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The Effect of Nixtamalization on Physical Properties and Antinutritional Content of White Sorghum Flour from Garut, Indonesia

(Kesan Nixtamalisasi terhadap Sifat Fizikal dan Kandungan Anti Nutrisi Tepung Sorgum Putih dari Garut, Indonesia)

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ABSTRACT

Sorghum grain originating from Garut, Indonesia, has great potential to be developed as an alternative staple food, as its protein and carbohydrate content are comparable to those of rice. However, the utilization of sorghum in food products remains limited due to its undesirable physical characteristics and the presence of anti-nutrient compounds. This study aimed to evaluate the effect of nixtamalization on physical characteristics and anti-nutrient content of sorghum grain. A randomized block design was employed with two factors: $Ca(OH)_2$ concentration (0.5%, 1.0% and 1.5% w/w) and cooking time (10 min, 20 min and 30 min). The results showed that nixtamalization significantly affected the physical characteristics of sorghum flour. The pasting profile exhibited variations in peak viscosity (1173.5 - 1949.25 cP), trough viscosity (866 - 1526 cP), final viscosity (1665 - 3774 cP), setback viscosity (220.5- 596 cP), pasting temperature (80.42-84.35 °C) and peak time (4.83-5.4 min). Furthermore, nixtamalization effectively reduced the levels of anti-nutritional factors, with phytic acid decreasing from 14.4 to 11.6 mg/g and tannin content decreasing from 2.4 to 0.0 mg/100 g. These findings indicate that the nixtamalization process improves the functional and decrease anti-nutritional properties of sorghum flour, enhancing its suitability for application in food product development and diversification. Therefore, nixtamalized sorghum flour could serve as a promising ingredient to support food security and promote the utilization of local crops in Indonesia.

Keywords: Anti-nutritional content; nixtamalization; physical properties; white sorghum flour

ABSTRAK

Sorgum dari Garut, Indonesia, mempunyai potensi besar untuk dibangunkan sebagai bahan makanan ruji alternatif kerana kandungan protein dan karbohidratnya setanding dengan beras. Walau bagaimanapun, penggunaan sorgum dalam produk makanan masih terhad disebabkan ciri fizikalnya yang kurang sesuai dan kehadiran sebatian anti-nutrien. Kajian ini bertujuan untuk menilai kesan proses nixtamalisasi ke atas ciri fizikal dan kandungan anti-nutrien biji sorgum. Reka bentuk rawak blok digunakan dengan dua faktor, iaitu kepekatan $Ca(OH)_2$ (0.5%, 1.0% dan 1.5% b/b) dan masa memasak (10 min, 20 min dan 30 min). Hasil kajian menunjukkan bahawa nixtamalisasi mempengaruhi ciri fizikal tepung sorgum dengan signifikan. Profil pelekat menunjukkan variasi dalam kelikatan puncak (1173.5-1949.25 cP), kelikatan lembah (866-1526 cP), kelikatan akhir (1665-3774 cP), kelikatan set semula (220.5-596 cP), suhu pelekat (80.42-84.35 °C) dan masa ke puncak (4.83-5.4 minit). Selain itu, nixtamalisasi terbukti berkesan mengurangkan kandungan sebatian anti-nutrien dengan kandungan asid fitik menurun dari 14.4 kepada 11.6 mg/g dan tanin dari 2.4 kepada 0.0 mg/100 g. Ini menunjukkan bahawa proses nixtamalisasi dapat meningkatkan sifat kefungsian serta mengurangkan kandungan anti-nutrien tepung sorgum, seterusnya meningkatkan kesesuaiannya untuk digunakan dalam pembangunan dan kepelbagaian produk makanan. Oleh itu, tepung sorgum hasil nixtamalisasi berpotensi menjadi bahan makanan yang menjanjikan untuk menyokong ketahanan makanan dan penggunaan tanaman tempatan di Indonesia.

Kata kunci: Kandungan anti nutrisi; nixtamalisasi; sifat fizikal; tepung sorgum putih

INTRODUCTION

Although rice production in Indonesia reaches nearly 50 million tons annually, the country still relies on imports to meet domestic demand. This situation highlights the need to diversify staple food sources to strengthen national food security. Sorghum is a promising cereal crop that can be further developed as an alternative food resource. One of its main advantages is its adaptability to marginal environments, including areas with low soil fertility, limited rainfall, and dry conditions unsuitable for other cereal crops without adequate irrigation (Zheng, Dang & Sui 2023). Sorghum (*Sorghum bicolor* L. Moench) is considered the fifth most important cereal crop in Indonesia after rice, wheat, maize, and barley (Ariningsih et al. 2023; Suarni 2016).

Nutritionally, sorghum is comparable to major cereals and contains components associated with functional foods. Sorghum grains typically comprise approximately 70-80% carbohydrates, 1-5% fat, 8-18% protein, 19% dietary fiber and various minerals depending on variety and growing conditions (Tanwar et al. 2023). Despite these advantages, its utilization in food and industrial applications remains limited due to unfavourable physicochemical characteristics and the presence of anti-nutritional compounds such as tannins and phytic acid. Tannins contribute to darker colour and a slightly astringent taste in sorghum-based products (Khoddami et al. 2023). Nevertheless, sorghum flour shows considerable potential for gluten-free applications, including bakery products such as cakes and bread, either alone or blended with other gluten-free flours.

Various modification approaches have been explored to improve sorghum flour characteristics through physical, chemical, and biological treatments. Physical modification using heat-moisture treatment (HMT) has been reported to enhance functional properties (Fonseca et al. 2021), although the method requires relatively long processing times. Chemical modifications through alkaline immersion both in 5-10% NaOH solution (Muliawan et al. 2023) and 0.05-0.15% Na_2CO_3 solution (Bahlawan et al. 2024) have also been investigated, but this treatment may reduce protein and starch contents (Wu et al. 2025). Biological modification via fermentation has demonstrated improvements in nutritional and functional quality (Kurniadi et al. 2013; Li et al. 2022; Setiarto & Widhyastuti 2016); however, maintaining consistent product quality remains challenging due to process variability.

Nixtamalization, an alkaline cooking and soaking process, offers an alternative modification strategy. During nixtamalization, grain tissues are softened and starch granules undergo partial gelatinization, producing a more homogeneous and elastic matrix (Maryana et al. 2025; Mendez et al. 2006). Previous studies on maize have shown that nixtamalization improves product texture, enhances niacin availability, increases calcium content and protein digestibility, and reduces microbial contamination (Hassan et al. 2023; Sefa-Dedeh et al. 2004; Zakiyah, Winarti & Yulistiani 2022). The process also slows starch retrogradation by promoting water absorption and structural modification of the pericarp, leading to the breakdown of cellulose, hemicellulose, and lignin components (Mariscal-Moreno, Sánchez & Cárdenas 2022). The resulting physicochemical properties of nixtamalized flour depend strongly on grain type and processing conditions (Hassan et al. 2023), and alkaline cooking has been recognized as an effective approach for improving cereal-based products (Jia et al. 2023).

Despite extensive research on maize, studies investigating nixtamalization of sorghum remain limited. Therefore, this study addresses an important research gap by investigating the effects of nixtamalization conditions, specifically $Ca(OH)_2$ concentration and cooking time, on the functional properties, pasting behaviour, and anti-nutritional compounds of white sorghum from Garut, Indonesia. It is hypothesized that controlled nixtamalization can modify starch structure and grain matrix interactions, thereby improve functional performance while reduce anti-nutritional factors. The findings are expected to provide scientific insight into sorghum processing and support its application in gluten-free and diversified food systems.

MATERIALS AND METHODS

RAW MATERIALS

The Bioguma white sorghum variety was obtained from a local farmer from Nav's Farm, Karangwitan, Garut, West Java, Indonesia.

SAMPLE PREPARATION

The $Ca(OH)_2$ solution was prepared according to the experimental design (Table 1), with three independent sample preparations performed for each treatment. Sorghum seeds were washed thoroughly and cooked at a temperature of 90-94 °C. The cooked seeds were then incubated for 24 h, rinsed thoroughly, and dried using a food dehydrator (ST-32, GETRA, Indonesia) at 40 °C for 24 h. After drying, the sorghum seeds were ground using a grinder (HC-800Y, Jing Gong, China) and sieved through an 80-mesh sieve (AS200, RETSCH, Germany) to obtain uniform flour. All samples were stored in zipper-lock plastic bags and placed in light-tight containers until further analysis.

EXPERIMENTAL ANALYSIS

Swelling power and solubility

Swelling power and solubility analyses were carried out following the method of Collado and Corke (1999) with modifications. A 200 mg sample was placed in a centrifuge tube (10-0502 Biologix Group Ltd., USA), and 10 mL of ethanol was added. The mixture sample was mixed until homogeneous using a vortex (IKA Vortex 3, IKA-Werke GmbH & Co. KG, Germany) and then heated

TABLE 1. Experimental design of sorghum nixtamalization

Code	Cooking time (min)	$Ca(OH)_2$ (%)
SP1	10	0.5
SP2	20	0.5
SP3	30	0.5
SP4	10	1
SP5	20	1
SP6	30	1
SP7	10	1.5
SP8	20	1.5
SP9	30	1.5

in a water bath (Memmert WB 7, Memmert GmbH + Co. KG, Germany) at 95 °C for 30 min. After heating, the samples were centrifuged at 3000 rpm (Centrifuge - EBA 20, Hettich, Germany) for 15 min to separate the gel and supernatant. The gel fraction was weighed to determine the swelling power, while the supernatant was transferred into a pre-weighed cup and dried in an oven (Memmert UF 110, Memmert GmbH + Co. KG, Germany) at 105 °C overnight until a constant weight was obtained. The swelling power and solubility were then calculated based on following equations:

$$\text{Swelling power (\%)} = \frac{(\textit{weight of gel + centrifuge tube} - \textit{weight of sampel + centrifuge tube})\ (g)}{\textit{weight of sampel}\ (g)} \times 100\% \quad (1)$$

$$\text{Solubility (\%)} = \frac{\textit{weight of dried supernatant}\ (g)}{\textit{weight of sampel}\ (g)} \times 100\% \quad (2)$$

Water and oil absorption capacity

Water and oil absorption capacities were determined using the modified method of Beuchat (1977), a standardized and widely validated procedure reported in previous studies (Attaugwu, Anyadioha & Ogbuokiri 2022; Kakar et al. 2022). A 1 g sample was placed into a centrifuge tube (10-0502 Biologix Group Ltd., USA), and 10 mL of distilled water or palm oil was added. The mixture was homogenized using a vortex mixer (IKA Vortex 3, IKA-Werke GmbH & Co. KG, Germany) and then allowed to stand at room temperature for 30 min. Afterward, the samples were centrifuged at 3000 rpm (Centrifuge - EBA 20, Hettich, Germany) for 15 min to separate the residue and supernatant. The supernatant was carefully decanted, while the residue along with the centrifuge tube was weighed. Water or oil absorption capacity was expressed as the percentage of water weight or oil weight absorbed by 1 gram of flour.

$$\text{Water and oil capacity (g/g dried flour)} = \frac{(\textit{density of water/oil} \times \textit{volume water/oil used} - \textit{weight of supernatant})}{1\ \textit{gram flour}\ (\textit{dried flour})} \quad (3)$$

Flour pasting properties

The pasting properties of the samples were determined following the modified method of Faridah et al. (2014) using Rapid Visco Analyzer (RVA 131 4500, Perten Instruments, Springfield, IL, USA). The moisture content of the nixtamalized sorghum flour was measured using a moisture analyzer (MX-50, A&D Company Ltd., Japan) and the obtained values were entered into the RVA software (standard 1 configuration) to calculate the appropriate sample weight and the volume of distilled water required. The software converts the measurement configuration of samples with different moisture levels, ensuring that all samples are evaluated under standardized measurement conditions. The RVA analysis provided data on provide peak viscosity, trough viscosity, breakdown, final viscosity, setback viscosity, peak time, and pasting temperature.

Tannin content

Tannin content was determined following the modified method of Espitia-Hernandes et al. (2022). The sample was first extracted using ethanol, then 20 µL of the extract was added with 20 µL of Folin-Ciocalteu reagent and incubated at room temperature (25 °C) for 5 min in a 96-well microplate (Biologix Group Ltd., USA). Subsequently, 20 µL of 0.01 M sodium carbonate (Na_2CO_3) was added and the mixture was incubated at room temperature (25 °C) for another 5 min. After incubation, 125 µL of distilled water was added to the solution. Tannic acid (ACS reagent grade, 90%, Sigma-Aldrich, USA) was used as the standard and prepared at concentrations of 0, 30, 60, 90, 120, 150, and 180 ppm. Absorbance was measured at 790 nm using an ELISA microplate reader (Synergy HTX S1LFTA, BioTek Instrument, USA). The tannin content was calculated based on calibration curve of tannic acid ($Y = 0.0013X + 0.0559$, $R^2 = 0.99$).

Phytic acid content

Phytic acid content was determined following the modified method of Espitia-Hernandes et al. (2022). The samples were extracted using 0.5 N HNO_3 solution for 4 h. Subsequently, 1 mL of extract was mixed with 0.4 mL of distilled water and 1 mL of Fe ammonium sulphate (50 µL Fe/mL) in a dark vial. The mixture was heated in a boiling water bath (Memmert WB 7, Memmert GmbH + Co. KG, Germany) for 20 min and then cooled at room temperature. After cooling, 5 mL of amyl alcohol and 0.1 mL of ammonium thiosulfate solution (100 g/L) were added. The solution was transferred into a 96-well microplate (Biologix Group Ltd., USA) and was measured at a wavelength of 495 nm using an ELISA microplate reader (Synergy HTX S1LFTA, BioTek Instrument, USA). Phytic acid (90 90%, Sigma-Aldrich, USA) was used as standard and made at concentrations of 0, 10, 20, 30, 40, 50, 60, 80, 90, and 100 ppm. The phytic acid content was calculated based on calibration curve of phytic acid ($Y = 0.0018X + 0.7898$, $R^2 = 0.99$).

Statistical analysis

A completely randomized design with three replications was used in this experiment. Data were expressed as mean ± standard deviation for all measured parameters. The data were analyzed using two-way analysis of variance (ANOVA), followed by Duncan's Multiple Range Test (DMRT) as a post hoc test to determine significant differences among mean values. Differences were considered statistically significant at $P<0.05$. Statistical analyses were performed using IBM SPSS Statistics Version 21 (IBM Corp., USA).

RESULTS AND DISCUSSION

EFFECT OF NIXTAMALIZATION ON SWELLING POWER OF SORGHUM FLOURS

Swelling power represents the ability of starch granules to absorb water and swell, indicating the strength of associative forces within the granules (Awuchi, Victory & Echeta 2019). It is considered an important quality parameter commonly used as an indicator of functional properties in flour systems (Zulaidah 2011). As shown in Figure 1(a), both cooking time and $Ca(OH)_2$ concentration influenced the swelling power of nixtamalized sorghum flour. The highest swelling power was observed in sample SP7 (8.67 g/g), whereas the lowest value occured in sample SP3 (7.55 g/g). Although these values were lower than those typically reported for wheat flour, they were comparable to swelling power values of fermented brown sorghum processed with tape yeast (Armanda & Putri 2016).

Previous studies have reported swelling power values ranging from 2.55 to 8.66 g/g in lime-nixtamalized sorghum (Boniface & Gladys 2011). This finding suggests that alkaline treatment and thermal processing may influence water absorption capacity. Increased swelling power is generally associated with enhanced water uptake during heating and may reflect modifications in starch molecular organization (Rojas-Molina et al. 2024). Swelling behaviour is often influenced by factors such as amylose–amylopectin interactions, granule integrity, and processing temperature (Murilo-Chávez, Wangb & Bello-Pérez 2008). Sorghum starch typically exhibits limited swelling below 50 °C, with a marked increase occurring near its gelatinization range (65-75 °C) (Kigogy et al. 2013). Therefore, variations in swelling power among treatments may reflect differences in the extent of starch hydration and thermal response induced by nixtamalization conditions rather than definitive changes in starch composition.

The solubility of starch is influenced by several factors, including its botanical source, swelling power, strength of inter-associative forces within the amorphous and crystalline domains, and the presence of other components such as phosphorus (Kumoro et al. 2012). Figure 1(b) shows that sample SP8 exhibited the highest solubility value (4.38 g/g), whereas SP7 showed the lowest (3.22 g/g). All nixtamalized sorghum flour samples showed higher solubility values than the control (2.82 g/g), suggesting that alkaline processing using $Ca(OH)_2$ increased the solubility of sorghum flour. Increased solubility may be associated with partial starch gelatinization and molecular dispersion during nixtamalization (Rojas-Molina et al. 2024). The higher solubility observed may indicate improved hydration properties, which are relevant for applications requiring rapid reconstitution or digestibility (Awuchi, Victory & Echeta 2019).

EFFECT OF NIXTAMALIZATION ON WATER AND OIL ABSORPTION CAPACITY OF SORGHUM FLOURS

Water absorption capacity (WAC) refers to the ability of flour to absorb and retain water, facilitating the formation of homogeneous dough when mixed with water (Awuchi, Victory & Echeta 2019). It determines the amount of water available for starch gelatinization during cooking (Boniface & Gladys 2011) and is a critical factor influencing the functionality of starch-based products in the food industry (Zhang et al. 2024). Figure 2(a) shows that the WAC of sorghum flour was influenced by the nixtamalization process. The highest WAC was recorded in sample SP8 (290.01 ± 1.88%), while the lowest was observed in sample SP6 (241.95%). As shown in Table 2, all nixtamalized samples shows that the WAC values of all samples were higher (241.95 - 290.01%) compared to the control sample (216%). This trend is consistent with findings from corn nixtamalization studies, where WAC increases with lime concentration (Sefa Dedeh et al. 2004). Starches with high WAC are valuable for improving the texture and moisture retention of food products such as jams and bakery items (Magallanes-Cruz, Duque-Buitrago & del Rocío Martínez-Ruiz 2023). The observed increase in WAC can be attributed to partial gelatinization and the interaction between Ca^{2+}

and OH^- ions with starch molecules during nixtamalization (Sefa Dedeh et al. 2004). Additionally, WAC is influenced by starch composition, granule surface microstructure, crystalline and amorphous regions, and the presence of hydrophilic groups (Zhang et al. 2024). According to Boniface and Gladys (2011), lime treatment enhances water absorption by loosening the starch structure, thereby increasing its hydration capacity. High WAC values are beneficial for maintaining moisture in food products (Jia et al. 2023). In the food industry, starch serves as afunctional ingredient essential for preserving texture, consistency, and product quality (de Souza et al. 2021). Insufficient water availability can hinder optimal gel formation and reduce the functional performance of starch (Ntau, Sumual & Assa 2017).

Oil absorption capacity (OAC) refers to the ability of flour to bind fat molecules, an important functional property that affects texture, flavour retention, and mouthfeel in food products (Yonata et al. 2021). The oil and water binding capacities of food proteins depend on intrinsic factors such as amino acid composition, protein conformation and surface polarity or hydrophobicity (Akinyede & Amoo 2009). The results of OAC analysis are presented in Figure 2(b). Among the samples, SP8 exhibited the highest oil absorption capacity (128.34%), while SP7 showed the lowest (112.49%). Overall, nixtamalization of sorghum grain using $Ca(OH)_2$ reduced the OAC compared to the control sample (144.96%). Similar trends have been reported for nixtamalized biofortified maize (Shobha et al. 2015, Vandana & Srivastava 2019). However, Boniface and Gladys (2011) observed that lime treatment during nixtamalization could also increase oil absorption, suggesting that the effect may depend on processing conditions such as lime concentration, temperature, and cooking time. Analysis of Variance (ANOVA) showed a significant interaction between cooking time and $Ca(OH)_2$ concentration on the OAC of nixtamalized sorghum flour. These findings are supported by previous studies by Kakar et al. (2022), which highlighted the influence of processing variables on the functional properties of cereal flours.

The ability of flour to absorb oil contributes to improve sensory properties such as mouthfeel and flavour retention (Boniface & Gladys 2011; Ulyarti et al. 2022). According to Ntau, Sumual and Assa (2017), OAC is affected by starch structure, protein content and fat content. In the present study, nixtamalization of sorghum grains let to a reduction in oil absorption capacity. Further investigation is recommended to evaluate the functional performance of nixtamalaized sorghum flour in specific food applications, particularly in product where fat binding is critical for quality and sensory characteristics.

EFFECT OF NIXTAMALIZATION ON PASTING PROPERTIES OF SORGHUM FLOUR

The Rapid Visco Analyzer (RVA) is an instrument used to monitor the gelatinization behavior and pasting profile of flour-water and starch-water mixtures (Rahmiati et al. 2016). It provides a simulation of food processing conditions and is widely used to determine the effect of processing on the structural and functional characteristics of starch-based materials (Copeland et al. 2009). In this study, RVA analysis showed that nixtamalization of sorghum grain using $Ca(OH)_2$ significantly affected key pasting parameters, including peak viscosity, trough viscosity, final viscosity, setback viscosity, gelatinization temperature, and gelatinization time. The viscosity properties of starch pastes and gels are critical determinants of their functionality and suitability for various food industry applications (Ai & Jane 2015). According to Lin et al. (2011), several factors influence the nature of the starch gelatinization pattern, including the botanical source, granule size, and the presence of components such as acid, sugar, fat and protein, enzymes; as well as processing conditions including cooking temperature and stirring rate.

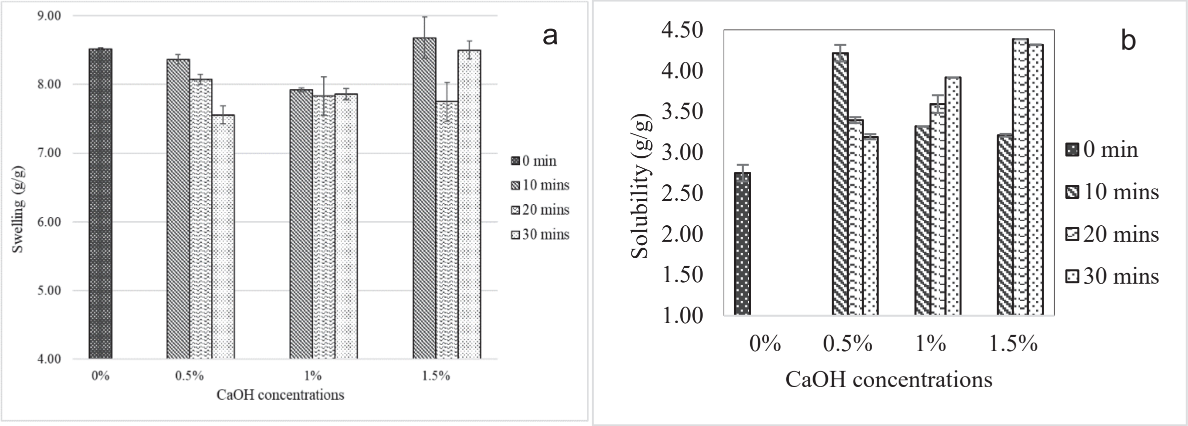

FIGURE 1. (a) Swelling power and (b) solubility of sorghum flour at various $Ca(OH)_2$ concentration and cooking time conditions

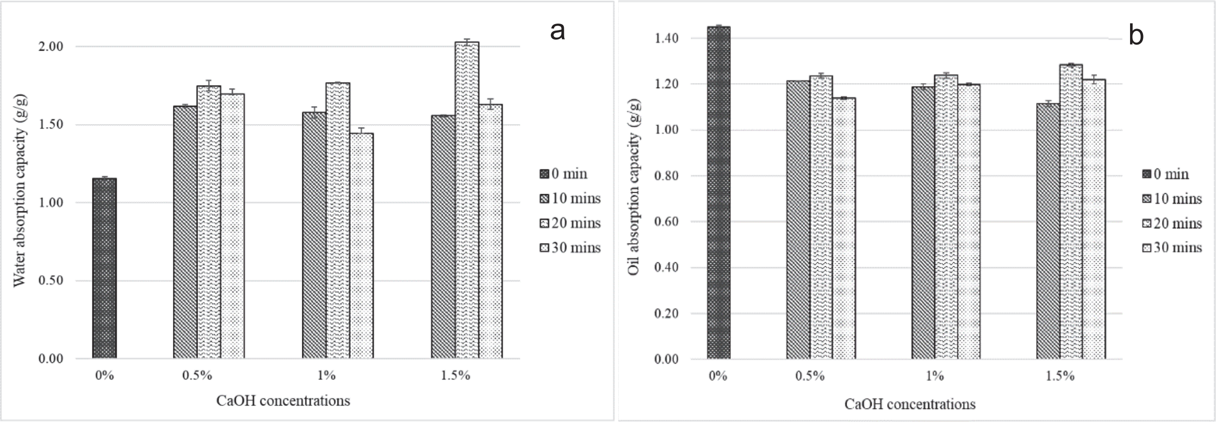

FIGURE 2. (a) Water absorption capacity and (b) Oil absorption capacity of sorghum flour at various $Ca(OH)_2$ concentration and cooking time conditions

TABLE 2. Pasting profiles (RVA) of nixtamalized sorghum flour

Time (min)	$Ca(OH)_2$ (%)	Peak viscosity (cP)	Trough viscosity (cP)	Breakdown viscosity (cP)	Final viscosity (cP)	Setback viscosity (cP)	Peak time (min)	Pasting temperature (°C)
0	0	2400.75^{a}	2255.25^{a}	145.50^{a}	3531.25^{a}	1276.00^{a}	6.51^{a}	92.64^{a}
10	0.5	1949.25^{ab}	1526.00^{b}	423.25^{a}	3744.00^{a}	2218.00^{a}	5.40^{b}	79.24^{c}
	1	1594.50^{b}	1385.50^{bc}	209.00^{a}	3084.50^{a}	1699.00^{a}	5.44^{b}	81.39^{bc}
	1.5	1223.25^{b}	1071.50^{bc}	151.75^{a}	2116.00^{a}	1044.50^{a}	5.39^{b}	83.57^{bc}
20	0.5	1758.50^{ab}	1392.50^{bc}	366.00^{a}	3114.50^{a}	1722.00^{a}	5.40^{b}	80.69^{bc}
	1	1367.25^{b}	1069.00^{bc}	298.25^{a}	2221.50^{a}	1152.50^{a}	5.08^{b}	82.35^{bc}
	1.5	1487.25^{b}	1169.50^{bc}	317.75^{a}	2706.75^{a}	1524.75^{a}	5.39^{b}	81.54^{bc}
30	0.5	1803.00^{ab}	1367.25^{bc}	435.75^{a}	3089.00^{a}	1721.75^{a}	5.34^{b}	80.45^{bc}
	1	1173.50^{b}	866.00^{c}	307.50^{a}	1665.00^{a}	799.00^{a}	4.84^{b}	84.13^{b}
	1.5	1254.75^{b}	1008.75^{bc}	246.00^{a}	2103.75^{a}	1095.00^{a}	5.43^{b}	84.35^{b}

Means with different letters within the same column indicate significant differences among samples ($p< 0.05$)

Pasting temperature

The present study showed that nixtamalization reduced the pasting temperature of sorghum flour. The highest pasting temperature was observed in SP9 (84.35 °C), while the lowest was recorded in SP1 (79.24 °C), whereas the untreated flour exhibited a substantially higher pasting temperature (92.64 °C) (Table 2). Analysis of variance (ANOVA) indicated a significant difference between the nixtamalized samples and the control ($P < 0.05$). The reduction in pasting temperature following $Ca(OH)_2$ treatment suggests that nixtamalization influenced the thermal behaviour of sorghum starch, allowing gelatinization to occur at lower temperatures. Previous studies have reported similar trends, where increasing alkaline concentration during nixtamalization was associated with reduced pasting temperature in corn flours (Leon-Villalobos et al. 2023). This behaviour has been attributed in the literature to modifications in starch molecular organization under alkaline conditions, which may facilitate water penetration and earlier viscosity development (Wu et al. 2025).

Peak viscosity

The results of this study showed that both cooking time and $Ca(OH)_2$ concentration influenced the peak viscosity of nixtamalized sorghum flour. Overall, all treatments exhibited a decrease in peak viscosity compared to the control (Table 2). However, analysis of variance (ANOVA) indicated that the differences among treatments were not statistically significant. Among the samples, SP1 showed the highest peak viscosity (1948.25 cP), while SP8 exhibited the lowest (1173.5 cP). Zakiyah, Winarti and Yulistiani (2022) reported that nixtamalized corn had maximum peak viscosity of 1147 cP, which is lower than the lowest peak viscosity observed in nixtamalized sorghum flour in this study. The findings are consistent with the range of values previously reported by Wulandari et al. (2019) and Leon-Villalobos et al. (2023), suggesting that nixtamalized sorghum flour maintains relatively high viscosity despite the effects of lime treatment and processing conditions. The stabilizing impact of Ca^{2+} on the swelling capacity of starch granules, which is triggered by the restriction of the diffusion of water into the granule's core, lowers the peak viscosity of starch solutions with high calcium levels (Leon-Villalobos et al. 2023).

Breakdown viscosity

This study showed that both cooking time and $Ca(OH)_2$ concentration influenced the breakdown viscosity of nixtamalized sorghum flour. All treatments exhibited an increase in breakdown viscosity compared to the control. However, analysis of variance (ANOVA) indicated that these differences were not statistically significant. Among the samples, SP7 recorded the highest breakdown viscosity (596 cP), while SP3 showed the lowest value (220.5 cP). As presented in Table 2, nixtamalized sorghum flour did not exhibit a sharp reduction between peak viscosity and breakdown viscosity compared to the untreated control. The control flour had a peak viscosity of 2400.7 cP, which sharply decreased to a breakdown viscosity of 145.5 cP, indicating substantial viscosity loss under continued heating and shear. This pronounced breakdown suggests that the native starch granules in the untreated flour were highly susceptible to mechanical and thermal disruption after reaching maximum hydration (Faridah et al. 2014). In contrast, nixtamalized samples treated with $Ca(OH)_2$, for example SP1, displayed a more moderate decrease in viscosity, suggesting relatively greater resistance to viscosity breakdown during pasting. The reduced viscosity loss may be associated with alkaline-induced modifications occurring during nixtamalization, including partial starch gelatinization, molecular reorganization, and interactions between Ca^{2+} ions and starch hydroxyl groups, as reported in previous studies (Leon-Villalobos et al. 2023). Calcium ions may promote ionic cross-linking within and between starch chains, thereby reinforcing granule integrity and limiting excessive swelling (Leon-Villalobos et al. 2023). However, once a sufficient concentration of Ca^{2+} ions are available to interact with accessible hydroxyl groups on starch molecules, additional calcium may not further enhance cross-linking or structural reinforcement since the number of reactive binding sites within starch granules is inherently limited (Leon-Villalobos et al. 2023). This might explain a non-significant effect of increasing $Ca(OH)_2$ concentration on breakdown viscosity.

Setback viscosity

Setback viscosity is an important parameter commonly associated with amylose reassociation during the cooling phase and is considered an indicator of retrogradation tendency and gel firmness (Pangesti, Parnanto & Ridwan 2014). Higher setback viscosity indicates a greater tendency for starch retrogradation, leading to increased gel formation during cooling phase (Agustin 2011). The results of this study showed that nixtamalization of sorghum grains affected the setback viscosity profile of the flour, with all treatments exhibiting varying values. The highest setback viscosity was observed in SP1 (0.5% $Ca(OH)_2$, 10 min) (2218 cP), whereas the lowest value was recorded in SP8 (1.5% $Ca(OH)_2$, 20 min) (799 cP), with the control flour exhibiting an intermediate setback viscosity of 1276 cP. The elevated setback observed in SP1 suggests that mild alkaline treatment promoted sufficient starch swelling and amylose leaching while largely preserving molecular chain integrity, thereby facilitating reassociation during cooling and resulting in a stronger gel network. In contrast, the markedly reduced setback in SP8 indicates that higher $Ca(OH)_2$ concentration combined with longer treatment time may have induced greater molecular disruption, possible alkaline-induced depolymerization, or structural rearrangement of starch polymers, thereby limiting effective amylose reassociation. The intermediate behaviour of the control reflects the natural retrogradation tendency of native starch without alkaline modification (Leon-Villalobos et al. 2023). These findings suggest that increasing the severity of $Ca(OH)_2$ treatment progressively reduces retrogradation potential, which may influence textural properties and shelf-life stability of the final product.

Final viscosity

Final viscosity is an important parameters for evaluating starch quality, as it reflects the ability of a material to form a gel after cooking and cooling (Osungbaro, Jimoh & Osundeyi 2010). Nixtamalization using calcium hydroxida ($Ca(OH)_2$) produced varying effects on the final viscosity of sorghum flour. In this study, the highest final viscosity was observed in sample SP1 (3744 cP), while the lowest value was recorded in sample SP8 (1665 cP). However, analysis of variance (ANOVA) indicated no significant difference between the nixtamalized samples and the control. In contrast, Osungbaro, Jimoh and Osundeyi (2010) reported that fermentation of cassava flour led to an increase in final viscosity. According to Lin et al. (2011), a sharp decrease in final viscosity indicates a reduced ability of starch to form a thick gel after heating and cooling, as well as lower resistance of the paste to shear forces during mixing.

Peak time

Table 2 shows that there was a significant difference in peak time between the nixtamalized samples and the control. However, no significant differences were observed among the nixtamalized samples themselves. The significantly lower peak time observed in nixtamalized sorghum indicates accelerated starch gelatinization and swelling. Alkaline treatment with $Ca(OH)_2$ likely disrupted hydrogen bonding and partially weakened starch–protein interactions, enhancing water penetration into granules (Leon-Villalobos et al. 2023). Consequently, viscosity development occurred more rapidly, allowing peak viscosity to be reached in a shorter time compared with the control.

EFFECT OF NIXTAMALIZATION ON TANNIN CONTENT OF SORGHUM FLOUR

Sorghum flour derived from the Garut variety was found to contain relatively high levels of tannin (approximately 2%), exceeding the maximum acceptable limit of 0.3% specified by Codex Standard (1989). Therefore, processing interventions to reduce tannin content are necessary to improve nutritional quality. The results of this study showed a reduction in tannin levels across all nixtamalized samples, with tannins not detected in SP6, SP8, and SP9 (Table 3). This suggests that higher $Ca(OH)_2$ concentrations combined with longer cooking times were effective in substantially reducing tannin content. The reduction in tannins may be associated with alkaline-induced chemical interactions reported in previous studies. It has been proposed that tannic acid can react with calcium hydroxide to form insoluble calcium tannate complexes, which may be removed during washing and steeping steps (Septianingsih, Fahrurrozi & Sediawan 2025; Shnawa et al. 2015). Similar reductions in tannin content with increasing lime concentration have been reported by Diaz, Morawicki and Mauromoustakos (2019), supporting the observed trend.

EFFECT OF NIXTAMALIZATION ON PHYTATE CONTENT OF SORGHUM FLOUR

The phytate content of sorghum nixtamalized in $Ca(OH)_2$ also showed a significant reduction compared to the control sample ($p<0.05$), as shown in Table 3. Abera, Yohannes and Chandravanshi (2023) reported that the antinutritional phytate and tannin contents of black kidney beans decreased after soaking and cooking. Comparable findings were reported by Nagessa, Chambal and Macuamule (2023), who observed reductions in antinutrients following various processing methods, including soaking in water, soaking in sodium bicarbonate by 24-hour and 48-h germination, as well as ordinary and pressure cooking. In some studies, cooking significantly ($p\leq0.05$) decreased the polyphenol content of karkade seeds, whereas other processing methods did not have a significant effect (Yagoub et al. 2004). Similarly, cooking was found to reduce phytate levels in green leafy vegetables (Ilelaboye, Amoo & Pikuda 2013). The observed reductions in these antinutrients may be attributed to thermal degradation and changes in chemical reactivity during cooking (Alonso, Aguirre & Marzo 2000; Wu et al. 2016; Yagoub et al. 2004). However, other studies have reported mixed results, showing that certain sorghum genotypes were not significantly affected by soaking, germination and cooking (Alonso, Aguirre & Marzo 2000; Wu et al. 2016).

TABLE 3. Effect of $Ca(OH)_2$ concentration and cooking time conditions on tannin and phytate acids content of sorghum flour

Time (min)	$Ca(OH)_2$ concentration	Tannin acid concentration (mg/100 g)	Phytate acid concentration (mg/g)
0	0	2.40 ± 0.08^{a}	14.43 ± 0.38^{a}
10	0.5	1.32 ± 0.30^{bc}	14.85 ± 0.30^{a}
	1	1.46 ± 0.25^{b}	12.18 ± 0.69^{c}
	1.5	1.20 ± 0.21^{bc}	14.34 ± 0.63^{a}
20	0.5	1.29 ± 0.42^{bc}	13.04 ± 0.11^{b}
	1	0.51 ± 0.17^{d}	11.68 ± 0.09^{c}
	1.5	nd.	11.59 ± 0.27^{c}
30	0.5	0.95 ± 0.05^{c}	13.27 ± 0.16^{b}
	1	nd.	13.19 ± 0.23^{b}
	1.5	nd.	13.20 ± 0.08^{b}

Means with different letters within the same column indicate significant differences among samples ($p< 0.05$)

CONCLUSIONS

Nixtamalization of sorghum grains using $Ca(OH)_2$ induces significant physical and functional changes, including enhanced solubility, water absorption capacity, and swelling power, along with reduced in oil absorption, color value, and degree of whiteness. The process also alters the gelatinization profile of sorghum flour, indicating modification of starch properties. Moreover, cooking sorghum seeds in $Ca(OH)_2$ solution effectively reduces of antinutrient contents such as phytic acid and tannins. These findings demonstrate that nixtamalization not only improves the functional and nutritional qualities of sorghum but also enhances its potential for wider food applications. Overall, nixtamalized sorghum represents a promising ingredient for developing value-added, nutrient-enriched food products that meet consumer preferences and industrial needs.

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