes? *Applied Microbiology and Biotechnology, 103*(3), 1059–1067. https://doi.org/10.1007/s00253-018-9537-9

Kumar, S. R., Sadiq, M. B., & Anal, A. K. (2022). Comparative study of physicochemical and functional properties of soaked, germinated and pressure-cooked faba bean. *Journal of Food Science and Technology, 59*(1), 257–267. https://doi.org/10.1007/s13197-021-05010-x

Kumar, S., & Saini, C. S. (2016). Study of various characteristics of composite flour prepared from the blend of wheat flour and gorgon nut flour. *International Journal of Agriculture, Environment and Biotechnology, 9*(4), 679–689. https://doi.org/10.5958/2230-732X.2016.00089.9

Kumar, V., Chaturvedi, S. K., & Singh, G. P. (2023). Brief review of malting quality and frontier areas in barley. *Cereal Research Communications, 51*(1), 45–59. https://doi.org/10.1007/s42976-022-00292-z

Kumari, S., Singh, B., & Kaur, A. (2023). Influence of malted buckwheat, foxtail and proso millet flour incorporation on the physicochemical, protein digestibility and antioxidant properties of gluten-free rice cookies. *Food Chemistry Advances, 3*, 100557. https://doi.org/10.1016/j.focha.2023.100557

Kunle, O. L., Alamuoye, N. O., Ajatta, M. A., & Ogundari, A. A. (2023). Effects of malting on physicochemical composition of maize and sorghum. *Journal of Plant Biology and Soil Health, 1*(1), 27–33. https://doi.org/10.33140/PBSHJ.1.1.27-33

Kushwaha, V. S., & Said, P. P. (2020). Characterization of functional flour from germinated grains. *Indian Journal of Pure & Applied Biosciences, 8*(6), 46–55. https://doi.org/10.18782/2582-2845.8113

Li, T., Huang, J., Yu, J., Tian, X., Zhang, C., & Pu, H. (2024). Effects of soaking glutinous sorghum grains on physicochemical properties of starch. *International Journal of Biological Macromolecules, 267*, 131522. https://doi.org/10.1016/j.ijbiomac.2024.131522

Ligarda-Samanez, C. A., Moscoso-Moscoso, E., Choque-Quispe, D., Ramos-Pacheco, B. S., Arévalo-Quijano, J. C., Cruz, G. D. L., & Calsina Ponce, W. C. (2023). Native potato starch and tara gum as polymeric matrices to obtain iron-loaded microcapsules from ovine and bovine erythrocytes. *Polymers, 15*(19), 3985. https://doi.org/10.3390/polym15193985

Lin, T., & Fernández-Fraguas, C. (2020). Effect of thermal and high-pressure processing on the thermo-rheological and functional properties of common bean (*Phaseolus vulgaris* L.) flours. *LWT, 127*, 109325. https://doi.org/10.1016/j.lwt.2020.109325

Liu, Y., Chen, Q., Fang, F., Liu, J., Wang, Z., Chen, H., & Zhang, F. (2021). The influence of konjac glucomannan on the physicochemical and rheological properties and microstructure of canna starch. *Foods, 10*(2), 422. https://doi.org/10.3390/foods10020422

Majzoobi, M., & Farahnaky, A. (2021). Granular cold-water swelling starch: Properties, preparation and applications- A review. *Food Hydrocolloids, 111*, 106393. https://doi.org/10.1016/j.foodhyd.2020.106393

Makanjuola, O. M., & Makanjuola, J. O. (2018). Chemical properties of corn starch as influenced by sprouting periods. *International Journal of Food Science and Nutrition, 3*(6), 90–94.

Malama, F., Nyau, V., Marinda, P., & Munyinda, K. (2020). Effect of sprouting on selected macronutrients and physical properties of four Zambian common bean (Phaseolus vulgaris) varieties. *Journal of Food and Nutrition Research, 8*(5), 238–243. https://doi.org/10.12691/jfnr-8-5-

Maldonado-Alvarado, P., Pavón-Vargas, D. J., Abarca-Robles, J., Valencia-Chamorro, S., & Haros, C. M. (2023). Effect of germination on the nutritional properties, phytic acid content, and phytase activity of quinoa (Chenopodium quinoa Willd). *Foods*, *12*(2), 389. https://doi.org/10.3390/foods12020389

Marshall, M. R. (2010). Ash analysis. In S. S. Nielsen (Ed.), *Food analysis* (4th ed., pp. 105–115). Springer US. https://doi.org/10.1007/978-1-4419-1478-1_7

Maskan, M. (2001). Kinetics of colour change of kiwifruits during hot air and microwave drying. *Journal of Food Engineering, 48*(2), 169–175. https://doi.org/10.1016/S0260-8774(00)00154-0

Ministry of Food and Agriculture (MoFA). (2018). *Planting for food and jobs: Maize (Zea mays* L.) manual. Accra, Ghana: Ministry of Food and Agriculture.

Ministry of Food and Agriculture. (2020). *2019 agricultural sector progress report (APR): Paper presented at the 2020 Agricultural Joint Sector Review (JSR), Accra, Ghana*. Ministry of Food and Agriculture**.**

Monroe, J., Barry, M., DeStefano, A., Aydogan Gokturk, P., Jiao, S., Robinson-Brown, D., & Shell, M. S. (2020). Water structure and properties at hydrophilic and hydrophobic surfaces. *Annual Review of Chemical and Biomolecular Engineering*, *11*(1), 523-557 https://doi.org/10.1146/annurev-chembioeng-120919-114657

Mouritsen, O. G., & Styrbæk, K. (2017). *Mouthfeel: how texture makes taste*. Columbia University Press

Muñoz-Llandes, C. B., Martínez-Villaluenga, C., Palma-Rodríguez, H. M., Román-Gutiérrez, A. D., Castro-Rosas, J., & Guzmán-Ortiz, F. A. (2023). Effect of germination on starch. In *Starch: Advances in modifications, technologies and applications* (pp. 457-486). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-35843-2_19

Murray, J. C., Kiszonas, A. M., & Morris, C. F. (2017). Influence of soft kernel texture on the flour, water absorption, rheology, and baking quality of durum wheat. *Cereal Chemistry*, *94*(2), 215-222. https://doi.org/10.1094/CCHEM-06-16-0163-R

Murungweni, K. T., Ramashia, S. E., & Mashau, M. E. (2024). Effect of malting on physicochemical, antioxidant, and microstructural properties of finger millet (Eleusine coracana) flours. *Food Science & Nutrition*, *12*(1), 547-563. https://doi.org/10.1002/fsn3.3790

Musah Bawa, N., K. Agbenorhevi, J., M. Kpodo, F., & Sampson, G. O. (2020). Pasting properties of starch-okra pectin mixed system. CYTA-*Journal of Food*, 18(1), 742-746. https://doi.org/10.1080/19476337.2020.1798277

Naraharasetti, B., Chakraborty, S., Siliveru, K., & Prasad, P. V. (2025). Thermal and Nonthermal Processing of Pearl Millet Flour: Impact on Microbial Safety, Enzymatic Stability, Nutrients, Functional Properties, and Shelf-Life Extension. *Comprehensive Reviews in Food Science and Food Safety*, *24*(3), e70190. https://doi.org/10.1111/1541-4337.70190

Nelson, K., Stojanovska, L., Vasiljevic, T., & Mathai, M. (2013). Germinated grains: A superior whole grain functional food? *Canadian Journal of Physiology and Pharmacology, 91*(6), 429–441**.** https://doi.org/10.1139/cjpp-2012-0351

Nkhata, K., Muyonga, J. P., Mupondwa, E. M., & Ndife, J. (2018). Effect of germination on thenutritional quality of cereal grains: A review. *Journal of Food Science and Technology*,55(1), 1-15. https://doi.org/10.1002/fsn3.846

Nwachoko, N., Akuru, U. B., Duke, B. N., & Egbunefu, C. O. (2023). Proximate Composition and Selected Physicochemical Parameters of Cake Prepared with Preservatives. *Int. J. Appl. Chem, 10*, 11-17. https://doi.org/10.14445/23939133/IJAC-V10I3P102

Nwosu, J. N., Owuamanam, C. I., Omeire, G. C., & Eke, C. C. (2014). Quality parameters of bread produced from substitution of wheat flour with cassava flour using soybean as an improved. *American Journal of Research Communication*, 2(3), 99-118.

Ocheme, O. B., Adedeji, O. E., Chinma, C. E., Yakubu, C. M., & Ajibo, U. H. (2018). Proximate composition, functional, and pasting properties of wheat and groundnut protein concentrate flour blends. *Food Science & Nutrition*, *6*(5), 1173-1178. https://doi.org/10.1002/fsn3.670

Ocheme, O. B., Adedeji, O. E., Lawal, G., & Zakari, U. M. (2015). Effect of germination on functional properties and degree of starch gelatinization of sorghum flour. Journal of Food Research, 4(2), 159–168. https://doi.org/10.5539/jfr.v4n2p159

Ojewumi, M. E., Adeeyo, O. A., Akingbade, O. M., Babatunde, D. E., Ayoola, A. A., Awolu, O. O., & Omodara, O. J. (2018). Evaluation of glucose syrup produced from cassava hydrolyzed with malted grains (rice, sorghum, and maize). *International Journal of Pharmaceutical Sciences and Research, 9*(8), 1000–1011. https://doi.org/10.13040/IJPSR.0975-8232.9(8).1000-11

Ojha, P., Adhikari, R., Karki, R., Mishra, A., Subedi, U., & Karki, T. B. (2018). Malting and fermentation effects on antinutritional components and functional characteristics of sorghum flour. *Food Science and Nutrition,* 6(1), 47–53. https://doi.org/10.1002/fsn3.525

Okoye, J. I., Ahmadu, D. L., & Egbujie, A. E. (2023). Evaluation of proximate composition, functional and pasting properties of millet-based breakfast cereals supplemented with soybean and date fruit flours. *International Journal of Scholarly Research in Engineering and Technology, 2*(2), 60–70. https://doi.org/10.56781/ijsret.2023.2.2.0033

Oladapo, A. S., Adepeju, A. B., Akinyele, A. A., & Adepeju, D. M. (2017). The proximate, functional and antinutritional properties of three selected varieties of maize (yellow, white and popcorn) flour. *International Journal of Scientific Engineering and Science, 1*(2), 23–26.

Olamiti, G., Takalani, T. K., Beswa, D., & Jideani, A. I. O. (2020). Effect of malting and fermentation on colour, thermal properties, functional groups, and crystallinity level of flours from pearl millet *(*Pennisetum glaucum) and sorghum (*Sorghum bicolor*). *Heliyon, 6*(12), e05467. https://doi.org/10.1016/j.heliyon.2020.e05467

Olapade, A. A., Babalola, Y. O., & Aworh, O. C. (2014). Quality attributes of fufu (fermented cassava) flour supplemented with bambara flour. *International Food Research Journal, 21*, 2025–2030.

Olu, M., Ogunmoyela, O. A. B., Adekoyeni, O. O., Jimoh, O., Oluwajoba, S. O., & Sobanwa, M. O. (2012). Rheological and functional properties of soy-poundo yam flour. *International Journal of Food Science and Nutrition Engineering, 2*(6), 101–107. https://doi.org/10.5923/j.food.20120206.01

Onwurafor, E., Ani, J., Nneka, U., & Ziegle, G. (2020). Quality evaluation of fermented maize-based complementary foods as affected by amylase-rich mungbean malt. *Journal of Food Stability, 3*(1), 26–37. https://doi.org/10.36400/J.Food.Stab.3.1.2020-0025

Onyango, C., Luvitaa, S. K., Lagat, K., & K'osambo, L. (2021). Impact of carrageenan copolymers from two red seaweed varieties on dough and bread quality. *Journal of Applied Phycology, 33*(5), 3347–3356. https://doi.org/10.1007/s10811-021-02524-x

Oseguera-Toledo, M. E., Contreras-Jiménez, B., Hernández-Becerra, E., & Rodriguez-Garcia, M. E. (2020). Physicochemical changes of starch during malting process of sorghum grain. *Journal of Cereal Science, 95*, 103069. 10.1016/j.jcs.2020.103069

Owheruo, J. O., Ifesan, B. O. T., & Kolawole, A. O. (2019). Physicochemical properties of malted finger millet (*Eleusine coracana*) and pearl millet (*Pennisetum glaucum*). *Food Science & Nutrition, 7*(2), 476–482. https://doi.org/10.1002/fsn3.816

Oyeyinka, S. A., Adeloye, A. A., Olaomo, O. O., & Kayitesi, E. (2020). Effect of fermentation time on physicochemical properties of starch extracted from cassava root. *Food Bioscience, 33*, 100485. https://doi.org/10.1016/j.fbio.2019.100485

Pathare, P. B., Opara, U. L., & Al-Said, F. A. J. (2013). Colour measurement and analysis in fresh and processed foods: A review. *Food and Bioprocess Technology, 6*(1), 36–60. https://doi.org/10.1007/s11947-012-0867-9

Pedrali, D., Giupponi, L., De la Peña-Armada, R., Villanueva-Suárez, M. J., & Mateos-Aparicio, I. (2023). The quinoa variety influences the nutritional and antioxidant profile rather than the geographic factors. *Food Chemistry, 402,* 133531. https://doi.org/10.1016/j.foodchem.2022.133531

Pérez-Díaz, I. M., Altuntas, E. G., & Juneja, V. K. (2017). Microbial fermentation in food preservation. In V. K. Juneja, H. N. Thippareddi, & J. B. Luchansky (Eds.), *Microbial control and food preservation: Theory and practice* (pp. 281–298). Cham: Springer. https://doi.org/10.1007/978-1-4939-7556-3_13

Prasadi, V. N., & Joye, I. J. (2023). Effect of soluble dietary fibre from barley on the rheology, water mobility, and baking quality of wheat flour dough. *Journal of Cereal Science, 112,* 103715. https://doi.org/10.1016/j.jcs.2023.103715

Qi, M., Jiang, L., Song, J., Suo, W., Deng, Y., Li, L., & Li, H. (2023). Extrusion modification of cassava flour for improved mashing efficiency. *LWT, 177,* 114565. https://doi.org/10.1016/j.lwt.2023.114565

Ragasa, C., Chapoto, A., & Kolavalli, S. (2014). *Maize productivity in Ghana* (Vol. 5). Intl Food Policy Res Inst.

Rajkumar, S., Nayar, R., Rajagopal, K., Valsalan, N., Chinnasamy, S., Vasudevan, V. N., & Manjunath, N. (2022). Product characterization of a traditional sausage aiming at geographical indication certification and entrepreneurship prospects: An empirical study of Goan "choris." *British Food Journal, 124*(11), 3821–3840. https://doi.org/10.1108/BFJ-06-2021-0619

Ramashia, S. E., Gwata, E. T., Meddows-Taylor, S., Anyasi, T. A., & Jideani, A. I. O. (2018). Some physical and functional properties of finger millet (*Eleusine coracana*) obtained in sub-Saharan Africa. *Food Research International, 104*, 110–118. https://doi.org/10.1016/j.foodres.2017.10.058

Ramos-Martín, F., & D'Amelio, N. (2022). Biomembrane lipids: When physics and chemistry join to shape biological activity. *Biochimie, 203,* 118–138. https://doi.org/10.1016/j.biochi.2022.07.011

Ramos-Pacheco, B. S., Choque-Quispe, D., Ligarda-Samanez, C. A., Solano-Reynoso, A. M., Palomino-Rincón, H., Choque-Quispe, Y., & Aiquipa-Pillaca, Á. S. (2024). Effect of germination on the physicochemical properties, functional groups, content of bioactive compounds, and antioxidant capacity of different varieties of quinoa (*Chenopodium quinoa* Willd.) grown in the high Andean zone of Peru. *Foods, 13*(3), 417. https://doi.org/10.3390/foods13030417

Rathore, H., Sehwag, S., Prasad, S., & Sharma, S. (2019). Technological, nutritional, functional and sensorial attributes of the cookies fortified with *Calocybe indica* mushroom. *Journal of Food Measurement and Characterization, 13*(2), 976–987. https://doi.org/10.1007/s11694-018-0012-1

Ratnawati, L., Desnilasari, D., Surahman, D. N., & Kumalasari, R. (2019). Evaluation of physicochemical, functional and pasting properties of soybean, mung bean and red kidney bean flour as ingredient in biscuit. In *IOP Conference Series: Earth and Environmental Science* (Vol. 251, p. 012026). IOP Publishing. https://doi.org/10.1088/1755-1315/251/1/012026

Reddy, C. K., Pramila, S., & Haripriya, S. (2015). Pasting, textural and thermal properties of resistant starch prepared from potato (*Solanum tuberosum*) starch using pullulanase enzyme. *Journal of Food Science and Technology, 52*(3), 1594–1601. https://doi.org/10.1007/s13197-013-1151-3

Rungpichayapichet, P., Mahayothee, B., Nagle, M., Khuwijitjaru, P., & Müller, J. (2016). Robust NIRS models for non-destructive prediction of postharvest fruit ripeness and quality in mango. *Postharvest Biology and Technology, 111,* 31–40. https://doi.org/10.1016/j.postharvbio.2015.07.006

Salami, K. O., Akinoso, R., Oyeyinka, S. A., & Kayode, R. M. O. (2018). Proximate, anti-nutrient composition and sensory properties of germinated cereal grain with added souring fruit extract. *Annals: Food Science & Technology*, *19*(2), 275-280.

Sammartino, M. (2015). Enzymes in brewing. *MBAA Technical Quarterly, 52*(3), 156–164. https://doi.org/10.1094/TQ-52-3-0818-0

Sanni, D. M., & Fatoki, T. H. (2017). Evaluation of malting properties and activities of three enzymes from sorghum (Sorghum bicolor) during malting. *African Journal of Food Science & Technology*, *8*(6), 90-98. http:/dx.doi.org/10.14303/ajfst.2017.113

Serna-Saldivar, S. O. (2023). Maize. In *ICC Handbook of 21st Century Cereal Science and Technology* (pp. 131-143). Academic Press.

Shafie, B., Cheng, S. C., Lee, H. H., & Yiu, P. H. (2016). Characterization and classification of whole-grain rice based on rapid visco analyzer (RVA) pasting profile. *International Food Research Journal*, *23*(5).

Shah, A., & Smith, D. L. (2020). Flavonoids in agriculture: Chemistry and roles in, biotic and abiotic stress responses, and microbial associations. *Agronomy, 10*(8), 1209. https://doi.org/10.3390/agronomy10081209

Sharma, M., Mridula, D., Yadav, D. N., & Gupta, R. K. (2015). Physico-chemical characteristics of maize and sorghum as affected by popping. *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences*, *85*, 787-792. https://doi.org/10.1007/s40011-015-0509-x

Sharma, S., & Garg, A. P. (2023). Effect of germination on the physicochemical and anti- nutritional properties of finger millet (Eleusine coracana), pearl millet (Pennisetum glaucum), and sorghum (Sorghum bicolor). *Pharma Innov. J*, *12*, 4763-4772. https://www.doi.org/10.22271/tpi

Sharma, S., Singh, A., & Singh, B. (2019). Characterization of in vitro antioxidant activity, bioactive components, and nutrient digestibility in pigeon pea (Cajanus cajan) as influenced by germination time and temperature. *Journal of food biochemistry*, *43*(2), e12706. https://doi.org/10.1111/jfbc.12706

Shimelis, E. A., Meaza, M., & Rakshit, S. (2006). Physico-chemical properties, pasting behavior, and functional characteristics of flours and starches from improved bean (Phaseolus vulgaris L.) varieties grown in East Africa. *Journal of Food Science and Technology, 43*(5), 632–639. https://www.researchgate.net/publication/267306103

Shin, J. E. (2022). Functional Constipation. In *Sex/Gender-Specific Medicine in the Gastrointestinal Diseases* (pp. 259-272). Singapore: Springer Nature Singapore.

Sibanda, F., Jideani, V. A., & Obilana, A. O. (2024). Nutritional, biochemical, and functional properties of pearl millet and Moringa oleifera leaf powder composite meal powders. *Foods*, *13*(5), 743. https://doi.org/10.3390/foods13050743

Sibian, M. S., Saxena, D. C., & Riar, C. S. (2017). Effect of germination on chemical, functional and nutritional characteristics of wheat, brown rice and triticale: a comparative study. *Journal of the Science of Food and Agriculture*, *97*(13), 4643-4651. https://doi.org/10.1002/jsfa.8336

Singh, A. K., Rehal, J., Kaur, A., & Jyot, G. (2015). Enhancement of attributes of cereals by germination and fermentation: A review. *Critical Reviews in Food Science and Nutrition*, *55*(11), 1575-1589. https://doi.org/10.1080/10408398.2012.706661

Siyuan, S., Tong, L., & Liu, R. (2018). Corn phytochemicals and their health benefits. *Food Science and Human Wellness*, *7*(3), 185-195. https://doi.org/10.1016/j.fshw.2018.09.003

Statistics Research and Information Directorate (SRID), Ministry of Food and Agriculture. (2011). *Agriculture in Ghana: Facts and figures* (May 2011). Accra, Ghana: SRID-MoFA.

Sun, X., Zhang, Y., Li, J., Aslam, N., Sun, H., Zhao, J., ... & He, S. (2019). Effects of particle size on physicochemical and functional properties of superfine black kidney bean (Phaseolus vulgaris L.) powder. *PeerJ, 7*, e6369. https://doi.org/10.7717/peerj.6369

Taylor, J. R., & Duodu, K. G. (2015). Effects of processing sorghum and millets on their phenolic phytochemicals and the implications of this to the health-enhancing properties of sorghum and millet food and beverage products. *Journal of the Science of Food and Agriculture*, *95*(2), 225-237. https://doi.org/10.1002/jsfa.6713

Tene, S. T., Ndinteh, D. T., Dongmo, J. R., Adebo, O. A., Kewuyemi, Y. O., Kamdem, M. H. K., & Womeni, H. M. (2022). Optimization using response surface methodology of amylolytic capacity of maize Atp-Y and Coca-sr varieties: in vitro digestibility capacity, physico- chemical and functional properties of optimal sample. *Journal of Agriculture and Food Research*, *9*, 100342. https://doi.org/10.1016/j.jafr.2022.100342

Thitisaksakul, M., Sangwongchai, W., Mungmonsin, U., Promrit, P., Krusong, K., Wanichthanarak, K., & Tananuwong, K. (2021). Granule morphological and structural variability of Thai certified glutinous rice starches in relation to thermal, pasting, and digestible properties. *Cereal Chemistry*, *98*(3), 492-506. https://doi.org/10.1002/cche.10389

Tripp, R., & Ragasa, C. (2015). Hybrid maize seed supply in Ghana. GSSP working papers. *International Food Policy Research Institute*, Washington, DC.

Udeh, H. O., Duodu, K. G., & Jideani, A. I. O. (2018). Effect of malting period on physicochemical properties, minerals, and phytic acid of finger millet (Eleusine coracana) flour varieties. *Food Science and Nutrition*, 6(7), 1858–1869. https://doi.org/10.1002/fsn3.696

Udoro, E. O., Anyasi, T. A., & Jideani, A. I. O. (2020). Characterization of the root and flour of South African Manihot esculenta Crantz landraces and their potential end-use properties. *International Journal of Food Properties*, *23*(1), 820-838. https://doi.org/10.1080/10942912.2020.1759625

Vela, A. J., Villanueva, M., & Ronda, F. (2024). Ultrasonication: An efficient alternative for the physical modification of starches, flours and grains. *Foods*, *13*(15), 2325. https://doi.org/10.3390/foods13152325

Wang, R., & Hartel, R. W. (2021). Understanding stickiness in sugar-rich food systems: A review of mechanisms, analyses, and solutions of adhesion. *Comprehensive*

Reviews in Food Science and Food Safety, *20*(6), 5901-5937. https://doi.org/10.1111/1541-4337.12833

Wani, I. A., Andrabi, S. N., Sogi, D. S., & Hassan, I. (2020). Comparative study of physicochemical and functional properties of flours from kidney bean (Phaseolus vulgaris L.) and green gram (*Vigna radiata* L.) cultivars grown in Indian temperate climate. *Legume Science*, *2*(1), e11. https://doi.org/10.1002/leg3.11

Wongnaa, C. A., & Awunyo-Vitor, D. (2019). Scale efficiency of maize farmers in four agro ecological zones of Ghana: A parametric approach. Journal of the Saudi Society of *Agricultural Sciences*, 18(3), 275-287. https://doi.org/10.1016/j.jssas.2017.08.003

Xolo, T., Keyser, Z., & Jideani, V. A. (2024). Effect of sorghum and maize malt particle size on physicochemical, stability, microbiological, and sensory characteristics of Umqombothi. *Applied Sciences,* 14(14), 6119. https://doi.org/10.3390/app14146119

Yan, W., Yin, L., Zhang, M., Zhang, M., & Jia, X. (2021). Gelatinization, retrogradation and gel properties of wheat starch–wheat bran arabinoxylan complexes. *Gels*, *7*(4), 200. https://doi.org/10.3390/gels7040200

Yang, G., Zhou, D., Hu, D., Fan, L., Li, R., & Wang, S. (2025). Development of potential processing technologies for germinated edible seeds and their applications in food: a comprehensive review. *Critical Reviews in Food Science and Nutrition*, 1- 32. https://doi.org/10.1080/10408398.2025.2505237

Yenasew, A., & Urga, K. (2022). Effect of germination period on physiochemical properties of elite finger millet varieties. *Cogent Food & Agriculture*, *8*(1), 2093045. https://doi.org/10.1080/23311932.2022.2093045

Yenasew, A., & Urga, K. (2023). Effect of the germination period on functional properties of finger millet flour and sensorial quality of porridge. *Food Science & Nutrition*, *11*(5), 2336-2343. https://doi.org/10.1002/fsn3.3240

Zambrano, M. V., Dutta, B., Mercer, D. G., MacLean, H. L., & Touchie, M. F. (2019). Assessment of moisture content measurement methods of dried food products in small-scale operations in developing countries: A review. *Trends in Food Science & Technology*, *88*, 484-496. https://doi.org/10.1016/j.tifs.2019.04.006

Zhang, X., Wang, Q., Liu, Z., Zhi, L., Jiao, B., Hu, H., & Shi, A. (2023). Plant protein-based emulsifiers: Mechanisms, techniques for emulsification enhancement and applications. *Food Hydrocolloids*, 109008. https://doi.org/10.1016/j.foodhyd.2023.109008

Zhong, L., Fang, Z., Wahlqvist, M. L., Wu, G., Hodgson, J. M., & Johnson, S. K. (2018). Seed coats of pulses as a food ingredient: Characterization, processing, and applications. *Trends in Food Science & Technology*, *80*, 35-42. https://doi.org/10.1016/j.tifs.2018.07.021

Zhou, Y., Wang, M., Wang, L., Liu, L., Wu, Y., & Ouyang, J. (2023). Comparison of the effect of ultrasound and microwave on the functional properties and in vitro digestibility of normal maize starch and potato starch. *Journal of Food Process Engineering*, *46*(2), e14222. https://doi.org/10.1111/jfpe.14222