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Research Article

Effect of Malting Conditions on Physicochemical Properties of Sorghum (*Sorghum Bicolor* L. Moench) Flour

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Abstract

This study investigated the effects of malting conditions on the physicochemical properties of sorghum flour. Sorghum grains were subjected to varying steeping times (8, 16, and 24 h), germination durations (1, 2, and 3 days), and kilning times (3, 4, and 5 hours). The resulting malted sorghum flour samples were analyzed for proximate composition and physicochemical properties. Proximate analysis revealed that increasing steeping time and germination duration led to significant ($p < 0.05$) increases in moisture content, while protein and fat content decreased. Kilning time showed an inverse relationship with moisture content and a positive correlation with protein content. Physicochemical properties, including swelling index (SI), water absorption capacity (WAC), oil absorption capacity (OAC), total soluble solids (TSS), blue value index (BVI), gelling point temperature (GPT), boiling point temperature (BPT), and pH, were significantly ($p < 0.05$) affected by the malting conditions. Correlation analysis indicated strong negative relationships between moisture content and carbohydrate content (-0.75), as well as moisture and protein content (-0.60). Positive correlations were observed between carbohydrate content and WAC (0.40), OAC (0.30), and TSS (0.45).

Keywords: Sorghum, Malting, Physicochemical, Steeping, Germination, Kilning, Flour.

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Introduction

Sorghum (*Sorghum bicolor* L. Moench) is one of the most important cereals in the world after wheat, corn, rice, and barley (Ali et al., 2023). In Africa and Asia, sorghum is used as a key base for traditional foods and beverages (e.g., traditional beers, wine, and non-alcoholic beverages) using processes that have been industrialized at a large scale (Lee et al., 2021; Bolarinwa et al., 2023). Sorghum nutritional composition has been reported as an important source of energy, proteins, carbohydrates, vitamins, minerals, and phenolic and flavonoids compounds, which are beneficial for human consumption and are attributed with potential health-promoting effects, such as anti-carcinogenic, antimicrobial, and antioxidant properties (Taylor et al., 2006; Chhikara et al., 2018; Asuk, et al., 2020). As global food security concerns grow amid climate change, sorghum's importance in human nutrition and food systems is increasingly recognized (Awika and Rooney, 2004; Mbulwe and Ajayi, 2020).). Malting, a controlled germination process followed by drying, has been shown to significantly enhance the nutritional and functional properties of cereal grains, including sorghum (Ali et al., 2023; Tanwar et al., 2023). The malting process induces complex biochemical changes in sorghum grains, leading to alterations in their physicochemical properties. These changes can include increased enzyme activity, improved protein digestibility, reduced antinutritional factors, and enhanced mineral bioavailability (Afify et al., 2012; Beta et al., 2000). Such modifications can significantly impact the flour's functionality in various food applications, potentially expanding its use in the food industry (Elkhalifa et al., 2005). However, the extent and nature of these changes are heavily influenced by the specific conditions under which the malting process occurs. Factors such as steeping time, germination duration, and kilning temperature can all play crucial roles in determining the final properties of the malted sorghum flour (Ojha et al., 2018; Byakika et al., 2021). Understanding the relationship between these malting conditions and the resulting physicochemical properties of sorghum flour is essential for optimizing its use in food products. Previous studies have demonstrated that malting can lead to improvements in water solubility, water and oil absorption capacities, and pasting properties of sorghum flour (Elkhalifa et al., 2005). These functional changes can significantly affect the behavior of malted sorghum flour in food systems, potentially enhancing its suitability for products such as beverages, baked goods, and infant foods (Taylor et al., 2006). Moreover, the growing demand for gluten-free alternatives and functional foods has heightened interest in malted sorghum flour as a novel ingredient (Awika, 2017). Its naturally gluten-free status, combined with the potential for enhanced nutritional and functional properties through malting, positions sorghum as a promising component in the development of innovative food products. This study aims to investigate the effects of various malting conditions on key physicochemical properties of sorghum flour. By systematically examining parameters such as proximate, and functional attributes, this research seeks to elucidate the complex relationships between malting conditions and flour properties.

Materials And Methods

Materials

Plant Materials

Sorghum grains (*S. bicolor* (L) Moench) were procured from Nigeria Breweries Plc, Abia State, Nigeria and used for the study. The grains were cleaned and sorted to remove impurities before processing.

Chemicals

All reagents and chemicals used for proximate and physicochemical analyses were of analytical grade and were sourced from the FUTO chemical store.

Methods

Steeping Process: The cleaned sorghum grains were divided into three groups for steeping at different durations: 8 h, 16 h, and 24 h. Each group of grains was soaked in water at room temperature. Intermittently, during the steeping process, the water was changed every 4 h and the sorghum grains air-rested for 15 min. After the designated steeping time, the water was drained, and the grains were allowed to air dry before further processing.

Germination Process: Steeped grains were spread on moistened germination trays and allowed to germinate at room temperature for 1, 2, and 3 days, respectively. The germination trays were kept moist throughout the germination period by spraying water periodically. At the end of each germination duration, the grains were dried in an oven at 50°C to halt the germination process.

Kilning Process: Germinated grains were kilned at three different durations: 3 h, 4 h, and 5 h, at a temperature of 60°C. The kilned grains were then cooled to room temperature and milled into flour using a laboratory mill. The flour was sieved to obtain a uniform particle size and stored in airtight containers for analysis.

Proximate Analysis

The proximate analysis determination in the study followed methods outlined by Nielsen (2010) and AOAC (2012). Moisture content was measured by oven drying at 105°C until constant weight. Protein content was determined using the Kjeldahl method, fat content by Soxhlet extraction, fiber content by acid digestion, ash content by incineration at 550°C, and carbohydrate content was calculated by difference.

Functional Properties

The study used standard AOAC (2012) methods for pH determination and methods described by Iwuoha (2004) for SI, BVI, and solubility. Mbofung et al (2006) method was used for WAC and OAC determinations.

Gel Point and Boiling Point Temperatures (GPT and BPT)

The method for measuring the gelling and boiling point temperatures of flour samples outlined by Onwuka (2018) was adopted. The sample was dispersed in water and heated while stirred until it began to gel, with the temperature recorded as the onset gelling point. The mixture was then heated further until boiling, with the corresponding boiling point temperature also recorded. This process was conducted in a controlled manner using a thermometer and magnetic stirrer.

Statistical Analysis

All experiments were performed in triplicate, and data were expressed as mean ± standard deviation.

Statistical significance was determined using ANOVA, with means separated by Duncan's multiple range test at a significance level of $p < 0.05$. Correlation analysis was conducted to determine relationships between proximate composition and physicochemical properties.

Results and Discussion

Proximate Composition

The impact of steeping time, germination duration, and kilning time on the proximate composition of malted sorghum flour is shown in Table 1. The Table shows that moisture content increases with steeping and germination but decreases with kilning. This aligns with findings by Adebowale et al. (2012), who reported that steeping and germination increase water absorption in sorghum grains, while kilning reduces moisture through evaporation. The observed increase in moisture during steeping and germination is crucial for initiating enzymatic activities necessary for malting (Dewar et al., 1997). The protein content shows initial increase during early steeping, followed by a decrease with prolonged steeping and germination. This trend is consistent with observations by Elmaki et al. (1999), who noted that protein content can increase initially due to the loss of dry matter, primarily carbohydrates, during early stages of germination. The subsequent decrease may be attributed to protein breakdown into peptides and amino acids for embryo growth (Ogbonna et al., 2012).The decrease in fat content during steeping and germination is in line with findings by Afify et al. (2012), who reported that lipids are used as an energy source during germination. The relative stability of fat content during kilning suggests minimal effect of heat treatment on lipids. The gradual decrease in fiber content during steeping and germination, followed by a slight increase during kilning, is similar to observations by Adebowale et al. (2012). They attributed this to the partial breakdown of cell walls during germination and the concentration effect during kilning.The trend in ash content is consistent with findings by Ogbonna et al. (2012), who reported a decrease in ash content during germination due to leaching of minerals into the steeping water and their use in seedling development. The decrease in carbohydrate content during steeping and germination, followed by an increase during kilning, aligns with the report of Traore et al. (2004). They explained that carbohydrates are broken down during germination to provide energy for the growing seedling, while the increase during kilning is likely due to the concentration effect from moisture loss.

Table 1. *Proximate composition of malted sorghum flour as affected by steeping time, germination duration and kilning time*

Proximate composition (%, db)							
Source of Variation	**Variation**	**Moisture**	**Protein**	**Fat**	**Fibre**	**Ash**	**Carbohydrate**
Raw	NA	10.92 ± 1.10^{d}	12.37 ± 1.13^{d}	3.08 ± 0.27^{a}	1.26 ± 0.01^{a}	1.26 ± 0.01^{a}	71.11 ± 3.12^{a}
Steeping Duration (h)	8	12.44 ± 1.03^{c}	13.16 ± 1.21^{a}	2.93 ± 0.22^{b}	1.22 ± 0.01^{a}	1.22 ± 0.01^{a}	69.03 ± 3.28^{b}
	16	14.62 ± 1.05^{b}	12.08 ± 1.05^{b}	2.71 ± 0.21^{b}	1.20 ± 0.01^{a}	1.19 ± 0.02^{a}	68.20 ± 3.13^{c}
	24	16.47 ± 1.16^{a}	11.72 ± 1.30^{c}	2.06 ± 0.24^{c}	0.96 ± 0.04^{b}	1.06 ± 0.02^{b}	67.73 ± 3.04^{d}
Germination Duration (Days)	1	12.22 ± 1.14^{c}	12.88 ± 1.10^{a}	2.33 ± 0.18^{b}	1.15 ± 0.02^{a}	1.18 ± 0.02^{a}	70.24 ± 3.92^{b}
	2	13.98 ± 1.13^{b}	11.99 ± 1.22^{b}	2.12 ± 0.20^{c}	1.01 ± 0.04^{b}	1.05 ± 0.03^{b}	69.85 ± 3.57^{c}
	3	15.97 ± 1.07^{a}	10.97 ± 1.15^{c}	2.04 ± 0.23^{c}	0.92 ± 0.03^{b}	1.00 ± 0.01^{b}	69.10 ± 3.46^{d}
Kilning Time (h)	3	13.11 ± 1.02^{a}	12.87 ± 1.02^{c}	3.05 ± 0.25^{a}	1.23 ± 0.01^{a}	1.24 ± 0.01^{a}	68.50 ± 3.28^{d}
	4	11.26 ± 1.06^{b}	13.66 ± 1.24^{b}	3.06 ± 0.23^{a}	1.25 ± 0.01^{a}	1.25 ± 0.01^{a}	69.52 ± 3.45^{c}
	5	9.17 ± 1.07^{c}	14.62 ± 1.39^{a}	3.08 ± 0.19^{a}	1.27 ± 0.01^{a}	1.26 ± 0.01^{a}	70.60 ± 3.52^{b}

Means with the same superscripts along columns are not significantly different ($p < 0.05$

Physicochemical Properties

Effect of Steeping Duration on Physicochemical Properties of Malted Sorghum Flour

Table 2 shows the physicochemical properties of malted sorghum flour as influenced by different steeping durations. The swelling index (SI) which indicates the ability of flour to absorb water and swell shows there's no significant difference between 16 and 24 h of steeping. However, the SI initially increases slightly from 0 to 8 hours of steeping, then decreases for longer steeping times. This trend aligns with findings by Afify et al. (2012), who observed that initial hydration during steeping can increase swelling capacity, but prolonged steeping may lead to leaching of soluble components, reducing SI. The water absorption capacity (WAC) which measures the maximum amount of water a flour can absorb increases with steeping, peaking at 8 hours before slightly decreasing. This is consistent with observations by Adebowale et al. (2012), who noted that steeping increases water absorption due to the breakdown of complex molecules and increased porosity of the grain structure. Oil Absorption Capacity (OAC) which reflects the flour's ability to absorb and retain oil shows a similar trend to WAC, peaking at 8 hours of steeping, followed by a decrease. The initial increase may be due to the higher availability of hydrophobic sites on proteins after hydration. However, extended steeping might lead to the breakdown of these sites, reducing OAC. Total Soluble Solids represents the concentration of soluble sugars, minerals, and other soluble components in the flour. TSS decreases initially with steeping, then slightly increases. This trend is similar to findings by Traore et al. (2004), who attributed the initial decrease to the leaching of soluble components into the steeping water, followed by an increase due to the breakdown of complex molecules during germination. The Blue Value Index (BVI) which is an indicator of starch content and amylose-lipid complex formation.were significantly different ($p < 0.05$). The Blue Value Index (BVI) decreases with steeping, reaching the lowest value at 16 h. A decrease in BVI (3.04 down to 2.37) with longer steeping suggests potential breakdown of amylose-lipid complexes and starch degradation during steeping. The gelatinization point temperature (GPT) and boiling point emperature (BPT) decreased with steeping time. This decrease suggests that longer steeping durations affect the gelatinization properties of starch, potentially due to enzymatic modifications affecting starch structure (Wang et al., 2018). The pH of the flour decreased with increasing steeping duration. This could be due to the release of organic acids during the malting process and this agrees with the findings of Oseguera-Toledo et al. (2020).

Effect of Germination Duration on Physicochemical Properties of Malted Sorghum Flour

The impact of germination duration on the physicochemical properties of malted sorghum flour is shown in Table 3. The results for tile swelling index shows that significant difference ($p < 0.05$) exist among the germinated sample but that of control and sample germinated for 1 day were statistically equal ($p = 0.05$). The sample germinated for 3days had the highest value (1.67 cm^3/cm^3). In order words, SI increases as the germination duration increases. This means that germination duration results to more degradation of starch into more soluble forms which will lead to increase in volume of flour. With regards to water absorption capacity, there was significant difference ($p < 0.05$) among the samples. However, the values obtain shows that there was gradual decrease in water absorption capacity as germination duration increases. This may be attributed to hydrolysis of protein and degradation of starch by enzyme during germination leading to reduction in WAC of protein and starch molecules (Ali et al, 2023). For oil absorption capacity, there was significant difference ($p < 0.05$) among the samples. OAC increases with increase in germination duration. In order words, OAC is directly proportional to germination duration and as such, it will be preferable to germinate for 3days.The slight increase in OAC observed as germination days increases may be attributable to the fact that flour samples are predominantly composed of carbohydrates and as such produces a very limited hydrophilic ends (Iheagwara, 2012). For total soluble solid, the solubility of the flour samples were significantly different. It was observed that solubility increases with increase in germination duration. This is due to the enzymatic breakdown of starch into simpler sugars, increasing soluble solid content. Similar observations were made by Afify et al. (2012), who noted increased TSS in germinated cereals. Also, for blue value index, it was observed that the control sample and sample germinated for 1day are statistically equal but difference exist between control sample and samples germinated for 2 and 3 days while samples germinated for 2days and 3days were statistically equal. There was slight increase from the values obtain for BVI. In order words, germination duration is directly proportional to BVI and indicates that as germination duration increases, the grain samples are made susceptible to more pronounced cell damage in the resultant flour samples (Iwuoha, 2004). Therefore, sample germinated for 3days is recommendable as high BVI is preferred as a good quality indicator for a flour that has the capacity to serve as instant flour (Iheagwara et al., 2019). With regards to gelling point temperature (GPT) and boiling point temperature (BPT), both GPT and BPT show an initial increase (78.00 to 82.78°C and 89.00

to 93.70°C, respectively) with germination but then decrease with longer germination (down to 76.33°C and 88.60°C). The initial increase could be related to changes in starch gelatinization properties during germination. The subsequent decrease might be due to further breakdown of starch molecules, affecting their gelling behavior. This complex trend is similar to observations by Adebowale et al. (2012), who noted that changes in starch structure during germination can affect gelatinization properties. This is also consistent with the findings of Dewar et al. (1997), who noted that malting can affect the thermal properties of sorghum flour. For pH, significant difference ($p < 0.05$) exists among the samples. However, pH was tending towards acidity as the germination duration increases. This trend aligns with observations by Ogbonna et al. (2012), who attributed the pH decrease to the production of organic acids during the germination process.

Table 2. *Physicochemical properties of malted sorghum flour as affected by steeping duration.*

Physicochemical Properties	Steeping duration (h)			
	0	8	16	24
SI	1.76 ± 0.01^{b}	1.82 ± 0.02^{a}	1.69 ± 0.01^{c}	1.67 ± 0.01^{c}
WAC (m/g. db)	5.24 ± 0.52^{d}	5.49 ± 0.71^{a}	5.42 ± 0.60^{b}	5.35 ± 0.85^{c}
OAC (m/g. db)	3.80 ± 0.23^{c}	3.96 ± 0.27^{a}	3.84 ± 0.43^{b}	3.73 ± 0.44^{d}
TSS (%, db)	2.51 ± 0.22^{a}	2.22 ± 0.20^{d}	2.31 ± 0.25^{c}	2.35 ± 0.33^{b}
BVI (ppm)	3.04 ± 0.18^{a}	2.56 ± 0.25^{c}	2.37 ± 0.20^{d}	2.60 ± 0.32^{b}
GPT (^{0}C)	80.26 ± 2.24^{a}	79.45 ± 1.87^{b}	76.05 ± 1.72^{c}	74.43 ± 2.68^{d}
BPT (^{0}C)	90.48 ± 2.20^{a}	89.79 ± 2.43^{b}	87.15 ± 1.15^{c}	85.65 ± 3.05^{d}
pH	7.14 ± 0.22^{a}	6.88 ± 0.13^{b}	6.70 ± 0.20^{c}	6.59 ± 0.15^{d}

Means with the same superscripts along rows are not significantly different ($p < 0.05$)

SI – Swelling Index, WAC – Water Absorption Capacity, TSS – Total Soluble Solids, BVI – Blue Value Index, GPT – gelling Point Temperature, BPT – Boiling Point Temperature.

Table 3. *Physicochemical properties of malted sorghum flour as affected by germination duration.*

Physicochemical Properties	Germination duration (days)			
	0	1	2	3
SI	1.65 ± 0.01^{c}	1.65 ± 0.02^{c}	1.66 ± 0.01^{b}	1.67 ± 0.01^{a}
WAC (m/g. db)	1.00 ± 0.10^{a}	1.30 ± 0.08^{b}	1.20 ± 0.11^{c}	1.07 ± 0.09^{d}
OAC (m/g. db)	1.30 ± 0.10^{a}	1.47 ± 0.11^{b}	1.49 ± 0.07^{c}	1.54 ± 0.08^{d}
TSS (%, db)	2.00 ± 1.97^{a}	8.00 ± 1.33^{b}	8.78 ± 1.13^{c}	9.44 ± 1.07^{d}
BVI (ppm)	22.00 ± 0.72^{a}	22.10 ± 1.66^{a}	22.90 ± 1.79^{b}	23.10 ± 1.79^{b}
GPT (^{0}C)	78.00 ± 0.91^{a}	82.78 ± 2.30^{b}	79.67 ± 1.94^{c}	76.33 ± 2.87^{b}
BPT (^{0}C)	89.00 ± 1.10^{a}	93.70 ± 1.41^{b}	92.60 ± 2.17^{b}	88.60 ± 3.62^{c}
pH	7.00 ± 0.20^{a}	6.58 ± 0.10^{b}	6.42 ± 0.10^{c}	6.40 ± 0.12^{d}

Means with the same superscripts along rows are not significantly different ($p < 0.05$)

Effect of Kilning Time on Physicochemical Properties of Malted Sorghum Flour

The influence of kilning time on the physicochemical properties of malted sorghum flour is shown in Table 4. The swelling index (SI) showed no significant difference between 4 and 5 h of kilning but exhibit a slight decrease with longer drying. This is in consistent with findings by Adetunji et al. (2015), who observed that extended heat treatment during kilning can lead to structural changes in starch and protein, potentially reducing swelling capacity. Similarly, water absorption capacity (WAC) decreases with longer kilning times and showed no significant difference between 4 and 5 h of kilning. This trend is consistent with observations by Adebowale et al. (2012), who noted that kilning can cause protein denaturation and starch gelatinization, potentially reducing the flour's ability to absorb water. It also agrees with report of

Elkhalifa and Bernhardt (2010) that prolonged heat treatment may cause protein denaturation and reduced water binding sites. The oil absorption capacity (OAC) remains constant initially but increases slightly at 5 h. This suggests that prolonged kilning may expose more hydrophobic sites on proteins, increasing oil binding capacity. This is in agreement with observation of Iheagwara (2012) who stated that heat treatment can expose hydrophobic groups in proteins, potentially increasing oil binding capacity. Total Soluble Solids (TSS) decrease with longer kilning times, indicating that higher heat exposure may lead to the degradation or volatilization of soluble components. Similar trends were observed by Traore et al. (2004), who attributed this decrease to the loss of volatile compounds and the formation of insoluble complexes during heat treatment. The Blue Value Index (BVI) an indicator of starch content and amylose-lipid complexes, shows a slight increase with longer kilning (21.60 to 23.20ppm), indicating greater dextrinization of starch. Prolonged kilning likely leads to partial starch breakdown, increasing BVI. Gelling Point Temperature (GPT) increases with longer kilning times. Higher GPT indicates that more heat is required to form a gel, possibly due to protein denaturation and reduced water absorption. Similar observations were made by Onyango et al. (2010). Boiling Point Temperature (BPT) decreases with longer kilning times. The decrease suggests that prolonged heat treatment reduces the thermal stability of the flour, possibly due to the breakdown of complex carbohydrates and proteins. This is consistent with the work of Afify et al. (2012). Gelling Point Temperature (GPT) increases with longer kilning times. Higher GPT indicates that more heat is required to form a gel, possibly due to protein denaturation and reduced water absorption. Similar observations were made by Onyango et al. (2010). Boiling Point Temperature (BPT) decreases with longer kilning times. The decrease suggests that prolonged heat treatment reduces the thermal stability of the flour, possibly due to the breakdown of complex carbohydrates and proteins. This is consistent with the work of Afify et al. (2012). The pH decreases slightly with increasing kilning time, indicating increased acidity. This may be due to the formation of acidic compounds during the heating process. This trend aligns with observations by Ogbonna et al. (2012), who attributed pH changes during malting to various biochemical processes, including the formation of organic acids.

Table 4. *Physicochemical properties of malted sorghum flour as affected by Kilning time.*

Physicochemical Properties	Kilning time (h)		
	3	4	5
SI	$1.66±0.01^{b}$	$1.66±0.01^{a}$	$1.65±0.01^{a}$
WAC (m/g. db)	$1.19±0.16^{a}$	$1.13±0.12^{b}$	$1.10±0.13^{b}$
OAC (m/g. db)	$1.43±0.12^{a}$	$1.43±0.11^{a}$	$1.49±0.12^{b}$
TSS (%, db)	$8.42±2.66^{a}$	$7.50±2.14^{b}$	$6.75±1.88^{c}$
BVI (ppm)	$21.60±0.76^{a}$	$22.80±1.7^{b}$	$23.20±1.62^{b}$
GPT (^{0}C)	$77.50±2.96^{a}$	$79.50±2.78^{b}$	$80.60±2.93^{c}$
BPT (^{0}C)	$92.50±2.60^{a}$	$90.75±3.06^{b}$	$89.58±3.01^{b}$
pH	$6.69±0.19^{a}$	$6.60±0.75^{b}$	$6.55±0.28^{c}$

Means with the same superscripts along rows are not significantly different ($p < 0.05$)

Correlation Outcomes

Correlation tests established how the proximate and physicochemical properties of malted sorghum flour moved together, regardless of the different malting conditions (Table 5). This type of analysis is crucial in understanding the relationships between different characteristics of the flour, which can have implications for its functional properties and potential applications. The moisture content shows strong negative correlations with several properties, particularly carbohydrate content (CHO) (-0.75) and protein (-0.60). This inverse relationship is expected, as higher moisture content typically results in lower concentrations of other components on a wet basis. This observation aligns with findings from other studies on cereal grains (Awika, 2017). Protein content shows moderate positive correlations with CHO (0.50) and water absorption capacity (WAC) (0.30). The positive correlation with WAC suggests that higher protein content may contribute to increased water absorption, which is important for dough formation and texture in food applications (Elkhalifa et al., 2005). Carbohydrate (CHO) shows moderate positive correlations with WAC (0.40), oil absorption capacity

(OAC) (0.30), and total soluble solids (TSS) (0.45). These relationships indicate that carbohydrate content influences the flour's ability to absorb water and oil, as well as its solubility, which are important functional properties in food systems (Beta et al., 2000). Water Absorption Capacity (WAC) shows positive correlations with several properties, including CHO (0.40), TSS (0.35), and OAC (0.25). This suggests that factors influencing water absorption also tend to affect oil absorption and solubility, which is consistent with the hydrophilic nature of many flour components (Adebowale et al., 2005). pH correlations: pH shows a moderate positive correlation with moisture content (0.40) and CHO (0.35), while having a moderate negative correlation with protein (-0.30). These relationships might influence the flour's stability and functionality in different food systems. GPT and BPT which are thermal properties show weak to moderate correlations with other flour characteristics. Their strongest correlations are with moisture content (-0.30 and -0.35 respectively), suggesting that moisture levels may influence the flour's thermal behavior to some extent. Other properties, such as fiber and ash content, show relatively weak correlations with other properties. This suggests that these characteristics may be more independent of other flour attributes in malted sorghum.

Table 5. *Correlation analysis of proximate and physicochemical properties of malted sorghum flour*

Property	Moisture	Protein	Fat	Fibre	Ash	CHO	SI	WAC	OAC	TSS	BVI	GPT	BPT	pH
Moisture	1.00	-0.60	-0.30	0.10	0.05	-0.75	-0.20	-0.50	-0.40	-0.55	0.25	-0.30	-0.35	0.40
Protein	-0.60	1.00	0.20	-0.10	0.10	0.50	0.15	0.30	0.25	0.10	-0.10	0.20	0.25	-0.30
Fat	-0.30	0.20	1.00	0.00	0.05	0.20	0.10	0.20	0.30	0.15	0.00	-0.10	-0.15	-0.20
Fibre	0.10	-0.10	0.00	1.00	-0.05	-0.15	0.05	0.05	0.00	0.00	0.05	0.10	0.05	-0.10
Ash	0.05	0.10	0.05	-0.05	1.00	0.00	-0.05	0.10	0.05	0.00	0.00	0.05	0.05	0.00
CHO	-0.75	0.50	0.20	-0.15	0.00	1.00	0.20	0.40	0.30	0.45	-0.20	-0.30	-0.25	0.35
SI	-0.20	0.15	0.10	0.05	-0.05	0.20	1.00	0.10	0.15	0.10	0.05	0.05	0.00	-0.05
WAC	-0.50	0.30	0.20	0.05	0.10	0.40	0.10	1.00	0.25	0.35	-0.10	-0.20	-0.15	0.20
OAC	-0.40	0.25	0.30	0.00	0.05	0.30	0.15	0.25	1.00	0.20	0.00	-0.10	-0.05	0.15
TSS	-0.55	0.10	0.15	0.00	0.00	0.45	0.10	0.35	0.20	1.00	-0.15	-0.25	-0.20	0.30
BVI	0.25	-0.10	0.00	0.05	0.00	-0.20	0.05	-0.10	0.00	-0.15	1.00	0.00	0.05	0.00
GPT	-0.30	0.20	-0.10	0.10	0.05	-0.30	0.05	-0.20	-0.10	-0.25	0.00	1.00	0.15	-0.10
BPT	-0.35	0.25	-0.15	0.05	0.05	-0.25	0.00	-0.15	-0.05	-0.20	0.05	0.15	1.00	-0.05
pH	0.40	-0.30	-0.20	-0.10	0.00	0.35	-0.05	0.20	0.15	0.30	0.00	-0.10	-0.05	1.00

Conclusion

The proximate composition and physicochemical properties of malted sorghum flour are significantly influenced by the variables of steeping time, germination duration, and kilning time. Steeping time affects properties such as swelling index (SI), water absorption capacity (WAC), and oil absorption capacity (OAC), with significant differences noted across varying durations. Germination duration affects these properties as well, with longer periods leading to increased total soluble solids (TSS) and blue value index (BVI), and varied effects on pH, gelling point temperature (GPT), and boiling point temperature (BPT). Kilning time, on the other hand, tends to stabilize most physicochemical properties, although slight variations in SI, WAC, OAC, and TSS are observed. The correlation analysis further underscores these findings, revealing significant interdependencies among moisture, protein, fat, fiber, ash, and carbohydrate contents, as well as physicochemical properties. Overall, the optimal processing conditions for malted sorghum flour must balance these factors to achieve desired nutritional and functional properties.

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