Effects of storage conditions on the physicochemical properties of different sorghum varieties

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ABSTRACT

Storage duration is a critical postharvest factor influencing the quality of sorghum grains; however, its interaction with varietal differences remains insufficiently explored. This study evaluated the effects of storage duration on the physicochemical characteristics of selected sorghum (*Sorghum bicolor* L.) varieties using a randomized complete block design (RCBD) with variety and storage duration as experimental factors. Physicochemical parameters, including moisture, lipid, protein, amylose, total carbohydrate contents, and color attributes (L*, a*, and b*), were analyzed across variety–storage combinations. The results revealed that storage duration significantly affected moisture, lipid, protein, and amylose contents, while varietal effects were significant for amylose and total carbohydrate contents. Significant variety × storage interactions were observed for moisture, lipid, protein, and amylose, indicating genotype-dependent responses to storage. Amylose content showed the most pronounced decline during extended storage across all varieties, whereas total carbohydrate content and color attributes remained relatively stable. These findings demonstrate that storage-induced quality changes in sorghum are strongly influenced by both storage duration and varietal characteristics, highlighting the importance of genotype-specific storage strategies to maintain nutritional and functional quality.

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1. INTRODUCTION

Sorghum (*Sorghum bicolor* L.) is an important cereal crop cultivated extensively in semi-arid and tropical regions due to its exceptional tolerance to drought, high temperatures, and marginal soils. As a staple food and industrial raw material, sorghum plays a crucial role in global food security by providing a substantial source of carbohydrates, moderate protein, lipids, and functional phytochemicals (Awika & Rooney, 2004; FAO, 2022). In addition to its agronomic resilience, sorghum has gained increasing attention as an alternative grain for sustainable food systems. However, maintaining grain quality during postharvest storage remains a major challenge (Olorunfemi & Kayode, 2021), as physicochemical degradation during storage can significantly reduce nutritional value, functional properties, and consumer acceptability (Martinez & Carballo, 2021; Oladeji et al., 2024).

Storage duration is a key postharvest factor influencing the physicochemical characteristics of sorghum grains. Prolonged storage may induce changes in moisture content, which directly affects metabolic activity, microbial growth, and shelf life (Bankole & Mabekoje, 2004). Protein quality may deteriorate due to enzymatic degradation or structural denaturation, while lipids are particularly susceptible to oxidative rancidity, leading to off-flavors and nutritional losses (Ziegler et al., 2018). Furthermore, starch components especially amylose and total carbohydrates may undergo structural modification during storage, influencing gelatinization behavior, digestibility, and processing performance of sorghum-based products (Taylor & Emmambux, 2010).

The magnitude of storage-induced physicochemical changes varies significantly among sorghum varieties due to differences in kernel morphology, starch–protein matrix, lipid composition, and pigment concentration. Varietal differences in amylose content have been reported to affect starch stability and retrogradation during storage, while variations in protein and fat content influence oxidative stability and overall grain quality (Ratnavathi & Patil, 2013). In addition, color parameters, which serve as important quality indicators, are sensitive to storage-related reactions such as pigment degradation and non-enzymatic browning, potentially reducing market value and consumer acceptance (Rooney & Awika, 2005). These varietal responses highlight the importance of genotype-specific evaluation under extended storage conditions, Previous studies have demonstrated that storage duration plays a critical role in altering the physicochemical characteristics of herbal materials, particularly moisture content and chemical stability, which in turn affect product quality and functionality (Bunga et al., 2015).

Despite extensive research on sorghum composition, comprehensive studies addressing the combined effects of storage duration on key physicochemical parameters including protein, fat, amylose, total carbohydrates, moisture content, and color across different sorghum varieties remain limited. This lack of integrated understanding constrains the development of effective storage strategies tailored to specific genotypes. Therefore, investigating the impact of storage duration on the physicochemical characteristics of selected sorghum varieties is essential to minimize postharvest quality losses, enhance storage stability, and support the sustainable utilization of sorghum in food and agro-industrial applications.

2. METHOD

2.1 Materials

Grains of six varieties of sweet sorghum tested, namely Suri 3 (V1), Super 1 (V2), Super 2(V3), Soper 6 (V4), Soper 7 (V5), and Soper 9 (V6) selected sorghum (*Sorghum bicolor* L.) varieties were obtained from the Maros Cereal Research Center, South Sulawesi and replanted in Sampali field, Universitas Muhammadiyah Sumatera Utara, harvested at full physiological maturity. The grains were transported to the Postharvest Laboratory, universitas Muhammadiyah Sumatera Utara laboratory within 24 h after harvest and subjected to initial cleaning to remove broken kernels, insect-damaged grains, dust, and other extraneous materials. Only visually sound and uniform kernels were used for the experiment.

2.2 Experimental Design and Storage Protocol

The study was conducted using a completely randomized factorial design with two independent factors: sorghum variety and storage duration. Each treatment combination consisted of three independent replicates. Approximately 100 grams of cleaned sorghum grains from each variety were sealed in high-density polyethylene bags with low oxygen permeability. Samples were stored under controlled ambient conditions (temperature 27 ± 2 °C and relative humidity 70 ± 5%) for a total storage period of three months. Storage temperature and relative humidity were continuously monitored using calibrated digital data loggers.

Sampling was conducted at four predetermined storage intervals: initial (0 month) (S1) and 3 months (S2). At each sampling time, grain samples were removed from storage, immediately sealed to prevent moisture exchange, and prepared for physicochemical analyses.

2.3 Physicochemical Analyses

2.3.1 Moisture Content Determination

Moisture content was determined using the gravimetric oven-drying method following AOAC Official Method 925.10. Approximately 5.00 ± 0.01 g of sample was weighed into a pre-dried and pre-weighed aluminum moisture dish. Samples were dried in a forced-air oven at 105 ± 2 °C for 24 h until constant mass was achieved. After drying, samples were cooled in a desiccator for 30 min prior to weighing. Moisture content was calculated as the percentage loss in mass relative to the initial sample weight

2.3.2 Protein content

Crude protein content was determined using the Kjeldahl method according to AOAC Official Method 979.09. Approximately 1.00 ± 0.01 g of sample was digested with concentrated sulfuric acid in the presence of a mixed catalyst until a clear digest was obtained. The digested solution was neutralized with excess sodium hydroxide and subjected to steam distillation using an automated Kjeldahl distillation unit. The liberated ammonia was trapped in boric acid solution and titrated with standardized hydrochloric acid. Total nitrogen content was calculated, and crude protein content was obtained using a nitrogen-to-protein conversion factor of 6.25. Results were expressed on a dry matter basis.

2.3.3 Lipid

Crude fat content was analyzed using Soxhlet extraction following AOAC Official Method 920.39. Approximately 3.00 ± 0.01 g of oven-dried sample was placed in a cellulose extraction thimble and extracted with n-hexane for 6 h under continuous reflux. Upon completion of extraction, the solvent was evaporated using a rotary evaporator, and the extracted lipid residue was dried at 105 °C to constant weight. Fat content was expressed as a percentage of dry sample weight.

2.3.4 Total Carbohydrate Content

Total carbohydrate content was calculated by difference according to AOAC guidelines using the following equation:

$$\text{Total carbohydrates (\%)} = 100 - (\text{Moisture} + \text{Crude protein} + \text{Crude fat} + \text{Ash}) \quad (1)$$

All calculations were performed on a dry weight basis.

2.3.5 Amylose Content Determination

Amylose content was quantified using the iodine-binding colorimetric method with slight modifications. Approximately 100 mg of sorghum flour was dispersed in 1 mL of 95% ethanol to prevent clumping, followed by the addition of 9 mL of 1 N sodium hydroxide. The suspension was heated in a boiling water bath for 10 min to ensure complete starch solubilization and gelatinization. After cooling to room temperature, the solution was quantitatively transferred to a volumetric flask and diluted with deionized water. An aliquot of the diluted solution was reacted with iodine–potassium iodide reagent, and absorbance was measured at 620 nm using a UV–Visible spectrophotometer. Amylose concentration was calculated using a standard curve prepared with pure amylose and expressed as a percentage of total starch.

2.3.6 *Color Measurement (L, a*, b*)**

Color characteristics of sorghum flour were determined using a calibrated portable colorimeter based on the CIE L*ab** color space. The instrument was standardized prior to measurement using a certified white calibration tile. Samples were placed in a uniform sample cup to ensure consistent surface coverage and minimize light scattering. Color measurements were recorded at three randomly selected points on the sample surface. The L* value represents lightness (0 = black, 100 = white), a* indicates redness (+) or greenness (−), and b* indicates yellowness (+) or blueness (−). Mean values were reported for each parameter.

2.4 Statistical Analysis

All physicochemical analyses were conducted in triplicate, and results were expressed as mean ± standard deviation. Data were analyzed using two-way analysis of variance (ANOVA) to assess the effects of sorghum variety, storage duration, and their interaction. When significant differences were observed ($p < 0.05$), mean separation was performed using Duncan's multiple range test. Statistical analyses were carried out using Statistical Analysis System (SAS) 4.3 statistical software.

3. RESULTS AND DISCUSSION

3.1 Result

This section presents the research results obtained through the data collection and processing stages in accordance with the predetermined research design. The data presented represents empirical conditions in the field and has been systematically analysed to answer the research objectives and questions. The presentation of results focuses on key findings relevant to the variables studied, providing an objective overview of patterns, trends, and relationships between variables as a basis for scientific discussion in the following section. The results are presented in the following table:

Table 1. Physicochemical characteristics of sorghum grains under different variety and storage combinations

Treatment	Moisture (%)	Lipid (%)	Amylose (%)	Protein (%)	L*	a*	b*	Carbohydrate
V1S1	18.14 ± 0.00^{a}	0.75 ± 0.00^{f}	34.82 ± 0.00^{b}	11.50 ± 0.00^{c}	15.50 ± 0.00^{a}	4.43 ± 0.00^{a}	1.36 ± 0.00^{a}	0.150 ± 0.00^{a}
V1S2	0.18 ± 0.00^{f}	5.50 ± 0.00^{c}	10.33 ± 0.00^{f}	12.75 ± 0.00^{b}	14.22 ± 0.00^{b}	4.20 ± 0.00^{a}	1.22 ± 0.00^{b}	0.130 ± 0.00^{b}

V2S1	15.42 ± 0.00^{b}	0.68 ± 0.00^{f}	31.49 ± 0.00^{c}	11.03 ± 0.00^{c}	14.44 ± 0.00^{b}	4.70 ± 0.00^{a}	0.79 ± 0.00^{c}	0.213 ± 0.00^{a}
V2S2	6.00 ± 0.00^{d}	6.00 ± 0.00^{c}	9.79 ± 0.00^{f}	13.55 ± 0.00^{a}	14.00 ± 0.00^{b}	4.60 ± 0.00^{a}	0.77 ± 0.00^{c}	0.200 ± 0.00^{a}
V3S1	18.13 ± 0.00^{a}	1.43 ± 0.00^{e}	31.05 ± 0.00^{c}	12.25 ± 0.00^{b}	14.84 ± 0.00^{b}	4.44 ± 0.00^{a}	1.02 ± 0.00^{b}	0.0067 ± 0.00^{d}
V3S2	2.95 ± 0.00^{e}	6.50 ± 0.00^{b}	10.00 ± 0.00^{f}	14.00 ± 0.00^{a}	14.30 ± 0.00^{b}	4.01 ± 0.00^{a}	1.01 ± 0.00^{b}	0.0087 ± 0.00^{d}
V4S1	18.16 ± 0.00^{a}	1.44 ± 0.00^{e}	38.27 ± 0.00^{b}	12.25 ± 0.00^{b}	15.30 ± 0.00^{a}	4.51 ± 0.00^{a}	1.08 ± 0.00^{b}	0.075 ± 0.00^{c}
V4S2	0.28 ± 0.00^{f}	9.20 ± 0.00^{a}	9.98 ± 0.00^{f}	13.67 ± 0.00^{a}	14.90 ± 0.00^{b}	4.20 ± 0.00^{a}	1.04 ± 0.00^{b}	0.075 ± 0.00^{c}
V5S1	9.32 ± 0.00^{c}	2.25 ± 0.00^{d}	37.27 ± 0.00^{b}	11.90 ± 0.00^{c}	15.33 ± 0.00^{a}	4.34 ± 0.00^{a}	1.53 ± 0.00^{a}	0.013 ± 0.00^{d}
V5S2	0.78 ± 0.00^{f}	8.50 ± 0.00^{a}	10.00 ± 0.00^{f}	13.50 ± 0.00^{a}	14.99 ± 0.00^{b}	4.00 ± 0.00^{a}	1.34 ± 0.00^{a}	0.010 ± 0.00^{d}
V6S1	21.92 ± 0.00^{a}	1.15 ± 0.00^{e}	44.96 ± 0.00^{a}	10.33 ± 0.00^{c}	14.53 ± 0.00^{b}	4.67 ± 0.00^{a}	1.03 ± 0.00^{b}	0.056 ± 0.00^{c}
V6S2	0.71 ± 0.00^{f}	8.40 ± 0.00^{a}	10.32 ± 0.00^{f}	14.20 ± 0.00^{a}	14.55 ± 0.00^{b}	4.20 ± 0.00^{a}	1.01 ± 0.00^{b}	0.062 ± 0.00^{c}
V*S	*	*	*	*	NS	NS	NS	NS

3.1.1 Effect of Storage Duration and Variety on Moisture Content

Moisture content decreased markedly from S1 to S2 across all sorghum varieties, and RCBD analysis confirmed that storage duration significantly affected moisture content ($p < 0.01$), while varietal effects were not significant. A significant variety × storage interaction ($p < 0.05$) indicated that the magnitude of moisture reduction differed among varieties. Varieties with higher initial moisture content at S1, such as V6, experienced more pronounced reductions during storage compared to others. This behavior suggests that varietal structural differences, including pericarp thickness and kernel compactness, influenced moisture migration rates during storage. Similar moisture loss patterns have been widely reported in stored cereal grains and are primarily attributed to moisture equilibration with ambient relative humidity (Bankole & Mabekoje, 2004; Ratnavathi & Patil, 2013). Moisture reduction is a critical driver of subsequent physicochemical changes, as it alters enzymatic activity and internal diffusion processes within the grain matrix.

3.1.2 Effect on Lipid Content

Lipid content was significantly affected by storage duration ($p < 0.01$) and by the variety × storage interaction ($p < 0.05$), whereas the main effect of variety was not significant. Across all varieties, lipid content was consistently higher at S2 than at S1, with V4S2, V5S2, and V6S2 exhibiting the highest values. This increase is most plausibly explained by a concentration effect associated with moisture loss rather than actual lipid synthesis. Nevertheless, the significant interaction suggests that varieties differed in their lipid response to storage, which may be linked to inherent differences in fatty acid composition and endogenous antioxidant capacity. Previous studies have shown that lipid fractions in sorghum and other cereals are highly sensitive to storage conditions and prone to oxidative reactions, particularly during extended storage periods (Taylor & Emmambux, 2010; Ziegler et al., 2018). The results of biochemical analysis showed that there were variations in water, ash, lipid, amylose, and protein contents among varieties. Soper 9 recorded the highest amylose and moisturecontent, while Super 2 and Soper 6 showed the highest protein content. Soper 7 had the highest lipid content and lowest water content (Tarigan et.al., 2025)

3.1.3 Effect on Amylose Content

Amylose content was significantly influenced by variety ($p < 0.05$), storage duration ($p < 0.01$), and their interaction ($p < 0.01$). At S1, substantial varietal differences were observed, with V6S1 exhibiting the highest amylose content, followed by V4S1 and V5S1, indicating strong genetic control over starch composition. However, amylose content declined sharply at S2 for all varieties, resulting in relatively uniform values across genotypes. The significant variety × storage interaction indicates that the extent of amylose reduction varied among varieties, reflecting differential starch stability during storage. These findings suggest that prolonged storage induces starch structural modification, possibly through enzymatic activity or molecular rearrangement, which has been reported to alter amylose–amylopectin ratios in stored cereals (Rooney & Awika, 2005; Kim & Kim, 2021). Given the critical role of amylose in determining gelatinization and textural properties, this pronounced reduction has important implications for the functional quality of sorghum-based products (Taylor & Emmambux, 2010; Hamaker & Bugusu, 2003).

3.1.4 Effect on Protein Content

Protein content was significantly affected by storage duration ($p < 0.01$) and by the variety × storage interaction ($p < 0.05$), while the main effect of variety was not significant. Protein values were consistently higher at S2 than at S1 across all varieties, with V3S2 and V6S2 showing the highest protein contents. This increase is likely attributable to relative enrichment due to moisture loss rather than actual protein accumulation. Similar trends have been reported in stored cereal grains, where reductions in moisture content lead to apparent increases in protein concentration (Dejene et al., 2025). The significant interaction suggests that varietal differences influenced protein stability during storage, potentially through differences in protein–starch interactions and matrix organization within the endosperm.

3.1.5 Effect on Total Carbohydrate Content

Total carbohydrate content was significantly affected by variety ($p < 0.01$), but not by storage duration or the interaction between variety and storage. Differences among varieties were evident at both storage durations, indicating that carbohydrate content was predominantly governed by genetic factors. The absence of a storage effect suggests that total carbohydrate levels remained quantitatively stable under the applied storage conditions. As total carbohydrates were calculated by difference, these varietal differences likely reflect inherent variation in starch accumulation and grain composition among sorghum genotypes, as previously reported (Awika & Rooney, 2004). Although total carbohydrate content remained stable, qualitative changes in starch composition, particularly amylose reduction, were substantial.

3.1.6 Effect on Color Attributes (L*, a*, and b*)

No significant effects of variety, storage duration, or their interaction were observed for color parameters (L*, a*, and b*). Color values remained relatively stable across all variety–storage combinations, indicating minimal visual changes during storage. This stability suggests that the storage conditions applied were insufficient to induce pigment degradation or non-enzymatic browning reactions. Sorghum grain color is largely associated with phenolic compounds and pericarp pigmentation, which are generally stable under dry storage conditions (Rooney & Awika, 2005). From a practical perspective, the stability of color attributes is advantageous for maintaining visual quality and consumer acceptance during storage.

4. CONCLUSION

This study confirms that storage duration is the primary factor affecting the physicochemical quality of sorghum grains, significantly influencing moisture, lipid, protein, and amylose contents, while varietal differences mainly governed amylose and total carbohydrate contents. Among the evaluated varieties, V6 exhibited the highest initial amylose content, followed by V4 and V5, indicating superior starch quality at early storage, whereas extended storage markedly reduced amylose levels across all varieties, leading to a convergence of starch composition at the later storage stage. Although protein and lipid contents increased during prolonged storage due to moisture loss, the magnitude of these changes varied among varieties, as reflected by significant variety × storage interactions. In contrast, total carbohydrate content and color attributes remained relatively stable regardless of storage duration. Overall, V6 can be considered the most promising variety in terms of initial physicochemical quality, while the pronounced storage-induced deterioration of amylose highlights the importance of combining varietal selection with appropriate storage management to preserve the nutritional and functional quality of sorghum grains.

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