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Studies on effect of storage on biochemical attributes in hurda sorghum

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Abstract
Sorghum (*Sorghum bicolor* L. Moench) is a major cereal crop cultivated in semi-arid regions, valued for its drought and heat tolerance and serving as an affordable source of calories in developing countries. In Maharashtra, the tender green sorghum grain, locally known as "hurda," is traditionally consumed for its rich nutritional profile. The present study, conducted during the rabi season of 2024-25 at the Sorghum Improvement Project and the Department of Biochemistry, Mahatma Phule Krishi Vidyapeeth, Rahuri, aimed to evaluate the nutritional parameters by storage studies were performed on two selected genotypes (RSSGV-89 and Phule Madhur) under three temperature conditions (room temperature, freeze and deep freeze) and two packaging materials (50 micron LDPE, 100 micron HDPE) at 0,7,14,21, 28 days with seven days of interval. Storage studies indicated a gradual decline in quality parameters over 28 days. In RSSGV-89, moisture content decreased from 56.79% (C0) to 51.05% (C4), total sugar from 5.47% to 4.74%, reducing sugar from 3.37% to 2.74%, and total phenol from 7.10 mg/g to 5.52 mg/g. Similarly, in Phule Madhur, moisture reduced from 56.57% to 50.17%, total sugar from 5.06% to 4.28%, reducing sugar from 3.31% to 2.61%, and total phenol from 7.00 mg/g to 5.52 mg/g. Deep freeze storage (T3) maintained higher retention of moisture, sugars, and phenols compared to room temperature (T1). Overall, RSSGV-89 emerged as the most promising genotype, combining superior nutritional composition in acceptable storage stability, followed closely by Phule Madhur. These genotypes show strong potential for commercial hurda production and can contribute to enhancing dietary quality in sorghum growing regions.

Keywords: Sorghum, Hurda, Genotype, Storage, Nutritional Parameters

Introduction

Sorghum (*Sorghum bicolor* L), a major cereal crop globally, is highly valued for its adaptability to various environmental conditions, especially in arid and semi-arid regions. Known for its drought resistance, sorghum plays a crucial role in food security, particularly in developing countries. Botanical name of sorghum is *Sorghum bicolor* L. Moench. It is an important food source for millions of people due to its ability to survive in harsh weather conditions. There is a considerable variation in sorghum for levels of proteins, lysine, lipids, carbohydrates, fiber, calcium, phosphorus, iron, thiamine and niacin (Shobha *et al*., 2008; Chavan *et al*., 2009) [23, 2]. Sorghum is rich in fiber and minerals, apart from having a sufficient quantity of carbohydrates (72%), proteins (11.6%) and fat (1.9%). Starch is the major constituent of the grain. The protein in sorghum contains albumin globulin (15%), prolamine (26%) and glutelin (44%). (Darekar *et al*., 2020) [5]. The USA is ranked first in sorghum production globally, contributing about 13% of global total production, followed by Nigeria (11%), Sudan (8%), Mexico (8%), and Ethiopia (7%) in 2023 While India ranks 6th in total sorghum production (Khalifa and Eltahir, 2023). Maharashtra is the largest producer (37.88%) of sorghum followed by Karnataka (20.68%). In Maharashtra, the major sorghum producing districts are Osmanabad, Nanded, Yavatmal, Buldhana, Parbhani, Kolhapur, Solapur, Amravati, Pune and Ahilyanagar (Gautam and Singh, 2018) [8].

Tender sorghum, known as "Hurda" in some regions, is a widely grown cereal crop, especially in dry areas where other crops may not grow well. In India, sorghum is harvested and consumed at the milky stage in parts of North Karnataka and South Maharashtra and is known by different regional names *viz*., seethani in Karnataka and hurda in Maharashtra. Particularly in the developed countries there is growing demand for gluten free foods and beverages from people with celiac disease and other intolerances to wheat that cannot eat products from wheat, barley or rye. Tender jowar which is highly seasonal and available only for a limited period (Meti *et al*., 2014) [18]. Based on survey in districts of Northern dry zone of Karnataka, it was noted that two varieties of Seethanijola viz., Sakkari Mukkari Jola and Raosaheb are being cultivated by the farmers for seetani purpose among elders that eating seetani for one month keeps the body healthier for whole year (Patil *et al*., 2010) [19].

sorghum is stored after processing is equally important. Factors such as temperature, moisture, and storage time can cause changes in the grain's quality. Over time, nutrients can break down or become less available, and the grain might lose its freshness or taste. Therefore, it is important to study how roasting and storage affects the nutritional quality of sorghum. Efficient storage of cereal grains is essential to maintain their quality from harvest to consumption. (While traditional methods like bag and pit storage are still in use, modern grain preservation has increasingly shifted towards advanced techniques such as aeration, refrigerated storage, modified atmospheric storage (MAS), and hermetic systems. These innovations help regulate temperature, control moisture, and prevent pest infestations, making them ideal for long-term storage and large-scale operations (Sagar and Pareek, 2020) [20].

Storage temperature and packaging method significantly influence the biochemical composition and shelf life of high-moisture products like chestnuts. The retention of moisture and stability of sugars such as sucrose, glucose, and fructose are highly dependent on the exposure to air and the type of packaging used during storage. It has been observed that chestnuts stored in vacuum-sealed conditions are better able to retain their moisture and sugar profiles compared to those stored in open-air or non-vacuum packaging, especially under varying temperature regimes such as room temperature (21 °C), cold storage (3 °C), and freezing (-18 °C). The use of vacuum packaging combined with low-temperature storage has shown potential in reducing moisture loss and sugar degradation, thereby having importance in preserving the nutritional quality of perishable commodities like Hurda (tender sorghum) during post-harvest handling (Correia *et al*., 2009) [4].

Chavan *et al*. (2013) [2] studied the storage behaviour of sorghum hurda under different packaging and environmental conditions to determine its shelf-life and consumer acceptability. He reported that hurda packed in cloth bags could be stored safely for 2 days at room temperature (27 ± 2 °C) and up to 4 days under refrigerated conditions (10 ± 2 °C) without significant loss in quality. Storage temperature and packaging conditions play a critical role in maintaining the moisture content, sensory qualities, and overall shelf life of grains and tender cereals such as sorghum hurda. Seethani grains stored at refrigerated (8 ± 3 °C), room temperature (28 ± 5 °C), and high-temperature conditions (45 °C) showed different responses in moisture retention and taste. Moisture content remained stable under refrigerated and room temperature conditions, while high temperature led to a rise from 4.26% to 5.87% within 20 days (Semwal and Hemalatha, 2017) [21]. However, no visible microbial growth or infestation occurred. Organoleptic qualities like taste, texture, colour, and appearance remained in the "like moderately" to "like very much" range (scores of 7-8) at both room and refrigerated storage (Semwal and Hemalatha, 2017) [21]. These findings suggest that effective packaging, such as HDPE bags and potentially vacuum or modified atmosphere packaging (MAP), is essential for maintaining the quality of perishable grains like tender sorghum during transportation and marketing stages, where deterioration is common.

Storage plays a critical role in determining the shelf life, nutritional content, and organoleptic quality of food products. For perishable products like hurda, improper storage can lead to deterioration of its quality, affecting both its safety and nutritional value. Understanding the effects of storage on hurda can help in identifying suitable preservation techniques, ensuring that it retains its nutritional benefits and sensory attributes. During storage, various biochemical and physical changes can occur, leading to the deterioration of nutrients in hurda. Storage temperature and packaging conditions significantly influence microbial stability in perishable grains such as tender sorghum. Grains stored at lower temperatures tend to resist microbial growth, thereby preserving quality and safety (Wanjiru, 2020) [26]. In the case of seethani grains, no visible microbial infestation was observed across various storage conditions, including high-temperature storage (45 °C), despite a rise in moisture levels. This suggests that good packaging practices and short-term storage may prevent microbial spoilage in sensitive grains like hurda, which is otherwise prone to rapid deterioration during marketing and transport (Semwal and Hemalatha, 2017) [21].

This research aims to understand the changes that happen to sorghum during storage. Specifically, it will look at how the levels of important nutrients like reducing sugar, non-reducing sugar, total suagar, moisture, phenol will change under these situations. The goal is to provide useful information on how to store hurda sorghum in a way that keeps its nutritional value intact, benefiting both consumers and food producers (Mate *et al*., 2020, Deribe and Kassa, 2020) [16, 7].

Objectives

1.1. To study the biochemical changes during storage of hurda grain sorghum.

Materials and Methods

Hurda grain sorghum genotypes included in the investigation are as below and were obtained from Sorghum Improvement Project, MPKV, Rahuri.

Table 1: List of hurda grain sorghum genotypes used for study

Sr. no.	Name of genotype
1	Phule Madhur
2	Phule Uttara

Experimental site

The site for the experimental field was selected at Sorghum Improvement Project, MPKV, Rahuri and the sample analysis was conducted in the laboratory of Department of Biochemistry, Post Graduate Institute, MPKV, Rahuri.

Tender hurda grain storage study

In the storage study, nutritional parameters *viz*, moisture, reducing sugar, non-reducing sugar, total sugar, and phenol were analysed simultaneously. Two genotypes, Phule Madhur and RSSGV89 were used for nutritional parameters. For each sample, 1000 grams of hurda was threshed, separated, and cleaned. About 50 grams of hurda was packed in 50 and 100 micron LDPE and HDPE bags under packaging conditions. Samples were then stored at normal room temperature, freeze temperature, and deep freeze temperature and analysed for above nutritional parameters at 0, 7, 14, 21 and 28 days with 7 days interval and the samples were separated and packed accordingly and analysed as per schedule.

Moisture content

Moisture content was determined by employing the standard method of analysis (AOAC, 1965).

$$\text{Moisture (\%)} = \frac{W1\text{-}W2}{W} \times 100$$

Where,
W1 = Weight (g) of the dish with the material before drying
W2 = Weight (g) of the dish with the material after drying
W = Weight (g) of the sample

Reducing sugar

Reducing sugars were determined by Somogyi's modified method (1952).

Total sugar

Total sugar percentage was calculated by the method suggested by Sadasivam and Manickam (1992).

Non-reducing sugar

It is determined by difference between total and reducing sugar.

Non-reducing sugar (%) = Total sugar (%) - Reducing sugar (%)

Total phenol content

Phenol content was estimated by the method suggested by Bray and Thorpe (1954). Phenols react with phosphomolybdic acid in Folin-Ciocalteau's reagent in alkaline medium and produce blue colored complex (molybdenum blue).

Statistical analysis

Statistical data analysis was carried out as per factorial Randomized Block Design.

Results and Discussion

Changes in moisture content

The results on changes in moisture content of RSSGV-89 hurda sorghum genotype during storage as affected by different storage condition, packaging materials, and storage period are presented in Table 2. It was recorded that moisture content decreased gradually over the storage period from 56.79% at 0 days to 51.05% at 28 days. Among storage periods, the highest moisture content was recorded at 0 days (56.79%), and the lowest at 28 days (51.05%). Among storage conditions, the average moisture content was 52.58% under room temperature (T1), 52.58% under freeze temperature (T2), and 52.37% under deep freeze (T3), showing minimal variation across treatments. Among containers, moisture content was slightly higher in HDPE (53.54%) as compared to LDPE (52.50%). The interaction effect of temperature, packaging material, and storage period showed that the maximum moisture (56.79%) was recorded in all T×P×C combinations at 0 days (T1P1C0, T2P1C0, T3P1C0, T1P2C0, T2P2C0, and T3P2C0), whereas the minimum moisture content (49.50%) was found under T2P1C4 (Freeze temperature + LDPE at 28 days).

The statistical analysis revealed that the treatment had no significant effect on the moisture content. However, the storage period had a significant effect, indicating the progressive decline of moisture over time. The interaction among temperature, packaging material, and storage period was non-significant. This can be attributed to the similar effect of treatments across packaging materials and storage conditions.

The results on changes in moisture content of Phule Madhur genotype hurda sorghum during storage as affected by different temperatures, packaging materials, and storage durations are presented in Table 3. It was observed that moisture content decreased gradually over the storage period from 56.57% at 0 days to 50.17% at 28 days. Among storage periods, the highest moisture content was recorded at 0 days (56.57%), and the lowest at 28 days (50.17%). Among storage conditions, the average moisture content was 52.28% under room temperature (T1), 52.28% under freeze temperature (T2), and 52.08% under deep freeze (T3), showing minimal variation across treatments. Among containers, moisture content was slightly higher in HDPE (52.97%) as compared to LDPE (52.02%). The interaction effect of temperature, packaging material, and storage period showed that the maximum moisture (56.57%) was recorded in all T×P×C combinations at 0 days (T1P1C0, T2P1C0, T3P1C0, T1P2C0, T2P2C0, and T3P2C0), whereas the minimum moisture content (48.90%) was found under T2P1C4 (freeze temperature + LDPE at 28 days).

The statistical analysis revealed that the treatment had no significant effect on the moisture content. However, the storage period had a significant effect, indicating the progressive decline of moisture over time. The interaction among temperature, packaging material, and storage period was non-significant. This can be attributed to the similar effect of treatments across packaging materials and storage conditions.

In the present study, a gradual decline in moisture content was observed during storage of hurda under different temperature and packaging conditions. A comparable observation was reported by Wang *et al.* (2022) [25], where various freezing methods applied to fresh sweet corn demonstrated that brine and strong wind freezing effectively minimized water loss during long-term storage. These methods helped retain moisture by reducing tissue damage and slowing down dehydration processes, thus supporting the current findings that freezing treatments better preserve the moisture content in fresh cereal grains.

In the present study, LDPE packaging and low-temperature storage played a significant role in retaining the moisture content of hurda grains. A similar observation was made by Mehan *et al.* (2014) [17], the study on minimally processed baby corn, where storage at 12.5 °C in 25-micron LDPE bags with perforations effectively reduced moisture loss and extended shelf life under modified atmosphere conditions. This supports the current findings that LDPE packaging helps minimize dehydration during storage of fresh produce.

Simonyan et al. (2007) [24] studied some physical properties of Samaru Sorghum 17 within the moisture range of 8.89 - 16.5 per cent wb, which is the typical moisture range for threshing and storage of sorghum. Chenlo *et al.* (2010) [3] reported that moisture content decreased significantly in chestnuts stored without packaging at room (21 °C) and cold chamber (3 °C) temperatures over 10 weeks. In contrast, vacuum-packed samples maintained their moisture levels regardless of storage temperature.

Kibar *et al*. (2021) [13] observed that moisture content in quinoa grains increased with both storage duration (0, 60, 120, 180, 240, 300, 360 days) and temperature. Specifically, for the Mint Vanilla variety, moisture content increased at storage temperatures of 10 °C and 25 °C over 360 days. This increase is attributed to the hygroscopic nature of quinoa grains, which absorb moisture from the environment during storage.

Changes in total sugar content

The results on changes in total sugar content of RSSGV-89 genotype hurda sorghum during storage as affected by different temperatures, packaging materials, and storage durations are presented in Table 2. It was observed that total sugar content decreased gradually over the storage period from 5.47% at 0 days to 4.74% at 28 days. Among storage periods, the highest total sugar content was recorded at 0 days (5.47%), and the lowest at 28 days (4.74%). Among storage conditions, the average total sugar content was 5.02% under room temperature (T1), 5.02% under freeze temperature (T2), and 5.01% under deep freeze (T3), showing minimal variation across treatments. Among containers, total sugar content was found to be equal in both LDPE (5.04%) and HDPE (5.04%). The interaction effect of temperature, packaging material, and storage period showed that the maximum total sugar (5.47%) was recorded in all T×P×C combinations at 0 days (T1P1C0, T2P1C0, T3P1C0, T1P2C0, T2P2C0, and T3P2C0), whereas the minimum total sugar content (4.52%) was found under T1P1C4 (room temperature + LDPE at 28 days).

The statistical analysis revealed that the treatment had no significant effect on the total sugar content. However, the storage period had a significant effect, indicating the progressive decline of total sugar over time. The interaction among temperature, packaging material, and storage period was non-significant. This can be attributed to the similar effect of treatments across packaging materials and storage conditions.

The results on changes in total sugar content of Phule Madhur genotype hurda sorghum during storage as affected by different temperatures, packaging materials, and storage durations are presented in Table 3. It was observed that total sugar content decreased gradually over the storage period from 5.06% at 0 days to 4.28% at 28 days. Among storage periods, the highest total sugar content was recorded at 0 days (5.06%), and the lowest at 28 days (4.28%). Among storage conditions, the average total sugar content was 4.66% under room temperature (T1), 4.66% under freeze temperature (T2),and 4.66% under deep freeze (T3), showing no variation across treatments. Among containers, total sugar content was equal in LDPE (4.66%) and HDPE (4.66%), indicating no container-wise difference. The interaction effect of temperature, packaging material, and storage period showed that the maximum total sugar (5.06%) was recorded in all T×P×C combinations at 0 days (T1P1C0, T2P1C0, T3P1C0, T1P2C0, T2P2C0, and T3P2C0), whereas the minimum total sugar content (4.23%) was found under T1P1C4(room temperature + LDPE at 28 days).

The statistical analysis revealed that the treatment, storage container, and interaction had no significant effect on the total sugar content. However, the storage period had a significant effect, indicating a progressive decline of total sugar over time.

Jood et al. (1993) [10] found that total soluble sugar content increased substantially during longer storage durations due to the breakdown of complex carbohydrates such as starch into glucose, fructose, and sucrose, especially during 4 months of ambient storage.

According to Kumar and Ezekiel (2005) [14] of seven Potato cultivars were stored at 10-12 °C for 150 days, and changes in sucrose (total sugar) content were recorded. In most genotypes, sucrose increased during storage; for example, in 'Kufri Chipsona-2', it rose from 141 to 233 mg/100 g fresh weight, and in 'Kufri Jyoti', it increased from 125 to 416 mg/100 g. After reconditioning at 20±2 °C for 1-2 weeks, sucrose levels remained high in some cultivars, showing that storage duration and temperature influenced total sugar content significantly.

Changes in reducing sugar content

The results on changes in reducing sugar content of RSSGV-89 genotype hurda sorghum during storage as affected by different temperatures, packaging materials, and storage durations are presented in Table 2. It was observed that reducing sugar content decreased gradually over the storage period from 3.37% at 0 days to 2.74% at 28 days. Among storage periods, the highest reducing sugar content was recorded at 0 days (3.37%), and the lowest at 28 days (2.74%). Among storage conditions, the average reducing sugar content was 2.99% under room temperature (T1), 2.99% under freeze temperature (T2), and 2.99% under deep freeze (T3), showing no variation across treatments. Among containers, reducing sugar content was slightly higher in HDPE (3.01%) as compared to LDPE (2.95%). The interaction effect of temperature, packaging material, and storage period showed that the maximum reducing sugar content (3.37%) was recorded in all T×P×C combinations at 0 days (T1P1C0, T2P1C0, T3P1C0, T1P2C0, T2P2C0, and T3P2C0), whereas the minimum reducing sugar content (2.65%) was found under T3P1C4 (deep freeze temperature + LDPE at 28 days).

The statistical analysis revealed that the treatment had no significant effect on the reducing sugar content. However, the storage period had a significant effect, indicating the progressive decline of reducing sugar over time. The interaction among temperature, packaging material, and storage period was non-significant. This can be attributed to the similar effect of treatments across packaging materials and storage conditions.

The results on changes in reducing sugar content of Phule Madhur genotype hurda sorghum during storage as affected by different temperatures, packaging materials, and storage durations are presented in Table 3. It was observed that reducing sugar content decreased gradually over the storage period from 3.31% at 0 days to 2.61% at 28 days**.** Among storage periods, the highest reducing sugar content was recorded at 0 days **(**3.31%**),** and the lowest at 28 days (2.61%)**.** Among storage conditions, the average reducing sugar content was 2.92% under room temperature (T1)**,** 2.92% under freeze temperature (T2)**,** and 2.91% under deep freeze (T3)**,** showing negligible variation across treatments. Among containers, reducing sugar content was slightly higher in HDPE (2.92%) as compared to LDPE (2.88%). The interaction effect of temperature, packaging material, and storage period showed that the maximum reducing sugar (3.31%) was recorded in all T×P×C combinations at 0 days (T1P1C0, T2P1C0, T3P1C0, T1P2C0, T2P2C0, and T3P2C0), whereas the minimum reducing sugar content (2.50%) was found under T2P1C4 (freeze temperature + LDPE at 28 days).

The statistical analysis revealed that the treatment, storage container, storage period, and their interaction had no significant effect on the reducing sugar content.

In the current investigation, reducing sugar and non-reducing sugar levels in hurda showed variations based on storage temperature and packaging conditions. Wang *et al.* (2022) [25], similarly reported that among different freezing techniques used on sweet corn, brine and strong wind freezing effectively maintained reducing sugar content during extended storage. Since reducing sugars primarily include reducing sugars such as glucose and fructose, their preservation under freezing conditions highlights the importance of cold storage in retaining the sweetness and nutritional quality of fresh grains, aligning with the current study's results on sugar retention.

Jood and Kapoor (1993) [10] reported that reducing sugar content increased in wheat, maize, and sorghum grains during storage of up to 4 months, which was attributed to the enzymatic breakdown of starch into simpler sugars during the storage period.

Kumar and Ezekiel (2005) [14] revealed that of seven Potato cultivars were stored at 10-12 °C for 150 days, and reducing sugar levels were observed to increase in most genotypes during storage. For example, 'Kufri Lauvkar' showed a high increase up to 333 mg/100 g fresh weight, but after 2 weeks of reconditioning, it reduced significantly to 32 mg/100 g. Similar trends were seen in 'Kufri Chipsona-1' and 'Kufri Jyoti', where reducing sugars decreased after reconditioning.

According to Barna *et al.* (2017) [1] Sugar beet was stored at temperatures of 2, 6, 10, 15, and 20 °C for up to 60 days to study changes in reducing sugar content. The results showed that reducing sugar levels varied non-uniformly over time, depending on storage temperature. Higher temperatures generally caused an increase in reducing sugar content during longer storage periods. This indicates that both storage time and temperature significantly affect reducing sugar levels in sugar beet.

Changes in non-reducing sugar content

The results on changes in non-reducing sugar content of RSSGV-89 genotype hurda sorghum during storage as affected by different temperatures, packaging materials, and storage durations are presented in Table 2. It was observed that non-reducing sugar content decreased gradually over the storage period from 2.10% at 0 days to 2.00% at 28 days. Among storage periods, the highest non-reducing sugar content was recorded at 0 days (2.10%), and the lowest at 28 days (2.00%). Among storage conditions, the average non-reducing sugar content was 2.03% under room temperature (T1), 2.03% under freeze temperature (T2), and 2.02% under deep freeze (T3), showing minimal variation across treatments. Among containers, non-reducing sugar content was slightly higher in LDPE (2.09%) as compared to HDPE (2.03%). The interaction effect of temperature, packaging material, and storage period showed that the maximum non-reducing sugar content (2.10%) was recorded in all T×P×C combinations at 0 days (T1P1C0, T2P1C0, T3P1C0, T1P2C0, T2P2C0, and T3P2C0), whereas the minimum non-reducing sugar content (1.81%) was found under T1P1C4 (room temperature + LDPE at 28 days).

The results on changes in non-reducing sugar content of Phule Madhur genotype hurda sorghum during storage as affected by different temperatures, packaging materials, and storage durations are presented in Table 3. It was observed that non-reducing sugar content decreased gradually over the storage period from 1.75% at 0 days to 1.67% at 28 days**.** Among storage periods, the highest non-reducing sugar content was recorded at 7 days (1.87%)**,** and the lowest at 28 days (1.67%)**.** Among storage conditions, the average non-reducing sugar content was 1.74% under room temperature (T1)**,** 1.74% under freeze temperature (T2)**,** and 1.76% under deep freeze (T3)**,** showing negligible variation across treatments. Among containers, non-reducing sugar content was slightly higher in LDPE (1.78%) as compared to HDPE (1.74%)**.** The interaction effect of temperature, packaging material, and storage period showed that the maximum non-reducing sugar (1.95%) was recorded under T2P1C1 (freeze temperature + LDPE at 7 days), whereas the minimum non-reducing sugar content (1.59%) was found under T3P2C4 (deep freeze + HDPE at 28 days).

Jood and Kapoor (1993) [11] observed that non-reducing sugar levels remained relatively stable during short-term storage but showed mild conversion into reducing sugars as storage duration increased, indicating gradual breakdown of sucrose under natural enzymatic processes.

Kumar and Ezekiel (2005) [14] reported that seven potato cultivars were stored at 10-12 °C for 150 days, and the non-reducing sugar (sucrose) content was monitored. Most cultivars showed an increase in non-reducing sugar during storage; for instance, in 'Kufri Chipsona-2', it rose from 141 to 233 mg/100 g fresh weight, and in 'Kufri Jyoti', from 125 to 416 mg/100 g. Even after reconditioning at 20±2 °C for 1-2 weeks, non-reducing sugar levels stayed high in some genotypes, indicating that both storage time and temperature had a significant impact on non-reducing sugar content.

Changes in total phenol content

The results on changes in total phenol content of RSSGV-89 genotype hurda sorghum during storage as affected by different temperatures, packaging materials, and storage durations are presented in Table 2. It was observed that total phenol content decreased gradually over the storage period from 7.10 mg/g at 0 days to 5.52 mg/g at 28 days. Among storage periods, the highest total phenol content was recorded at 0 days (7.10 mg/g), and the lowest at 28 days (5.52 mg/g). Among storage conditions, the average total phenol content was 6.03 mg/g under room temperature (T1), 6.03 mg/g under freeze temperature (T2), and 6.02 mg/g under deep freeze (T3), showing minimal variation across treatments. Among containers, total phenol content was slightly higher in HDPE (6.10 mg/g) as compared to LDPE (5.99 mg/g). The interaction effect of temperature, packaging material, and storage period showed that the maximum total phenol content (7.10 mg/g) was recorded in all T×P×C combinations at 0 days (T1P1C0, T2P1C0, T3P1C0, T1P2C0, T2P2C0, and T3P2C0), whereas the minimum total phenol content (5.10 mg/g) was found under T1P1C4 (room temperature + LDPE at 28 days).

The results on changes in total phenol content of Phule Madhur genotype hurda sorghum during storage as affected by different temperatures, packaging materials, and storage durations are presented in Table 3. It was observed that total phenol content decreased gradually over the storage period from 7.00 mg/gm at 0 days to 5.52 mg/gm at 28 days. Among storage periods, the highest total phenol content was recorded at 0 days (7.00 mg/gm), and the lowest at 28 days (5.52 mg/gm).

Among storage conditions, the average total phenol content was 6.01 mg/gm under room temperature (T1), 6.01 mg/gm under freeze temperature (T2), and 6.00 mg/gm under deep freeze (T3), showing minimal variation across treatments. Among containers, total phenol content was slightly higher in HDPE (6.08 mg/gm) as compared to LDPE (5.97 mg/gm).

The interaction effect of temperature, packaging material, and storage period showed that the maximum total phenol content (7.00 mg/gm) was recorded in all T×P×C combinations at 0 days (T1P1C0, T2P1C0, T3P1C0, T1P2C0, T2P2C0, and T3P2C0), whereas the minimum total phenol content (5.10 mg/gm) was found under T1P1C4 (room temperature + LDPE at 28 days).

In the present study, freezing storage was found to influence the phenolic content in hurda grains. Supporting this observation Xiang *et al.* (2020) [27] reported that storage of sweet corn kernels at −20 °C for six months resulted in a slight decline in phenolic compounds, indicating that low-temperature freezing helps retain phenol content to a greater extent compared to ambient storage. These findings reinforce the importance of cold preservation in minimizing phenolic degradation during storage.

In the present study, phenol content in hurda was better retained under freezing conditions during the 28-day storage period. Hossain *et al.* (2021) [9] reported that, a study on litchi fruits reported that storage at 4 °C for 30 days in HDPE packaging helped in significantly preserving total phenol content compared to untreated samples. This highlights the role of low-temperature storage and packaging in minimizing phenolic degradation over time.

Storage conditions significantly influence the nutritional stability and safety of roasted cereal products. During storage, temperature, humidity, and packaging materials affect the retention of antioxidants and phenolic compounds. Lang *et al*. (2019) [15] emphasized that prolonged storage, especially under high humidity and inadequate packaging, leads to degradation of phenolics and loss of antioxidant potential in grains. The appropriate storage practices are vital for preserving the nutritional quality of Hurda during post-processing handling and marketing.

Table 2: Effect of storage condition, storage period and packaging material on hurda sorghum genotype RSSGV-89.

Parameter	Moisture	Total sugar	Reducing sugar	Non-reducing sugar	Total phenol content
Storage condition			**RSSGV-89**		
T1	52.58	5.02	2.99	2.03	6.03
T2	52.58	5.02	2.99	2.03	6.03
T3	52.37	5.01	2.99	2.02	6.02
SE(m)±	0.49	0.05	0.03	0.02	0.06
CD at 5%	NS	NS	NS	NS	0.16
Storage container					
P1	52.50	5.04	2.95	2.09	5.99
P2	53.54	5.04	3.01	2.03	6.10
SE(m)±	0.40	0.04	0.02	0.02	0.05
CD at 5%	NS	NS	0.06	0.04	NS
Storage period					
C0	56.79	5.47	3.37	2.10	7.10
C1	53.48	5.16	3.06	2.10	6.06
C2	52.20	4.99	2.91	2.08	5.85
C3	51.58	4.84	2.81	2.02	5.70
C4	51.05	4.74	2.74	2.00	5.52
SE(m)±	0.64	0.06	0.04	0.02	0.07
CD at 5%	1.79	0.17	0.10	0.07	0.20
Interaction					
T1P1C0	56.79	5.47	3.37	2.10	7.10
T1P1C1	54.90	5.20	3.10	2.10	6.05
T1P1C2	51.30	4.95	2.85	2.10	5.84
T1P1C3	50.80	4.76	2.78	1.98	5.62
T1P1C4	49.60	4.52	2.71	1.81	5.10
T2 P1C0	56.79	5.47	3.37	2.10	7.10
T2 P1C1	51.60	5.16	3.02	2.14	6.00
T2 P1C2	50.20	5.02	2.88	2.14	5.71
T2 P1C3	49.70	4.88	2.80	2.08	5.38
T2 P1C4	49.50	4.76	2.71	2.05	5.20
T3 P1C0	56.79	5.47	3.37	2.10	7.10
T3 P1C1	53.30	5.15	2.98	2.17	6.08
T3 P1C2	52.80	5.03	2.82	2.21	5.91
T3 P1C3	52.00	4.91	2.77	2.14	5.87
T3 P1C4	51.50	4.81	2.65	2.16	5.81
T1P2C0	56.79	5.47	3.37	2.10	7.10
T1 P2C1	52.90	5.22	3.12	2.10	6.10
T1 P2C2	51.80	5.04	3.01	2.03	5.91
T1 P2C3	50.80	4.81	2.84	1.97	5.86
T1 P2C4	50.10	4.75	2.78	1.97	5.62

T2 P2C0	56.79	5.47	3.37	2.10	7.10
T2 P2C1	54.10	5.14	3.12	2.02	6.04
T2 P2C2	53.70	5.00	2.96	2.04	5.81
T2 P2C3	53.10	4.86	2.84	2.02	5.61
T2 P2C4	52.60	4.80	2.80	2.00	5.55
T3 P2C0	56.79	5.47	3.37	2.10	7.10
T3 P2C1	54.10	5.06	3.00	2.06	6.10
T3 P2C2	53.40	4.89	2.91	1.98	5.91
T3 P2C3	53.10	4.80	2.85	1.95	5.86
T3 P2C4	53.00	4.80	2.80	2.00	5.85
SE(m)±	1.91	0.18	0.11	0.07	0.22
CD @5%	NS	NS	NS	NS	NS

Table 3: Effect of storage condition, storage period and packaging material on hurda sorghum genotype P. Madhur.

Parameter	Moisture	Total sugar	Reducing sugar	Non-reducing sugar	Total phenol content
Storage condition	P.Madhur				
T1	52.28	4.66	2.92	1.74	6.01
T2	52.28	4.66	2.92	1.74	6.01
T3	52.08	4.66	2.91	1.76	6.00
SE(m)±	0.49	0.04	0.03	0.02	0.06
CD at 5%	NS	NS	NS	NS	0.16
Storage container					
P1	52.02	4.66	2.88	1.78	5.97
P2	52.97	4.66	2.92	1.74	6.08
SE(m)±	0.40	0.04	0.02	0.01	0.05
CD at 5%	NS	NS	NS	0.04	NS
Storage period					
C0	56.57	5.06	3.31	1.75	7.00
C1	53.20	4.87	3.00	1.87	6.06
C2	51.62	4.65	2.85	1.79	5.85
C3	50.93	4.44	2.72	1.71	5.70
C4	50.17	4.28	2.61	1.67	5.52
SE(m)±	0.63	0.06	0.03	0.02	0.07
CD at 5%	1.77	0.16	0.10	0.06	0.20
Interaction					
T1P1C0	56.57	5.06	3.31	1.75	7.00
T1P1C1	54.70	4.85	3.08	1.77	6.05
T1P1C2	51.20	4.66	2.89	1.77	5.84
T1P1C3	50.70	4.47	2.77	1.70	5.62
T1P1C4	49.40	4.23	2.61	1.62	5.10
T2 P1C0	56.57	5.06	3.31	1.75	7.00
T2 P1C1	51.30	4.90	2.95	1.95	6.00
T2 P1C2	50.00	4.65	2.78	1.87	5.71
T2 P1C3	49.50	4.42	2.60	1.82	5.38
T2 P1C4	48.90	4.25	2.50	1.75	5.20
T3 P1C0	56.57	5.06	3.31	1.75	7.00
T3 P1C1	52.80	4.86	2.98	1.88	6.08
T3 P1C2	51.50	4.63	2.81	1.82	5.91
T3 P1C3	50.60	4.46	2.68	1.78	5.87
T3 P1C4	50.00	4.30	2.58	1.72	5.81
T1P2C0	56.57	5.06	3.31	1.75	7.00
T1 P2C1	52.50	4.88	3.00	1.88	6.10
T1 P2C2	51.10	4.65	2.88	1.77	5.91
T1 P2C3	50.30	4.42	2.74	1.68	5.85
T1 P2C4	49.80	4.30	2.62	1.68	5.62
T2 P2C0	56.57	5.06	3.31	1.75	7.00
T2 P2C1	53.90	4.88	3.00	1.88	6.04
T2 P2C2	52.60	4.65	2.85	1.80	5.81
T2 P2C3	51.90	4.42	2.77	1.65	5.61
T2 P2C4	50.90	4.33	2.65	1.68	5.55
T3 P2C0	56.57	5.06	3.31	1.75	7.00
T3 P2C1	54.00	4.85	3.00	1.85	6.10
T3 P2C2	53.30	4.64	2.91	1.73	5.91
T3 P2C3	52.60	4.43	2.78	1.65	5.86
T3 P2C4	52.00	4.28	2.69	1.59	5.85
SE(m)±	1.89	0.17	0.10	0.06	0.22
CD @5%	NS	NS	NS	NS	NS

Where,
A) T_1 - T_3 : Storage conditions
T_1: Room temperature (27$\pm$2^{0}C)
T_2: Freeze condition (10$\pm$2^{0}C)
T_3: Deep freeze condition (4$\pm$2^{0}C)
B) P_1 and P_2 : Packaging material
P_1: Low density polyethylene bag (LDPE, 50 micron)
P_2: High density polyethylene bag (HDPE, 100 micron)
C) C_0 to C_4 : Storage period
C_0: 0 days
C_1: 7 days
C_2: 14 days
C_3: 21 days
C_4: 28 days

Conclusion

1. In the storage study, moisture, total sugar, reducing sugar, non-reducing sugar and phenol content declined gradually during 28 days of storage in both RSSGV-89 and Phule Madhur. Based on the data, hurda can be stored in good condition up to 14 days (C_2), as quality parameters like moisture, sugars, and phenol content remain stable. The most effective storage condition is deep freeze (T_3: 4±2 °C) with HDPE packaging (P_2), which helps in better preservation of quality during storage.
2. Overall, genotype RSSGV-89 was found consistently superior across nutritional as a storage studies, followed closely by Phule Madhur, suggesting both genotypes hold strong potential for future hurda commercialization and research applications.

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