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ORIGINAL RESEARCH ARTICLE

Techno-Functional and Sensory Performance of Ugandan Sorghum (Sorghum bicolor) Varieties in Gluten-Free Mechanically Formed Noodles

Olive Nzigire Katoke[1,2], Robert Mugabi[1]*, Ivan Muzira Mukisa[1]

[1]Department of Food Technology and Nutrition, School of Food Technology, Nutrition and Bioengineering, Makerere University, P.O. Box 7062, Kampala, Uganda.
[2]Department of Agronomy, Faculty of Agronomy and Environmental Sciences, University of Martyrs of Congo (UNIM-DRC), Democratic Republic of the Congo.
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ABSTRACT

Growing demand for gluten-free functional foods has renewed interest in sorghum (Sorghum bicolor), a nutritious and climate-resilient cereal. This study evaluated the physicochemical and sensory performance of noodles produced from three Ugandan sorghum varieties: NASARRI-M060 (red), NASARRI-MS001 (white), and NASARRI-M003 (brown). A standardized multi-ingredient formulation was used, and cooking loss, optimal cooking time, water absorption capacity, moisture content, and instrumental color were measured. Sensory quality was assessed by quantitative descriptive analysis with a trained panel (n = 10) and a consumer acceptability test using a nine-point hedonic scale (n = 20). Sorghum variety significantly affected cooking loss (1.69–5.25%) and moisture content (5.83–6.35%) ($p < 0.05$), but not cooking time (3.33–4.00 min) or water absorption capacity (143.0–148.5%). NASARRI-M060 had the lowest cooking loss (1.69%), indicating greater noodle-matrix integrity, while NASARRI-MS001 received the highest appearance score (7.1 ± 1.0). The formulations had generally similar sensory profiles, although brown color intensity and grittiness differed significantly ($p < 0.05$). Overall acceptability ranged from 5.0 for NASARRI-M003 to 6.0 for NASARRI-MS001. NASARRI-M060 and NASARRI-MS001 therefore show promise for gluten-free noodle production under the tested conditions, although compositional characterization, formulation optimization, and evaluation with larger and more diverse consumer groups are needed.

*Corresponding author
E-mail: robert.mugabi@mak.ac.ug (Robert Mugabi).
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1. INTRODUCTION

Noodles are one of the world's most consumed staple foods, produced from an unleavened dough, rolled or extruded into various shapes (Fu, 2008), and instant noodles have been steadily increasing their market share globally due to rapid urbanization, increasing disposable incomes and consumers' preference for convenience foods that are affordable, have long shelf life and are easy to prepare (Singla et al., 2024). According to the World Instant Noodles Association, the global consumption of instant noodles reached over 121 billion servings in 2023 with strong growth observed in the sub-Saharan Africa region. Traditionally, noodles have been made from wheat flour alone, because the gluten network in wheat provides the elasticity, cohesiveness and cooking tolerance of noodles that consumers expect (Yu, 2002; Obadi et al., 2021). However, there has been a recent trend toward the use of alternative cereal-based noodle formulations, driven by two major factors: the growing prevalence of celiac disease and non-celiac gluten sensitivity, and the growing consumer demand for functional, nutritious and minimally processed foods (Ciacci et al., 2007; Zoghi, Mirmahdi, & Mohammadi, 2021). Celiac disease is an autoimmune disorder caused by gluten in genetically predisposed individuals and affects about 1-2% of the global population, although the prevalence of celiac disease is thought to be higher in many developing countries because of limited diagnostic capabilities (Ciacci et al., 2007), although definitive prevalence data for sub-Saharan Africa specifically remain limited.

The only effective treatment for celiac disease is a strict, life-long adherence to a gluten-free (GF) diet, which has stimulated the rapid growth of the GF food market for example, global GF product sales reached USD 4.63 billion in 2017 and were forecast to grow to USD 6.47 billion by 2023 as demand broadened beyond medical necessity (Woomer & Adedeji, 2021), and is projected to expand even further in the coming decade (Grand View Research, 2026). However, many commercial GF products have poor texture, cooking performance and nutritional quality compared to wheat-based products, highlighting the need to develop innovative GF formulations based on underutilized cereals with improved nutritional profiles (Giuberti et al., 2015; Marti & Pagani, 2013). Recent advances in GF noodle technology have investigated the potential of hydrocolloids, modified starches and protein fortification to bridge the structural and sensory gap with conventional wheat noodles (Wangtueai et al., 2020; Zoghi et al., 2021), nevertheless, the identification of base flours with desired techno-functional behaviour and nutritional value remains a key research challenge. Sorghum (*Sorghum bicolor* L. Moench) is the world's fifth most important cereal, grown on more than 42 million ha of land in tropical and semi-arid regions of Africa, Asia and the Americas (Orr et al., 2016; Pontieri & Giudice, 2016), and it is gluten-free, drought-tolerant and adapted to marginal environments, making it a critical crop for food security in sub-Saharan Africa (Andiku et al., 2021; Hadebe, Modi & Mabhaudhi, 2021).

Nutritionally, sorghum grain contains 8-16% protein, 65-80% starch, 1.5-6.0% lipids and 1.2-6.5% dietary fiber and is a good source of B-vitamins, iron, zinc and potassium (Rooney & Saldivar, 2000), while pigmented sorghum varieties are rich in bioactive phytochemicals, including phenolic acids, flavonoids, condensed tannins and 3-deoxyanthocyanidins (a pigment class exclusive to sorghum) that have been reported to have strong antioxidant, anti-inflammatory and anti-proliferative properties (Dykes & Rooney, 2006; Carpentieri et al., 2021). Comprehensive reviews have shown that phenolics in sorghum may reduce the risk of chronic diseases such as cardiovascular disease, type 2 diabetes and certain types of cancer (Riedl & Hagerman, 2001), and sorghum starch also has unique properties such as high gelatinization temperatures and slow retrogradation that can have a significant impact on the texture and cooking properties of processed foods (Li et al., 2014). In East Africa, sorghum is mainly grown by smallholder farmers and is traditionally consumed as porridges, flatbreads and fermented beverages (Hadebe et al., 2021; Andiku et al., 2021), while Uganda produces about 300,000 metric tons of sorghum per year (Andiku et al., 2021), with the National Semi-Arid Resources Research Institute (NaSARRI) releasing several improved sorghum varieties with improved agronomic traits and grain quality.

However, value addition of sorghum beyond traditional foods and brewing is limited (Orr et al., 2016), which is a missed opportunity for industrial development and dietary diversification, while the development of innovative sorghum-based products such as GF noodles may offer opportunities to expand market opportunities for smallholder farmers, provide affordable GF foods for celiac patients (noting that certified gluten-free status would require strict ingredient sourcing and cross-contamination control) and strengthen food security through the promotion of a climate-resilient and locally adapted crop.

The main technological challenge in producing sorghum-based GF noodles is the absence of gluten, a viscoelastic protein network that provides structure, extensibility and cooking tolerance in wheat noodles (Akajiaku et al., 2017), and in the absence of gluten, the structure of GF noodles is formed by starch gelatinisation and retrogradation, protein cross-linking and the incorporation of structure-forming additives such as hydrocolloids, emulsifiers and extra protein sources (Li et al., 2014; Zoghi et al., 2021). Hydrocolloids such as xanthan gum and carboxymethyl cellulose (CMC) partially mimic the action of gluten by thickening the dough, enhancing water retention and creating gel-like networks that stabilise the noodles during cooking (Marti & Pagani, 2013; Palavecino et al., 2017), while egg proteins may further stabilise the structure through heat-induced gelation, producing a protein matrix that reinforces the starch network (Collado & Corke, 2016). In the present study, xanthan gum and CMC were used as hydrocolloids, and whole eggs were included as an additional protein source to reinforce the starch-based matrix of the sorghum GF noodles.

However, the effectiveness of these additives is highly dependent on the properties of the base flour, and sorghum cultivars vary widely in starch composition, protein content and digestibility, grain hardness and phenolic content, which can all influence noodle quality (Palavecino et al., 2020; Oliveira et al., 2022). Studies on sorghum-based noodles and pasta have demonstrated that the selection of sorghum cultivar is critical, for example, Palavecino et al. (2017) reported that Argentine sorghum varieties with higher amylose content produced GF spaghetti with lower cooking losses, and Suhendro et al. (2000) found that the starch gelatinization behaviour and flour particle size are very important in terms of the texture and cooking performance of the noodles. Obadi et al. (2021) also reviewed the role of starch, protein and hydrocolloids interaction in non-wheat noodle products, however, there is limited published information on the performance of modern Ugandan sorghum cultivars in noodle extrusion, particularly on how grain traits such as color, phenolic content and genetic background influence end-product quality.

Given that NaSARRI has released several improved sorghum varieties with diverse grain colors and compositions, a systematic evaluation of their noodle-making potential is required to inform variety selection for industrial food processing, and against this background, the present study aimed to evaluate the techno-functional and sensory performance of three Ugandan sorghum varieties (NASARRI-M060 (red), NASARRI-MS001 (white) and NASARRI-M003 (brown)) for the production of gluten-free extruded noodles. Specifically, the study aimed to determine how sorghum variety influences cooking quality parameters (cooking loss, optimal cooking time and water absorption), moisture content and color attributes of the noodles, describe the sensory profiles of the different formulations using Quantitative Descriptive Analysis (QDA), and assess consumer acceptability in order to identify which variety is best suited for making high-quality GF noodles. The results of this study are anticipated to contribute to the increasing body of literature in sorghum-based gluten-free product development, as well as valorize the Ugandan sorghum cultivars in the regional and international functional food markets.

2. MATERIALS AND METHODS

2.1 Raw Materials and Reagents

Three sorghum (*Sorghum bicolor* [L.] Moench) grain cultivars with different grain color phenotypes: NASARRI-M060 (red pericarp), NASARRI-MS001 (white pericarp) and NASARRI-M003 (brown pericarp) were obtained from the National Semi-Arid Resources Research Institute (NaSARRI) in Serere, eastern Uganda, because the choice of these varieties was based on the broad genetic diversity of grain color phenotypes in Uganda's improved sorghum germplasm to study the impact of grain characteristics on quality of gluten-free extruded products. The grains were harvested in the 2024 growing season and stored in airtight polypropylene bags at ambient temperature (about 25 °C) until processing, while other food-grade ingredients used, such as sucrose, sodium chloride (NaCl), sodium bicarbonate ($NaHCO_3$) and corn starch, were purchased from commercial suppliers in Kampala, Uganda. Note that sucrose and corn starch were procured as part of a broader ingredients inventory but were not included in the noodle formulation used in this study. Hydrocolloids, including xanthan gum (food grade, purity ≥ 99%) and carboxymethyl cellulose (CMC, food grade), were used as structural integrity enhancers of the gluten-free matrix, and the formulations also consisted of whole eggs, skimmed milk powder, margarine, food-grade glycerol and seasonings (dehydrated garlic, white pepper and chicken flavor). All chemicals and reagents used for the analytical measurements were of analytical grade.

2.2 Preparation of Sorghum Flour

The grains were hand sorted to remove the moldy kernels, stones, and other foreign materials. Cleaned sorghum grains were tempered with distilled water and equilibrated for 12 h at room temperature to a moisture content of approximately 12% to achieve uniform milling performance, and then tempered grains were milled into flour by a commercial disc mill (Staunch, Lebanon) and milled meal was passed through a 200-µm sieve to obtain a fine, homogeneous flour, which could be used to make uniform noodle extrudates. Particle size of flour is an important factor for gluten-free noodle production because it influences dough rheology and starch gelatinization behavior, and hence affects the cooking quality of noodles (Suhendro et al., 2000; Rao, 2019), therefore sieved sorghum flours were packaged in sealed polyethylene bags and stored at 4 °C until used.

2.3 Production of Sorghum Noodles

The noodle formulation and processing procedure was adapted from Muwanguzi, Asiimwe & Muyonga (2025), and the same procedure was followed for all three sorghum varieties in order to compare the quality of noodles under the same conditions. Each batch consisted of 190 g sorghum flour, 45 g skimmed milk powder (dissolved in 120 mL hot water, approximately 80 °C), 39 g melted margarine and three whole eggs (approximately 150 g), and to improve noodle structure and texture, 10 g xanthan gum, 5 g CMC, 10 g sodium bicarbonate ($NaHCO_3$), 5 g sodium chloride (NaCl) and 10 g food grade glycerol were added. Additionally, to improve the flavour, 15 g dehydrated garlic, 5 g white pepper and 5 g chicken seasoning (a commercially available chicken-flavour seasoning verified to contain no declared wheat-derived ingredients) were added. All dry ingredients were mixed in a planetary mixer (Kenwood Chef, UK) at speed 1 for 2 min, and the wet ingredients were gradually added and mixed at speed 2 for 8 min until a smooth well developed dough was obtained. The dough was rolled to a thickness of approximately 1.5 mm using a manual pasta sheeter (Atlas 150, Italy) and rested for 40 min at room temperature (approximately 25 °C) to allow for starch hydration and dough relaxation. Consequently, the rested sheets were then passed through a mechanical noodle extruder (Pasta Machine, China) with 2 mm round die It should be noted that this mechanical die-pressing and sheeting process constitutes mechanical forming rather than thermomechanical extrusion cooking, which involves a screw extruder operating under heat and pressure; the term 'mechanically formed' is therefore used in the revised title to describe this production method more precisely. to obtain uniform strands. Fresh noodles were laid on perforated stainless steel trays in a single layer and dried at 65 °C for 3 h in a forced air food dehydrator (NL-FD-4935, Saachi, China), and after drying, the noodles were cooled to room temperature, packed in polyethylene pouches and stored at ambient temperature until physicochemical and sensory analyses were carried out. Moreover, the whole processing procedure was repeated three times for each sorghum variety.

2.4 Physical and Color Analysis

2.4.1 Cooking Quality Attributes

Cooking quality was evaluated on the basis of optimum cooking time, cooking loss and water absorption capacity (WAC) using AACC Approved Methods (AACC, 2000), because optimum cooking time was measured following AACC Method 66-50. Briefly, 25 g of noodles were cooked in 300 mL boiling distilled water, and strands were removed at 30 s interval, while a few strands at each interval were sandwiched between two transparent glass plates and pressed gently. The cooking time at which the opaque white core disappeared was considered the optimum cooking time, and cooking loss was measured according to AACC Method 66-50.01. For this test, 10 g noodles were cooked in 300 mL boiling distilled water for 5 min, and the cooked noodles were removed, consequently the cooking water including all leached solids was collected in a pre-weighed aluminum dish and dried in a forced air oven at 105 °C to constant weight. Cooking loss was expressed as the mass of dried residue as a percentage of the initial dry noodle weight. Water absorption capacity (WAC) was determined by weighing 25 g of the noodles before and after cooking for the previously determined optimal cooking time, and then draining for 30 s on a wire mesh, moreover WAC was expressed as percentage increase in weight in relation to the uncooked noodles. The measurements were performed in triplicate. Although cooking loss was measured at 5 min per the AACC Method 66-50.01 standardised protocol, it is acknowledged that this fixed endpoint exceeds the optimal cooking times of 3.33-4.00 min determined for each variety; this may moderately overestimate cooking loss relative to values that would be obtained at each variety's optimal cooking time.

2.4.2 Moisture Content

Moisture content of dried noodle samples was determined gravimetrically following AOAC Method 925.10 (AOAC, 2000). Approximately 3 g of dried noodles were accurately weighed into pre-dried aluminum dishes and placed in a forced-air oven at 105 °C for 3 h. Samples were transferred to a desiccator, cooled to room temperature, and reweighed. Moisture content was calculated as the percentage loss in weight relative to the initial sample weight. Determinations were performed in triplicate for each variety.

2.4.3 Instrumental Color Analysis

The color of both raw and cooked noodle samples was measured using a Lovibond Tintometer (Model E AF 900, Tintometer Ltd., UK) according to the manufacturer's operating instructions. Color readings were expressed in Lovibond units as yellow-orange and red-orange values. Although CIE L*a*b* colorimetry is the conventional standard for noodle colour measurement, the Lovibond Tintometer (Model E AF 900) was the instrument available for this study; Lovibond units allowed consistent semi-quantitative characterisation of the distinctive yellow-orange and red-orange colour differences among the three sorghum varieties. Measurements were taken in triplicate for each sample under standardized ambient lighting conditions. Cooked samples were prepared by cooking noodles at the previously established optimal cooking time and measuring color within 5 min of cooking to minimize color changes due to oxidation.

2.5 Sensory Evaluation

2.5.1 Consumer Acceptability Test

A preliminary consumer acceptability screening was conducted with 20 panelists recruited by open invitation from the Department of Food Technology and Nutrition, Makerere University. Eligible participants were adults (≥18 years) who regularly consumed noodles; individuals with known allergies to eggs, dairy products, or other formulation ingredients were excluded. Samples were coded with random three-digit numbers, and serving order was randomized and balanced to minimize positional and carryover effects. Panelists cleansed their palates with water between samples and rated appearance, taste, aroma, texture, and overall acceptability on a nine-point hedonic scale (1 = dislike extremely; 9 = like extremely) in individual booths under uniform fluorescent lighting. Each sample was served once; consequently, the consumer ratings were not replicated within individuals.

2.5.2 Quantitative Descriptive Analysis (QDA)

Sensory characteristics of the sorghum noodle samples were determined using the Quantitative Descriptive Analysis (QDA) procedure of Stone et al. (1974). Twenty-three volunteers from Makerere University were initially screened for their ability to detect and distinguish basic tastes and odors, for consistency of their responses, and 10 panelists (n = 10) were selected for the descriptive panel (Meilgaard et al., 2006), who were given 10 h of training (five 2-h sessions) and developed a consensus of sensory terms specific to sorghum noodles. They also practiced rating products using reference standards so that their ratings would be as consistent and repeatable as possible (Carpenter et al., 2000; Cross et al., 1978). Each panelist evaluated all three noodle samples in a single session, with samples served in randomised order. Panel performance was monitored during training sessions by checking within-panelist consistency using replicate assessments of reference samples. The consensus list of sensory terms included brown color intensity, saltiness, sorghum flavor, astringency, bitterness, sorghum aroma, seasoning aroma, grittiness, firmness, and chewiness. For the actual evaluations, cooked noodle samples were served monadically in a randomized order in containers labeled with three-digit codes, and panelists scored the intensity of each attribute on a 15-cm unstructured line scale with "none" (0) on one end and "extreme" (15) on the other end. Bottled drinking water was available for the panelists to rinse their mouth between the samples, and the mean intensity scores were calculated from the individual panelist ratings for each attribute and sorghum variety.

2.6 Statistical Analysis

All physical measurements were performed in triplicate, and results are expressed as mean ± standard deviation (SD). One-way analysis of variance (ANOVA) was used to evaluate differences among the three sorghum varieties for each response variable. When ANOVA indicated a significant effect ($p < 0.05$), Tukey's Honestly Significant Difference (HSD) post hoc test was applied for pairwise comparisons. All statistical analyses were conducted using Minitab version 16 (Minitab Inc., State College, PA, USA). The processing procedure was repeated three times per sorghum variety, yielding three independent production batches per variety. Physicochemical measurements were performed in triplicate per batch, and the mean of the three readings was used as the batch value ($n = 3$ independent batches) for ANOVA. Spider (radar) plots for QDA data were constructed using Microsoft Excel 2019.

3. RESULTS AND DISCUSSION

3.1 Cooking Quality Attributes

Cooking quality parameters are critical indicators of noodle behavior during hydrothermal processing and directly influence product appearance, texture, and consumer acceptability (Obadi et al., 2021). The cooking loss, optimal cooking time, and water absorption capacity (WAC) of the three sorghum-based noodle formulations are presented in **Table 1.**

Table 1. Cooking Quality Attributes of Noodles Produced from Three Ugandan Sorghum Varieties

Sorghum variety	Grain color	Cooking loss (%)	Cooking time (min)	WAC (%)
NASARRI MS001	White	$5.25^{c} \pm 0.15$	$4.00^{a} \pm 0.00$	$143.0^{a} \pm 5.23$
NASARRI M003	Brown	$2.67^{b} \pm 0.38$	$4.00^{a} \pm 0.00$	$144.0^{a} \pm 3.63$
NASARRI M060	Red	$1.69^{a} \pm 0.22$	$3.33^{a} \pm 0.58$	$148.5^{a} \pm 6.35$

Note: *Values are mean ± standard deviation (n = 3). Means within the same column bearing different superscript letters are significantly different (p < 0.05, Tukey's HSD test). WAC = water absorption capacity.*

3.1.1 Cooking Loss

Cooking loss differed significantly among the sorghum varieties ($p < 0.05$), ranging from 1.69% for NASARRI-M060 (red) to 5.25% for NASARRI-MS001 (white). Cooking loss indicates the amount of solid material transferred from noodles to cooking water and therefore reflects structural stability during boiling; lower values indicate better cooking tolerance (Yadav et al., 2011; Giuberti et al., 2015). The value recorded for NASARRI-M060 was below the generally accepted threshold for high-quality pasta (7–8%) and below values reported for several gluten-free formulations (Nilusha et al., 2019; Wangtueai et al., 2020).

The improved structural stability of the noodles produced using the red sorghum (NASARRI-M060) could probably be attributed to its composition; according to literature reviews, pigmented sorghum genotypes tend to have higher amounts of condensed tannins and phenols, which could bond with the starch and proteins through hydrogen bonding and hydrophobic forces, thereby improving the integrity of the matrix structure and minimising solid losses due to cooking (Riedl & Hagerman, 2001; Carpentieri et al., 2021). Unfortunately, due to the lack of tannin and phenolic content analysis in this research, this theory is only a hypothesis that requires further compositional evaluation. Also, other factors such as the different levels of starch crystallinity, protein content and grain hardness among the three varieties, which have not been analysed in this research, can affect the cooking losses recorded. Further investigations should include a compositional analysis of the sorghum flours. In addition, the tannin–protein complexes formed might also result in a more compact network hindering starch swelling and solubilization (Palavecino et al., 2017). The hydrocolloids (xanthan gum and CMC) and egg proteins in the recipe probably helped in reducing cooking loss by acting as gluten replacers and forming a continuous matrix that retains the noodle structure and minimizes solid leaching (Marti & Pagani, 2013; Zoghi et al., 2021), and these results are consistent with Palavecino et al. (2020), who found that variations in starch and protein properties between sorghum cultivars have a significant effect on cooking loss in gluten-free sorghum pasta.

3.1.2 Cooking Time and Water Absorption Capacity

Cooking time did not differ significantly among the three formulations ($p > 0.05$) and ranged from 3.33 to 4.00 min (**Table 1**). These short cooking times support rapid preparation; however, the noodles were not pre-gelatinized by steaming or frying and therefore should not be formally classified as instant noodles. The observed values are comparable with those reported for extruded rice noodles (5–8 min) and below the 8–12 min commonly reported for conventional wheat spaghetti (Hatcher et al., 2004; Obadi et al., 2021).

Water absorption capacity (WAC) was not significantly different ($p > 0.05$) between the three varieties, and the values recorded were 143.0-148.5% (Table 1), which indicates the amount of water that the noodles can absorb and retain during cooking, determined by starch swelling, protein hydration, and the water binding properties of dietary fibre and hydrocolloids in the formulation (Seetapan et al., 2019). Sorghum grain is rich in dietary fibre (8.5–26.3 g/100 g), which is mainly concentrated in the bran-rich outer layers and is comprised of hydrophilic polysaccharides with water-binding hydroxyl groups (Xiong et al., 2019). The wide range of fibre content values is attributed to genotypic and pericarp differences among the sorghum cultivars (Taylor & Duodu, 2019; de São José et al., 2026), and the similar WAC values of the three varieties in this study suggest that, despite the differences in grain colour and phenolic profile, the starch–fibre–hydrocolloid network as a whole absorbed and retained water to the same extent under the cooking conditions applied (Chandra & Samsher, 2013; Iwe et al., 2016). Therefore, from a product development point of view, it is useful because it means switching between the three types will not significantly affect cooking yield.

3.2 Moisture Content

The moisture content of the dried sorghum noodle samples ranged from 5.83% for the white (NASARRI-MS001) to 6.35% for the brown (NASARRI-M003) with the brown noodles retaining more moisture than the white noodles ($p < 0.05$; Table 2), and the results are lower than the 8–12% moisture content commonly reported for commercial instant dried noodles (Rani et al., 2018; Winarno, 1997). Therefore, the drying conditions (65 °C for 3 h in a forced-air dryer) used in this study removed moisture efficiently, and consequently, the lower moisture content is beneficial for storage as it retards microbial growth and enzyme activity, thereby extending shelf life (Winarno, 1997). However, very low moisture content can also make the noodle more brittle and prone to breakage during handling, packaging, and transportation, hence, the drying conditions may need to be fine-tuned in future studies to achieve an optimal balance between safety and physical strength of the product.

Table 2. Moisture Content of Dried Sorghum Noodles Produced from Three Ugandan Sorghum Varieties

Sorghum variety	Grain color	Moisture content (%)
NASARRI MS001	White	$5.83^{a} \pm 0.19$
NASARRI M003	Brown	$6.35^{b} \pm 0.15$
NASARRI M060	Red	$6.05^{ab} \pm 0.21$

Note: *Values are mean ± standard deviation (n = 3). Means bearing different superscript letters are significantly different (p < 0.05, Tukey's HSD test).*

The higher moisture content of the brown sorghum noodles (NASARRI-M003) is hypothetically attributed, in the absence of direct fibre and phenolic measurements, to elevated levels of dietary fibre and hydrophilic phenolic compounds concentrated in the outer pigmented layers of the grain (Xiong et al., 2019). The polar hydroxyl groups of these components facilitate hydrogen bonding with water, enhancing water retention and increasing the water-holding capacity of the dried noodles (Taylor & Duodu, 2019; de São José et al., 2026). Similar patterns have been reported for pigmented varieties of other cereal grains, which are generally more hygroscopic than non-pigmented varieties due to their phenolic and fibre fractions (Dykes & Rooney, 2006). However, from an industrial standpoint, the moisture contents obtained for the three types of sorghum noodles are low enough to meet microbiological safety requirements for dried noodle products, however, formal water activity measurement and shelf-life testing were not conducted in this study, and definitive shelf-life predictions cannot be made from moisture content data alone.

3.3 Color Analysis

Colour is the first visual cue by which consumers evaluate if they like or dislike noodle and pasta products (Marti et al., 2013; Raungrusmee et al., 2020), and in this study, the sorghum noodle samples had marked differences in colour, ranging from yellow-orange to red-orange (Figure 1; Table 3). Before cooking, the noodles from the brown sorghum (NASARRI-M003) had the highest yellow hue, whereas those from the red sorghum (NASARRI-M060) were darker and more red-orange, and these colour differences are mainly associated with natural grain pigmentation and secondary metabolite levels, especially total phenolics (c. 1.4-3.2 mg gallic acid equivalents/g) and condensed tannins (c. 10.0-68.0 mg catechin equivalents/g), mainly concentrated in the pericarp (Dykes & Rooney, 2006; Pontieri & Giudice, 2016).

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Fig. 1. Appearance of Noodles Produced from Three Ugandan Sorghum Varieties. (A–C) Uncooked noodles from NASARRI-M060 (A), NASARRI-M003 (B), and NASARRI-MS001 (C); (D–F) corresponding cooked noodles.

Table 3. Instrumental Color Analysis of Uncooked and Cooked Sorghum Noodles

Variety	Condition	Yellow-orange (Lovibond)	Red-orange (Lovibond)
NASARRI MS001 (White)	Uncooked	$1.3^{b} \pm 0.12$	—
NASARRI MS001 (White)	Cooked	$1.1^{a} \pm 0.10$	—
NASARRI M003 (Brown)	Uncooked	$3.8^{b} \pm 0.20$	$0.7^{b} \pm 0.06$
NASARRI M003 (Brown)	Cooked	$2.9^{a} \pm 0.15$	$0.5^{a} \pm 0.04$
NASARRI M060 (Red)	Uncooked	$2.1^{b} \pm 0.18$	$2.3^{b} \pm 0.15$
NASARRI M060 (Red)	Cooked	$1.8^{a} \pm 0.12$	$1.9^{a} \pm 0.10$

Note: Values are mean ± standard deviation (n = 3). Color expressed in Lovibond units. "—" indicates values below the detection threshold. Statistical comparisons were conducted using one-way ANOVA and Tukey's HSD test (p < 0.05). Means within the same column bearing different superscript letters are significantly different.

The distribution and concentration of pigments in the sorghum grain are genetically controlled by the R and Y genes responsible for the red and yellow pericarp colour, by the dominant Tp gene causing the formation of a brown testa and by the I gene, which enhances the intensity of the red and yellow pericarp colours (Pontieri & Giudice, 2016; Xiong et al., 2019), and other factors, such as the bran colour, the extraction rate in the milling process, starch damage and the activity of polyphenol oxidase enzymes, also contribute to the final colour of the dough and of the cooked noodles (Siah & Quail, 2018). The darker and less familiar colour of the pigmented sorghum noodles might be discouraging for some consumers at the first approach, but these pigments are associated with important functional properties, because pigmented sorghum types have been reported to have high antioxidant activity, with values as high as 28.4 µmol Trolox equivalents/g (FRAP assay), which fits the increasing interest in functional foods that provide health benefits beyond basic nutrition (Carpentieri et al., 2021; Riedl & Hagerman, 2001). It should be noted that antioxidant activity was not measured in the present study, and these values are cited from the published literature; they cannot be assumed to apply directly to the noodles evaluated here. Moreover, recent studies on the effects of processing on sorghum phenolics have shown that thermal treatments, such as cooking, can modify the phenolic profile, but do not completely destroy the antioxidant activity, so that a significant amount of these bioactive compounds remains in the cooked noodles (Asenstorfer, Wang & Mares, 2005). This finding is based on published studies on sorghum phenolics; antioxidant activity was not measured in the cooked noodles of the present study.

3.4 Quantitative Descriptive Analysis (QDA)

The trained panel developed a consensus vocabulary comprising attributes related to appearance (brown intensity), taste (saltiness, sorghum flavor), aftertaste (astringency, bitterness), aroma (sorghum aroma, seasoning aroma), and texture (grittiness, firmness, chewiness) (**Table 4**). The QDA sensory profiles of the three sorghum noodle formulations are presented in **Figure 2.**

Table 4. Sensory Descriptors, Definitions, and Reference Standards Used in Quantitative Descriptive Analysis

Category	Descriptor	Definition	Reference (Low)	Reference (High)
Appearance	Brown intensity	Degree of brown coloration	White sorghum flour	Dried red hibiscus petals
Taste	Saltiness	Basic taste elicited by NaCl	0.2% NaCl solution	1.0% NaCl solution
Taste	Sorghum flavor	Characteristic cereal taste	White rice porridge	Whole sorghum porridge
Aftertaste	Astringency	Dry, puckering mouthfeel	Dilute green tea	Strong black tea
Aftertaste	Bitterness	Basic bitter taste	0.05% caffeine	0.1% caffeine
Aroma	Sorghum aroma	Characteristic cereal odor	White rice	Whole sorghum flour
Aroma	Seasoning aroma	Perceived spice/seasoning	Unseasoned noodles	Heavily seasoned noodles
Texture	Grittiness	Sandy/gritty mouthfeel	Fine wheat noodles	Coarse maize porridge
Texture	Firmness	Resistance to biting	Overcooked wheat noodles	Al dente wheat pasta
Texture	Chewiness	Duration of mastication	Soft bread	Dried beef jerky

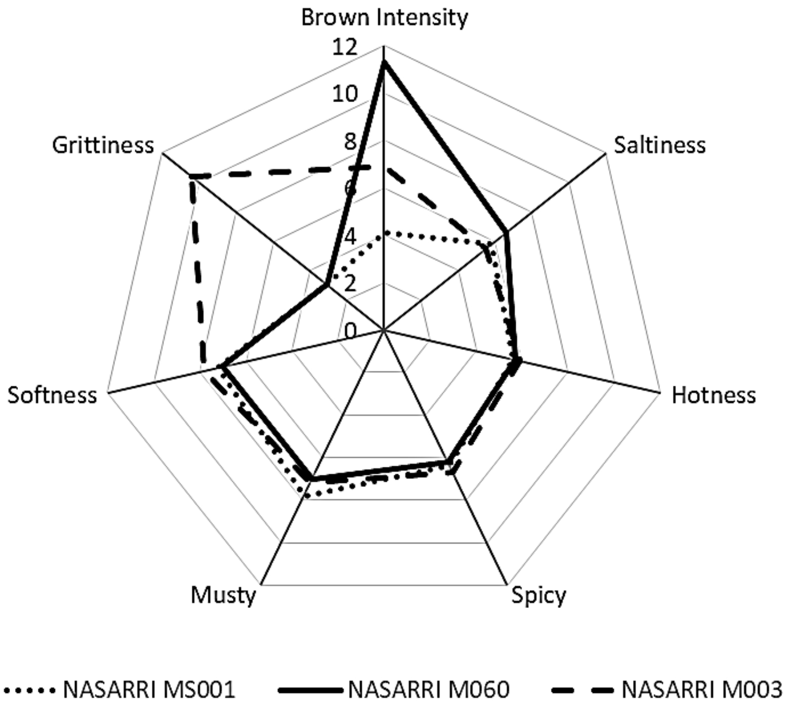

Fig. 2. Quantitative Descriptive Analysis Sensory Profiles of Noodles Produced from Three Ugandan Sorghum Varieties (NASARRI-M060, red; NASARRI-M003, brown; NASARRI-MS001, white).

In general, the three sorghum noodle samples showed similar sensory profiles, suggesting that the effect of variety on most of the panelists' attributes was not substantial. Only two attributes showed significant ($p < 0.05$) difference among the varieties (**Figure 2**), which were brown colour intensity and grittiness, because brown colour intensity of the noodles increased in the order of NASARRI-MS001 (white) < NASARRI-M003 (brown) < NASARRI-M060 (red), which is in line with the genetic control of pericarp and testa pigmentation by the R, Y, Tp and I genes (Pontieri & Giudice, 2016; Rooney & Saldivar, 2003; Xiong et al., 2019) and the increasing concentration of phenolic pigments from white to red sorghum. Noodles made from the brown sorghum variety (NASARRI-M003) recorded the highest grittiness scores, whereas the white sorghum variety (NASARRI-MS001) recorded the lowest, since grittiness of sorghum-based extruded products is greatly influenced by the distribution of flour particle sizes, grain hardness and the level of starch damage introduced during milling (Rao, 2019; Suhendro et al., 2000).

The higher grittiness of the brown noodles could be attributed to a harder or more vitreous endosperm or a greater amount of coarse bran particles that were not completely removed by sieving; therefore, milling treatments such as pin or jet milling, or use of finer or additional sieves may be employed in future to reduce perceived grittiness (Rao, 2019). The absence of significant differences detected for taste, aroma and aftertaste among the three varieties indicates that sorghum flour has a mild and neutral flavour base when adequately milled and seasoned, which is an advantage over some other tropical cereals like maize, which is very strongly flavour specific and can over-ride and limit its use in some product categories (Ciacci et al., 2007; Rooney et al., 1997).

Table 5. Consumer Acceptability Scores of Noodles Produced from Three Ugandan Sorghum Varieties (n = 20)

Variety (color)	Appearance	Taste	Aftertaste	Aroma	Texture	Overall
NASARRI MS001 (White)	$7.1^{b} \pm 1.0$	$5.7^{a} \pm 1.9$	$5.9^{a} \pm 1.9$	$5.8^{a} \pm 1.8$	$5.3^{a} \pm 1.9$	$6.0^{b} \pm 1.7$
NASARRI M003 (Brown)	$6.1^{b} \pm 1.2$	$4.8^{a} \pm 1.8$	$4.9^{a} \pm 2.0$	$5.1^{a} \pm 1.8$	$4.3^{a} \pm 1.3$	$5.0^{a} \pm 1.8$
NASARRI M060 (Red)	$4.7^{a} \pm 1.5$	$5.5^{a} \pm 1.7$	$5.2^{a} \pm 1.8$	$5.4^{a} \pm 1.6$	$4.8^{a} \pm 1.6$	$5.4^{ab} \pm 1.5$

Note: Values are mean ± standard deviation. Means within the same column bearing different superscript letters are significantly different (p < 0.05, Tukey's HSD test). Scores based on a 9-point hedonic scale (1 = dislike extremely; 9 = like extremely).

3.5 Consumer Acceptability

Consumer acceptability scores for the six evaluated sensory attributes are presented in Table 5. Significant differences ($p < 0.05$) among varieties were detected for appearance and overall acceptability, while no significant differences were observed for taste, aftertaste, aroma, or texture.

Mean values of appearance, taste, aroma, aftertaste, texture and overall acceptability of the sorghum noodles (n = 20) were analyzed, and results indicated that the appearance scores were significantly different ($p < 0.05$), with the highest mean rating for the white sorghum (NASARRI-MS001) noodles (7.1 ± 1.0, "like moderately") and the lowest for the red sorghum (NASARRI-M060) noodles (4.7 ± 1.5, "neither like nor dislike"), because the most preferred color of noodle by most consumers is one that is similar to that of conventional wheat products, which are usually opaque and golden yellow. These results should be interpreted with caution given the small sample size (n = 20) and the homogeneous, convenience nature of the panel (university staff and students); broader consumer studies with larger, more representative panels are needed to validate these findings. This preference may be due to the fact that darker or unconventional colors are often judged unfavorably (Asenstorfer, Wang & Mares, 2005; Marti et al., 2013), and the visual bias against pigmented grains is a general problem in gluten-free product development, because many consumers benchmark new products against the appearance of wheat-based noodles (Raungrusmee et al., 2020). To overcome this, pigmented sorghum flours may be blended with lighter ingredients, the pericarp may be partially removed to reduce the intensity of the color, or consumers may be educated about the health benefits of colored grains and their bioactive pigments. The mean ratings of taste, aroma, and aftertaste were not significantly different ($p > 0.05$) among the three types of sorghum, suggesting that the choice of sorghum variety did not have a significant impact on flavor-related attributes, which agrees with earlier reports that well-milled sorghum flour has a relatively mild and neutral taste and can fit well into many food systems (Rooney et al., 1997), and the addition of eggs to the formulation may also have helped to balance the flavor perception among samples by neutralizing astringency associated with tannins in the pigmented varieties (although this mechanism is speculative in the absence of measured tannin or astringency data) (Collado & Corke, 2016). There were no significant differences ($p > 0.05$) in texture scores, which suggests that the fine particle size of the flour used in this study could have produced similar starch gelatinisation and, consequently, similar texture properties among the three noodle types (Hatcher et al., 2008). The mean overall acceptability score ranged from 5.0 (brown sorghum noodles) to 6.0 (white sorghum noodles) (these scores correspond to 'neither like nor dislike' to 'like slightly' on the 9-point scale, indicating moderate rather than high acceptability, and the products would benefit from further formulation refinement to improve consumer ratings) and showed a significant difference ($p < 0.05$) between the two, although there was no significant difference ($p > 0.05$) in overall acceptability between white and red sorghum noodles, which means that the technological advantages of the red variety (e.g. more bioactive compounds and less cooking loss) do not necessarily result in lower consumer acceptance when the product is evaluated as a whole.

3.6 Limitations and Future Research Directions

However, there are several limitations of the study. Firstly, the consumer panel was small (n = 20) and comprised mainly of university staff and students, and further research should therefore use larger and more diverse consumer groups, especially those with celiac disease or gluten sensitivity, to further validate the acceptability results. Secondly, this study did not include proximate analysis (protein, fat, ash, fibre and carbohydrate) of the three sorghum varieties, which makes it difficult to explain fully why they differed in cooking quality and moisture content, and subsequent studies should therefore include detailed compositional and rheological tests on both the flours and the dough. Thirdly, only one noodle recipe was tested, with fixed levels of all additives, and it is possible that further improvements in product quality may be achievable through systematic adjustment of the type and amount of hydrocolloids, the egg content, and the drying conditions, for example using response surface methodology. Fourthly, no instrumental texture profile analysis (TPA) was undertaken, so the study relied solely on sensory texture ratings, and instrumental measurements of hardness, adhesiveness, cohesiveness and chewiness would provide useful objective data to support the panel results. Finally, the noodles were not subjected to formal shelf-life testing under different storage conditions, and the long-term stability of the product is still unknown, and future research should include microbiological and physicochemical shelf-life studies to determine the changes in product quality over time. Sixthly, the complex formulation containing multiple structuring agents (hydrocolloids, eggs, skimmed milk powder) may confound the attribution of cooking quality differences solely to sorghum variety; systematic formulation optimisation studies are needed to isolate cultivar-specific contributions. Seventhly, the study did not include a control sample (e.g., commercial wheat-based or commercial gluten-free noodles), which would have provided a meaningful benchmark for the cooking quality and sensory results obtained. Eighthly, cooking loss was measured at a fixed time of 5 min per AACC Method 66-50.01, which exceeded the optimal cooking times of 3.33-4.00 min; future studies should compare cooking loss at optimal and fixed time points. Ninthly, the Lovibond colour system was used in this study; future studies should employ CIE L*a*b* colorimetry for more internationally comparable colour data. Tenthly, the sensory evaluation would be strengthened by including allergen disclosure documentation, a formal panel ethics approval number, and evaluation of panelists in replicate sessions to confirm descriptor consistency.

4. CONCLUSION

All three Ugandan sorghum varieties—NASARRI-M060 (red), NASARRI-MS001 (white), and NASARRI-M003 (brown)—were suitable for producing mechanically formed gluten-free noodles with the standardized formulation used in this study. Variety significantly influenced cooking loss (1.69–5.25%) and moisture content (5.83–6.35%), but not cooking time (3.33–4.00 min) or water absorption capacity (143.0–148.5%). NASARRI-M060 had the lowest cooking loss, indicating greater matrix stability during cooking, whereas NASARRI-MS001 received the highest appearance and overall-acceptability ratings. The varieties did not differ significantly in taste, aroma, aftertaste, or texture, and quantitative descriptive analysis identified significant differences only in brown color intensity and grittiness. Overall acceptability ranged from 5.0 to 6.0 on the nine-point hedonic scale and should be interpreted cautiously because the consumer panel was small and relatively homogeneous. The results nevertheless identify NASARRI-M060 and NASARRI-MS001 as promising raw materials for gluten-free noodle production. Further research should include compositional and phenolic profiling, formulation optimization, instrumental texture analysis, shelf-life assessment, and evaluation with larger and more diverse consumer groups.

AUTHOR CONTRIBUTIONS

O.N.K.: Conceptualization, Investigation, Data collection, Writing—Original draft. **R.M.:** Conceptualization, Supervision, Methodology, Writing—Review and editing. **I.M.M.:** Supervision, Resources, Writing—Review and editing. All authors have read and approved the final manuscript.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

ETHICS STATEMENT

Ethical approval for the sensory evaluation was obtained from the Makerere University School of Food Technology, Nutrition and Bioengineering, Research and Higher Degrees Committee. All participants provided written informed consent prior to participation. Panelists were informed of the formulation ingredients, including eggs, skimmed milk powder, and chicken-flavour seasoning, and individuals with known food allergies or dietary restrictions to these ingredients were excluded from participation.

DATA AVAILABILITY STATEMENT

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

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REFERENCES

AACC. (2000). Approved methods of analysis (10th ed.). American Association of Cereal Chemists.

Akajiaku, L., Nwosu, J., Kabuo, N. O., Odi-Obi, E. N., & Uzoukwu, V. C. (2017). Using sorghum flour as part substitute of wheat flour in noodle making. *MOJ Food Processing & Technology, 5*(2), 250-257. https://doi.org/10.15406/mojfpt.2017.05.00120

Almahi, R. A. Y. (2018). *Production of noodles from wheat flour mixed with sorghum and millet and their nutritional and sensory characteristics* (Master's thesis, University of Khartoum) [Unpublished thesis].

Andiku, C., Shimelis, H., Laing, M., Shayanowako, A. I. T., Adrogu Ugen, M., Manyasa, E., & Ojiewo, C. (2021). Assessment of sorghum production constraints and farmer preferences for sorghum variety in Uganda: implications for nutritional quality breeding. *Acta Agriculturae Scandinavica, Section B — Soil & Plant Science*, *71*(7), 620–632. https://doi.org/10.1080/09064710.2021.1944297

AOAC. (2000). Official methods of analysis (17th ed.). Association of Official Analytical Chemists.

Arora, B., Yoon, A., Sriram, M., Singha, P., & Rizvi, S. S. (2020). Reactive extrusion: A review of the physicochemical changes in food systems. *Innovative Food Science & Emerging Technologies*, *64*, 102429. https://doi.org/10.1016/j.ifset.2020.102429.

Asenstorfer, R., Wang, Y., & Mares, D. (2005). Chemical structure of flavonoid compounds in wheat (*Triticum aestivum* L.) flour that contribute to the yellow colour of Asian alkaline noodles. *Journal of Cereal Science*, *43*(1), 108-119. https://doi.org/10.1016/j.jcs.2005.09.001

Carpenter, R., Lyon, D., & Hasdell, T. (2000). *Guidelines for sensory analysis in food product development and quality control* (pp. 71–91). Aspen Publishers. https://doi.org/10.1007/978-1-4615-4447-0.

Carpentieri, S., Soltanipour, F., Ferrari, G., Pataro, G., & Donsì, F. (2021). Emerging Green Techniques for the Extraction of Antioxidants from Agri-Food By-Products as Promising Ingredients for the Food Industry. *Antioxidants*, *10*(9). https://doi.org/10.3390/antiox10091417

Chandra, S., & Samsher, S. (2013). Assessment of functional properties of different flours. *African Journal of Agricultural Research, 8*(38), 4849–4852.

Ciacci, C., Maiuri, L., Caporaso, N., Bucci, C., Del Giudice, L., Massardo, D. R., Pontieri, P., Di Fonzo, N., Bean, S. R., Ioerger, B., & Londei, M. (2007). Celiac disease: In vitro and in vivo safety and palatability of wheat-free sorghum food products. *Clinical Nutrition, 26*(6), 799–805. https://doi.org/10.1016/j.clnu.2007.05.006

Collado, L. S., & Corke, H. (2016). Noodles: Rice and Starch. In C. W. Wrigley, H. Corke, K. Seetharaman, & J. Faubion (Eds.), *Encyclopedia of food grains* (2nd ed., Vol. 3, pp. 64–71). Academic Press.

Cross, H. R., Moen, R., & Stanfield, M. S. (1978). Training and testing of judges for sensory analysis of meat quality. Food Technology, 32, 48–54.

de São José, V. P. B., Pereira, S. M. S., Miranda Piermatei, Á. L., Queiroz, V. A. V., da Silva, B. P., Martino, H. S. D., & Tako, E. (2026). Preclinical evidence on the impact of sorghum (*Sorghum bicolor*) genotypes, fractions, and processing methods on intestinal health: a review of an ancient grain rich in phenolic and dietary fiber. *Critical Reviews in Food Science and Nutrition*, *66*(9), 1788–1812. https://doi.org/10.1080/10408398.2025.2556229

Dykes, L., & Rooney, L. W. (2006). Sorghum and millet phenols and antioxidants. *Journal of Cereal Science, 44*(3), 236–251. https://doi.org/10.1016/j.jcs.2006.06.007

Fu, B. X. (2008). Asian noodles: History, classification, raw materials, and processing. *Food Research International*, *41*(9), 888-902. https://doi.org/10.1016/j.foodres.2007.11.007

Giuberti, G., Gallo, A., Cerioli, C., Fortunati, P., & Masoero, F. (2015). Cooking quality and starch digestibility of gluten-free pasta using new bean flour. *Food Chemistry, 175*, 43–49. https://doi.org/10.1016/j.foodchem.2014.11.127

Grand View Research. (2026). *Gluten-free products market size, share & trends analysis report (2026–2033)*. Grand View Research, Inc.

Hadebe, S. T., Modi, A. T., & Mabhaudhi, T. (2021). Assessing Suitability of Sorghum to Alleviate Sub-Saharan Nutritional Deficiencies through the Nutritional Water Productivity Index in Semi-Arid Regions. *Foods*, *10*(2). https://doi.org/10.3390/foods10020385

Hatcher, D. W., Lagasse, S., Dexter, J. E., Rossnagel, B., & Izydorczyk, M. (2004). Quality Characteristics of Yellow Alkaline Noodles Enriched with Hull-less Barley Flour. *Cereal Chemistry*, *82*(1), 60-69. https://doi.org/10.1094/CC-82-0060

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). https://doi.org/10.1080/23311932.2016.1142409

Li, M., Zhu, K. X., Guo, X. N., Brijs, K., & Zhou, H. M. (2014). Natural Additives in Wheat-Based Pasta and Noodle Products: Opportunities for Enhanced Nutritional and Functional Properties. *Comprehensive reviews in food science and food safety*, *13*(4), 347–357. https://doi.org/10.1111/1541-4337.12066

Manthey, F. A., & Schorno, A. L. (2002). Physical and Cooking Quality of Spaghetti Made from Whole Wheat Durum. *Cereal Chemistry, 79*(4), 504-510. https://doi.org/10.1094/CCHEM.2002.79.4.504.

Marti, A., & Pagani, M. A. (2013). What can play the role of gluten in gluten-free pasta? *Trends in Food Science & Technology, 31*(1), 63–71. https://doi.org/10.1016/j.tifs.2013.03.001

Marti, A., Seetharaman, K., & Pagani, M. A. (2013). Rheological approaches suitable for investigating starch and protein properties related to cooking quality of durum wheat pasta. Journal of Food Quality, 36(2), 133–138.

Meilgaard, M. C., Civille, G. V., & Carr, B. T. (2006). Sensory evaluation techniques (4th ed.). CRC Press.

Muwanguzi, B., Asiimwe, A., & Muyonga, J. H. (2025). Optimization of Formulation for Production of Nutrient Enhanced Noodles Containing Sorghum, Cowpea and Wheat. *Asian Food Science Journal*, *24*(8), 10–19. https://doi.org/10.9734/afsj/2025/v24i8809.

Nilusha, R. A. T., Jayasinghe, M. J. K., Perera, D. A. N., & Perera, P. I. P. (2018). Development of Pasta Products with Nonconventional Ingredients and Their Effect on Selected Quality Characteristics: A Brief Overview. *International Journal of Food Science*, *2019*(1), 6750726. https://doi.org/10.1155/2019/6750726

Obadi, M., Xu, B., & Tao, H. (2021). Highland barley flour as a potential ingredient in noodle making. In B. Xu (Ed.), Highland barley processing technology and product development (pp. 165–184). Springer.

Oliveira, L. C., Schmiele, M., & Steel, C. J. (2022). Development of bread with rejected rice grain flour and sorghum flour. *Food Science and Technology, 42*, e78521.

Orr, A., Mwema, C., Gierend, A., & Nedumaran, S. (2016). *Sorghum and millets in Eastern and Southern Africa: Facts, trends and outlook* (Working Paper No. 62). International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

Palavecino, P. M., Bustos, M. C., Heinzmann, M. B., & Ruiz, A. I. T. (2016). Effect of ingredients on the quality of gluten-free sorghum pasta. *Journal of Food Quality, 39*(4), 299–310.

Palavecino, P. M., Ribotta, P. D., León, A. E., & Bustos, M. C. (2017). Gluten-free sorghum pasta: Starch digestibility and antioxidant capacity compared with commercial products. *Journal of the Science of Food and Agriculture, 97*(9), 2998–3005. https://doi.org/10.1002/jsfa.8146

Palavecino, P. M., Ribotta, P. D., León, A. E., & Bustos, M. C. (2020). Sorghum pasta and noodles: Technological and nutritional aspects. *Plant Foods for Human Nutrition, 75*(3), 326–336. https://doi.org/10.1007/s11130-020-00826-8

Pontieri, P., & Del Giudice, L. (2016). Sorghum: A novel and healthy food. In A. M. Ferrão (Ed.), Encyclopedia of food grains (2nd ed., pp. 33–42). Academic Press.

Raina, C. S. (2005). Effect of extrusion temperature on the cooking quality and sensory attributes of rice-based expanded snacks. *Journal of Food Processing and Preservation, 29*(5–6), 305–315.

Rani S, Singh R, Sehrawat R, Kaur BP, Upadhyay A (2018), Pearl millet processing: a review. *Nutrition & Food Science, 48*(1), 30–44, https://doi.org/10.1108/NFS-04-2017-0070

Rao, B. D. (2019). Sorghum value chain for food and fodder security. In C. Aruna, K. B. R. S. Visarada, B. V. Bhat, & V. A. Tonapi (Eds.), *Breeding sorghum for diverse end uses* (pp. 409–419). Woodhead Publishing. https://doi.org/10.1016/B978-0-08-101879-8.00023-1

Raungrusmee, S., Shrestha, S., Sadiq, M. B., & Anal, A. K. (2020). Influence of resistant starch, xanthan gum, inulin and defatted rice bran on the physicochemical, functional and sensory properties of low glycemic gluten-free noodles. *LWT*, *126*, 109279. https://doi.org/10.1016/j.lwt.2020.109279.

Riedl, K. M., & Hagerman, A. E. (2001). Tannin–protein complexes as radical scavengers and radical sinks. *Journal of Agricultural and Food Chemistry, 49*(10), 4917–4923. https://doi.org/10.1021/jf010683h

Rooney, L. W., & Saldívar, S. O. S. (2000). Sorghum. In K. Kulp & J. G. Ponte (Eds.), Handbook of cereal science and technology (2nd ed., pp. 149–175). Marcel Dekker.

Rooney, L. W., & Saldívar, S. O. S. (2003). Sorghum. In B. Caballero, L. C. Trugo, & P. M. Finglas (Eds.), Encyclopedia of food sciences and nutrition (2nd ed., pp. 5370–5378). Academic Press.

Rooney, L. W., & Waniska, R. D. (2000). Sorghum food and industrial utilization. In C. W. Smith & R. A. Frederiksen (Eds.), Sorghum: Origin, history, technology, and production (pp. 689–729). Wiley.

Rooney, L. W., Blakely, M. E., Miller, F. R., & Rosenow, D. T. (1997). Factors affecting the polyphenols of sorghum and their development and location in the sorghum kernel. In F. Shahidi & M. Naczk (Eds.), Food phenolics (pp. 57–76). Technomic Publishing.

Seetapan, N., Limparyoon, N., Yooberg, R., Leelawat, B., & Charunuch, C. (2019). Influence of addition of extruded rice flour on preparation and quality of fresh gluten-free yellow alkaline noodles. *Journal of Cereal Science*, *90*, 102828. https://doi.org/10.1016/j.jcs.2019.102828.

Siah, S., & Quail, K. J. (2018). Factors affecting Asian wheat noodle color and time-dependent discoloration—A review. *Cereal Chemistry*, *95*(2), 189-205. https://doi.org/10.1002/cche.10035.

Singla, D., Malik, T., Singh, A., Thakur, S., & Kumar, P. (2024). Advances in understanding wheat-related disorders: A comprehensive review on gluten-free products with emphasis on wheat allergy, celiac and non-celiac gluten sensitivity. *Food Chemistry Advances*, *4*, 100627. https://doi.org/10.1016/j.focha.2024.100627.

Sissons, M. J., Egan, N. E., & Gianibelli, M. C. (2012). Durum wheat pasta. In M. Sissons, J. Abecassis, B. Marchylo, & M. Carcea (Eds.), Durum wheat: Chemistry and technology (2nd ed., pp. 311–330). AACC International.

Stone, H., Sidel, J., Oliver, S., Woolsey, A., & Singleton, R. C. (1974). Sensory evaluation by Quantitative Descriptive Analysis. *Food Technology, 28*(11), 24–34.

Suhendro, E. L., Kunetz, C. F., McDonough, C. M., Rooney, L. W., & Waniska, R. D. (2000). Cooking characteristics and quality of noodles from food sorghum. *Cereal Chemistry, 77*(2), 96–100. https://doi.org/10.1094/CCHEM.2000.77.2.96

Tan, H. Z., Li, Z. G., & Tan, B. (2009). Starch noodles: History, classification, materials, processing, structure, nutrition, quality evaluating and improving. *Food Research International, 42*(5–6), 551–576. https://doi.org/10.1016/j.foodres.2009.02.015

Taylor, J. R. N., & Duodu, K. G. (2019). *Sorghum and millets: Chemistry, technology, and nutritional attributes* (2nd ed.). Academic Press.

Wangtueai, S., Phimolsiripol, Y., Vichasilp, C., Regenstein, J. M., & Schöenlechner, R. (2020). Optimization of gluten-free functional noodles formulation enriched with fish gelatin hydrolysates. *LWT*, *133*, 109977. https://doi.org/10.1016/j.lwt.2020.109977

Winarno, F. G. (1997). Food chemistry and nutrition. Gramedia Pustaka Utama. Jakarta.

Woomer, J. S., & Adedeji, A. A. (2021). Current applications of gluten-free grains - a review. *Critical reviews in food science and nutrition*, *61*(1), 14–24. https://doi.org/10.1080/10408398.2020.1713724.

Xiong, Y., Zhang, P., Warner, R. D., & Fang, Z. (2019). Sorghum Grain: From Genotype, Nutrition, and Phenolic Profile to Its Health Benefits and Food Applications. *Comprehensive reviews in food science and food safety*, *18*(6), 2025–2046. https://doi.org/10.1111/1541-4337.12506

Yadav, B.S., Yadav, R.B., & Kumar, M. (2011). Suitability of pigeon pea and rice starches and their blends for noodle making. *Lwt - Food Science and Technology, 44*, 1415-1421..

Yu, L. (2002). Wheat-based noodles and pasta as vehicles for health-promoting ingredients. In L. Marquart, J. L. Slavin, & R. G. Fulcher (Eds.), *Whole-grain foods in health and disease* (pp. 217–234). American Association of Cereal Chemists.

Zoghi, A., Mirmahdi, R. S., & Mohammadi, M. (2021). The role of hydrocolloids in the development of gluten-free cereal-based products for coeliac patients: A review. *International Journal of Food Science and Technology*, *56*(7), 3138-3147. https://doi.org/10.1111/ijfs.14887