Plant Archives Vol. 26, Supplement 2, 2026 pp.3340-3348 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2026.v26.supplement-2.424

COMPARATIVE EVALUATION OF PHYSICOFUNCTIONAL PROPERTIES AND NUTRITIONAL VARIATION IN POPPED-SORGHUM GENOTYPES: A STUDY ON RED, YELLOW AND WHITE VARIETIES

Ookanti Suma[1], B. Anila Kumari[1]*, Aparna Kuna[2] and A. Vijaya Kumar[3]

[1]Department of Foods and Nutrition, Post Graduate and Research Centre, P.J.T. Agricultural University, Hyderabad (500030), Telangana, India.

[2]International Programmes, P.J.T. Agricultural University, Hyderabad (500030), Telangana, India.

[3]Department of Veterinary Public Health and Epidemiology, College of Veterinary Science, Mamnoor, Warangal, 506166, Telangana, India.

*Corresponding author E-mail: baniladr@pjtau.edu.in

(Date of Receiving : 06-05-2026; Date of Revision : 29-06-2026; Date of Acceptance : 19-07-2026)

ABSTRACT

Sorghum is an underutilized grain with potential for ready-to-eat popped snacks, yet genotypic differences in popping, functional, nutritional and sensory traits remain unclear. This study evaluated three sorghum genotypes-CSV-80(Red Sorghum Pops), PSPY-1(Yellow Sorghum Pops) and M 31-1(White Sorghum Pops) for popping performance, proximate composition, functional properties, antioxidant compounds, color and sensory acceptability. Popping capacity varied significantly, with WSP giving the highest yield of fully popping kernels (55.67%) and RSP showing superior expansion ratio (19.50). Proximate analysis revealed RSP was nutritionally dense, having highest fat (5.62%) and protein (11.4%), while WSP and YSP were carbohydrate-rich (79.47%; 79.31%). Functional properties (WAC, WSI, OAC) were statistically uniform across genotypes. Color analysis using Hunter LAB showed no significant differences ($p > 0.05$) in popped products. L* values ranged narrowly from 33.20 in YSP to 35.98 in WSP while a* and b* values remained low and uniform. Red sorghum pops had the highest total phenolic content (31.61 mg GAE/g) without any rise in tannins. Sensory scores showed all three were well accepted, but white sorghum pops ranked highest for taste, flavor and overall liking, with an acceptability index of 89%. Results indicate genotype selection can target specific end uses: red sorghum for antioxidant-rich, protein-fortifies snacks and white sorghum for high-yield, energy-dense pops with better sensory appeal. Functional uniformity suggest interchangeability in processing. This work supports breeding and product development of sorghum-based expanded foods.

***Keywords* :** Colored Sorghum, Popping, Phytonutrient, Proximate composition, Sensory quality.

Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) or jowar in India, is regaining importance as a climate-resilient crop. It performs well under heat and drought due to its C4 photosynthetic pathway and low water demand (Saballos, 2008; FAO, 2023). Globally it ranks as the fifth major cereal, providing a staple diet for more than 500 million people across semi-arid regions of Africa and Asia (Taylor and Duodu, 2015). In India, recent initiatives have strengthened its position. The UN's International Year of Millets 2023 and the national "Shree Anna" branding have helped shift sorghum from a traditional subsistence crop toward a commercially relevant food ingredient (ICAR-IIMR, 2023). This renewed interest also aligns with changing consumer needs. The rising prevalence of type 2 diabetes, obesity and celiac disease has increased demand for gluten-free, low-glycemic foods (Svegrova *et al.*, 2016). Sorghum is well suited for this market. Its starch digests slowly and its polyphenols and dietary fiber help regulate post-meal blood sugar and support gut health (Pontieri *et al.*, 2021).

At the same time, busy lifestyles are driving growth in the ready-to-eat healthy snack sector. This creates a strong opportunity for puffed or popped sorghum products to replace conventional oil-fried snacks in the wellness market (Awika and Rooney, 2004; Singh *et al.*, 2022). Despite these benefits, some challenges remain. Sorghum kernels have a dense, vitreous endosperm that requires long cooking times, making them less convenient for urban consumers. Colored varieties also contain condensed tannins in the outer layers, which can cause astringency and reduce protein and mineral availability (Duodu *et al.*, 2003). Thermal processing offers a practical solution. High-temperature short-time (HTST) air puffing at 270-290°C rapidly converts internal moisture to steam, causing the kernel to expand into a light, crispy product (Mishra *et al.,* 2015). The process gelatinizes starch, improves water and oil absorption properties and reduces bitter tannins while releasing bound antioxidants, thereby improving taste and nutrient bio accessibility (Lopes *et al.*, 2023).

Popping quality is largely controlled by genetics, which influences kernel structure, starch type and phytochemical content. Indian sorghum shows wide genetic diversity, with grain color varying from white to yellow to deep red, each linked to different physical and nutritional traits (Rooney and Wansika, 2000). While popcorn has been studied extensively, there is limited work on how diverse Indian sorghum genotypes respond to modern automated HTST puffing systems. Specifically, data connecting processing effects with hydration behavior, nutrient retention and sensory quality are lacking. This gap restricts the selection of varieties best suited for expanded snacks.

To address this, the present study compared three Indian sorghum genotypes: M 35-1, a white winter cultivar with a hard, starchy kernel and mild flavor used as a benchmark; PSPY-1, a yellow-seeded type with higher carotenoid precursors of vitamin A and CSV 50 Red, a new red variety rich in polyphenols and tannins with potential anti-diabetic properties. Understanding these genotype-specific relationships is important because kernel structure and composition directly affect the texture, nutritional value and health benefits of the final product. This knowledge can guide the selection of sorghum types for targeted snack formulations, supporting the development of gluten-free, nutrient-dense foods that fit both global health trends and India’s millet promotion goals.

Materials and Methods

Three sorghum genotypes-namely M 35-1 (white), PSPY-1 (yellow) and CSV 50 (red) were procured from local farmers in Telangana state. All chemicals and glassware used in this research were of analytical grade and the equipment used were from the Department of Foods and Nutrition (Post Graduate and Research Centre), the Central Instrumentation Cell (CIC) and the Millet Processing and Incubation Centre (MPIC) at Professor Jayashankar Telangana Agricultural University.

Pretreatment and Conditioning of Grains: Sorghum grains were cleaned in cleaning cum grading equipment (M/s Dhan foundation) available at MPIC. Grains were hydrostatically soaked in distilled water for 2 h at room temperature, then drained (Mishra *et al.*, 2015). Surface moisture was removed with muslin cloth, followed by shade-drying for 15-20 min to achieve 14-18% moisture, critical for optimal expansion. Moisture was verified using a Mini Gae Plus moisture tester (Nakade *et al.*, 2020)

Popping process

Conditioned sorghum genotypes were popped individually in a specialized grain puffing machine (Technocrats machine, IIFPT, Thanjavur, Tamil Nadu) using HTST treatment at 190-120℃ to induce endosperm expansion (Nakade *et al.*, 2020). The product was immediately sieved into popped, semi popped and unpopped fractions and stored in airtight containers for analysis.

Color Analysis

Color of sorghum pops were measured using a Hunter Lab colorimeter (Colorflex 45°/ 0° Spectrophotometer Hunter, X Easy match QC Software) for L*(lightness), a* (redness-greenness) and b* (yellowness-blueness) values (Shahabi *et al.*, 2014). Chroma (C*) and hue angle (h*) were calculated from these parameters (Pathare *et al.*, 2012).

Texture Profile Analysis

Textural characteristics of individual sorghum pops were measured in triplicate using a Brookfield Texture analyser with a 35 mm cylinder probe (TA4/1000) (Maisont *et al.*, 2021). Single pops were placed on the fixture base and compressed under test mode with a target distance of 3 mm, test speed of 0.5 mm/s and trigger load of 5 g to prevent premature shattering. The probe was cleaned after each measurement.

Bulk Density

The bulk density (BD) of pops were measured according to the standard method given by Rybak-Chmielewska, (2003). It was calculated by using the formula: - $\rho = M/V$

True density

True density is nothing but the quotient of mass per unit volume of a sample, without considering pores in the material, i.e. (true volume). It was calculated by using the formula: - $\rho = W/V$

Popping capacity: Popping capacity was measured using a weighing balance. In each colored sorghum grain was popped and categorized into popped, semi-popped and unpopped kernels and expressed in percentage.

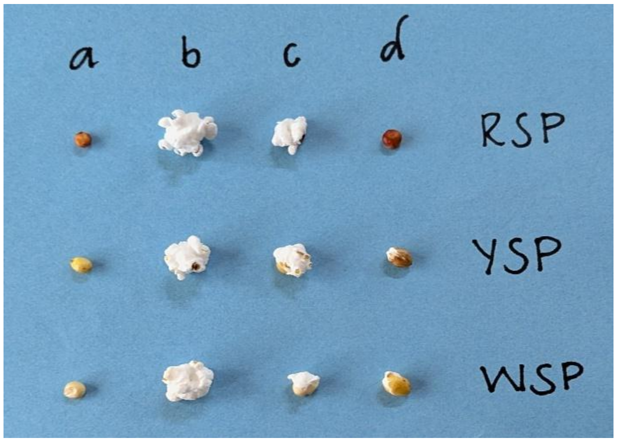

Plate 1: Visual representation of popping behavior in sorghum genotypes.

(a) Raw grain; (b) Fully popped kernel; (c) Semi-popped; (d) Unpopped kernel.

RSP: red sorghum; YSP: yellow sorghum popped; WSP: white sorghum popped

Expansion ratio (Tran *et al.*, 1999)

The expansion ratio for sorghum pops was expressed in total volume of popped millet to the total weight of popped millet.

Popped ratio (Tran *et al.*, 1999): The popped ratio was measured for millet by using the following formula.

$$\text{Popped ratio} = \frac{\text{Weight of grain (g) - unpopped grain (g)}}{\text{Weight of grain (g)}}$$

Water Absorption Capacity (WAC) and Water Solubility Index (WSI)

WAC and WSI were determined as per Sharma *et al.* (2004) and Sairam *et al.* (2011). Ground sorghum pop sample (1 g) was dispersed in 30 ml distilled water, held for 30 min at room temperature and centrifuged at 3000 rpm for min. The supernatant was dried at 100 ℃ to constant weight for WSI (%). The sediment was weighed for WAC (g/100g).

Oil Absorption Capacity (OAC)

OAC of ground sorghum pop sample was determined as per Sharma *et al.*, (2004) and Sairam *et al.*, (2011). Sample (1 g) was vortexed with 10 ml refined oil (V1), held for 30 min at room temperature and centrifuges at 3000 rpm for 30 min. Supernatant volume (V2) was measured and OAC was calculated as (V1-V2) per gram of sample, expressed as g/100g.

Sensory Evaluation

Three sorghum pop genotype were evaluated by 15 semi-trained panelists using a 9-point hedonic scale (1 = dislike extremely, 9 = like extremely). Attributes assessed were appearance, color, texture, taste, flavor, mouth adhesiveness and over acceptability. Evaluation was conducted at sensory lab, PGRC, Rajendranagar. Data were statistically analyzed to identify the most acceptable genotype. Acceptability index was calculated by using following formula.

$$\text{Acceptability Index (\%)} = \frac{\text{Mean score obtained for product}}{\text{Highest score possible on the scale}} \times 100$$

Proximate Analysis

Moisture, ash, crude fat, crude protein, crude fiber, carbohydrate and energy of popped sorghum were determined using standard AOAC methods (AOAC, 2016). Moisture content was estimated by hot-air oven drying at 105℃ to constant weight. Ash was determined by incineration in a muffle furnace at 550℃. Crude fat was extracted using Soxhlet apparatus with petroleum ether. Crude protein was estimated by micro-Kjeldhal method (N × 6.25). Crude fiber was determined by sequential acid-alkali digestion. Carbohydrate was calculated by difference and energy value was computed using Atwater factors. All analyses were done in triplicate.

Total Phenolic Content (TPC)

Extracts were prepared by cold macerating 2.0 g sorghum pop sample in 100 ml methanol for 24 h, followed by centrifugation (3000 rpm, 10 min) and filtration. For analysis, 1.5 ml diluted extract was mixed with 0.5 ml of 50% Folin-Ciocalteu reagent and 10 ml of 7.5% Na_2CO_3, then incubated at 37℃ for 1 h. Absorbance was measured at 750mm. TPC was calculated in triplicate using a gallic acid calibration curve and expressed as mg GAE/g extract.

Tannin content

Tannins were extracted by boiling 0.5g powdered sorghum pop sample in 75 ml water for 30 min, centrifuged (2000 rpm, 20 min) and diluted to 100 ml. for analysis, 1 ml extract was mixed with 75 ml water, 5 ml Folin-Denis reagent and 10 ml Na_2CO_3, then made to 100 ml. After 30 min, absorbance was read at 700 nm against a water blank. Tannin concentration was determined using a 0-100 µg tannic acid standard curve (Sadasivam and Manickam, 2018).

Statistical analysis

The results of various physical and chemical measurements of popped-sorghum quality were analyzed. The Analysis of Variance was calculated using the standard ANOVA procedure. The analysis of variance revealed significance at a $p < 0.05$ level. The standard error (SE) and critical difference (CD) at the 5% level were mentioned where required.

Results and Discussion

Table 1: Color parameters of the popped-sorghum genotypes

Genotype	L*	a*	b*	C	Hue angle (h°)
RSP	34.58 ± 0.85[a]	0.45 ± 0.00[a]	0.89 ± 0.00[a]	0.99 ± 0.00[a]	63.18[a]
YSP	33.20 ± 0.00[a]	0.40 ± 0.00[a]	0.79 ± 0.00[a]	0.79 ± 0.00[a]	87.10[a]
WSP	35.98 ± 1.55[a]	0.20 ± 0.00[a]	0.98 ± 0.00[a]	0.98 ± 0.00[a]	88.83[a]
P value	NS (0.205)	NS (1.0)	NS (1.00)[a]	NS (1.00)	NS (1.00)

Note: values are expressed as mean ± standard deviation of three determinants. Means with a column followed by a common letter do not differ significantly at ($p < 0.05$)

RSP: red sorghum pops, YSP: yellow sorghum pops, WSP: white sorghum pops

NS = Not significant ($p>0.05$)

Color of popped-sorghum was measured using Hunter LAB parameters: L* for lightness, a* for redness and b* for yellowness, along with Chroma and Hue. No significant differences ($p > 0.05$) were found among RSP, YSP and WSP. L* values varied slightly from 33.20 in YSP to 35.98 in WSP, while a* and b* values remained low and uniform across genotypes. Despite distinct pigmentation in raw grains, the popped products showed similar color. This is likely because popping exposes the pale starchy endosperm, masking the colored pericarp. This phenomenon of color homogenization upon thermal expansion has been documented in other pigmented grains. In agreement with previous findings that L*, a* and b* values of popped sorghum do not differ significantly across genotypes with varying pericarp color (Mishra *et al.*, 2014; Sharanagat *et al.*, 2019), the present study confirms that raw grain color exerts negligible influence on the appearance of the popped product, supporting consistent visual quality for commercial use.

Texture analysis

Texture is a key quality attribute that influences consumer acceptance of expanded snacks. The texture profile analysis of popped-sorghum genotypes revealed genotype-dependent variation in hardness, fracturability and adhesiveness, which define differences in mouthfeel and crunchiness. The textural profile of the popped-sorghum genotypes is detailed in Table 2.

Table 2: The textural characteristics of popped-sorghum genotypes

Genotype	Hardness (g)	Fracturability (g)	Deformation at hardness (mm)	Peak stress (N/m^2)	Adhesiveness (g.mm)	Resilience
RSP	3564± 106[a]	2804 ± 624[a]	4.93 ±0.00[a]	25138[a]	717.5 ± 146[a]	0.08 ± 0.01[a]
YSP	3700 ± 0[a]	3943 ± 242[a]	5.00 ± 0.00[a]	34091[a]	829.5 ± 69.5[a]	0.07 ± 0.00[a]
WSP	2025± 165[a]	3720 ± 40[a]	5.00 ± 0.00[a]	32513[a]	857.5 ± 152.5[a]	0.06 ± 0.02[a]
P value	NS (0.52)	NS (0.23)	<0.005	NS(0.30)	NS(0.74)	NS(0.66)
CD at 5%	6009	2027.64	0.01	19481.16	769.58	0.106
CV%	45.10%	13.50%	0.08%	14.80%	22.31%	33.86%

Note: values are expressed as mean ± standard deviation of three determinants. Means with a column followed by a common letter do not differ significantly at ($p < 0.05$)

RSP: red sorghum pops, YSP: yellow sorghum pops, WSP: white sorghum pops

NS = Not significant ($p>0.05$)

Significant difference in hardness were observed among the three sorghum genotypes. YSP recorded the highest hardness (3700 g) and peak stress (3943 ± 242 g), reflecting a dense, rigid endosperm that gives a firm, crunchy bite. This is higher than reported hardness for HTST-popped sorghum of ~1734 g (Nakade *et al.*, 2020) and microwave-puffed sorghum of 1620.7 g (Pawar *et al.*, 2014), indicating cultivar-specific differences in expansion behavior. In contrast, WSP had the lowest hardness (2025 ± 165 g) but high fracturability (3720 ± 40 g) and the greatest adhesiveness (857.5 ± 152.5 g.mm), indicating a porous structure with a softer, tender mouthfeel. RSP showed intermediate hardness (3563 ± 106 g) with the lowest peak stress (25,138 N/m²) and fracturability (2804 ± 624 g), suggesting a less brittle texture.

Deformation at hardness was similar across genotypes (~5.0 mm), pointing to a common yield point despite internal differences, consistent with brittle fracture behavior in expanded cereals. All samples had low resilience (0.060-0.085), typical of expanded starch matrices that deform irreversibly due to disruption of the starch-protein matrix during dry-heat treatment (Thermo-mechanical pre-treatments study, 2025). Based on texture, YSP suits consumers who prefer crunchiness, WSP fits those who like softer snacks and RSP provides a balance for product diversification.

Physical properties

Bulk and true density determine the lightness, texture and storage behavior of popped snacks. Analysis of sorghum pops showed clear genotypic differences in bulk density, while true density remained statistically similar despite numerical variation.

Table 3: Physical properties of different popped-sorghum genotypes

Genotype	Bulk density(g/ml)	True density(g/ml)
RSP	0.05 ± 0.05[b]	0.16 ± 0.00[a]
YSP	0.07 ± 0.07[a]	0.28 ± 0.02[a]
WSP	0.05 ± 0.00[b]	0.15 ± 0.05[a]
P Value	<0.05	NS (0.09)
CD at 5%	0.008	0.134
CV%	5.933%	29.322%

Note: values are expressed as mean ± standard deviation of three determinants. Means with a column followed by a common letter do not differ significantly at ($p < 0.05$)

RSP: red sorghum pops, YSP: yellow sorghum pops, WSP: white sorghum pops

NS = Not significant ($p>0.05$)

Bulk density differed significantly among genotypes ($p < 0.05$). YSP recorded the highest value (0.07 g/ml) and RSP the lowest (0.05 g/ml; CD = 0.008), with low CV (5.93%) confirming data consistency. True density ranged from 0.15 g/ml in WSP to 0.28 g/ ml in YSP but was not statistically different ($p = 0.09$) due to high variability (CV = 29.32%). All values were much lower than raw sorghum grains (~0.70-0.75 g/ml), indicating successful expansion during popping. The porous matrix formed by starch gelatinization explains this density reduction. Variation in bulk density likely reflects differences in endosperm structure and packing, while high porosity in popped in popped samples accounts for the non-significant true density results (Mishra *et al.*, 2014). These values are comparable to popped sorghum reported by Mishra *et al.*, 2014 and Sharma *et al.*, (2014)

Popping parameters

Popping ratio, expansion ratio and popping capacity are critical indicators of process efficiency and end-product quality in expanded snacks. Table 4 data show genotype-specific trends in behavior of RSP, YSP and WSP.

Table 4: Popping parameters of popped-sorghum

Genotype	Popped ratio	Expansion ratio	Popping capacity (%)		
			Popped	Semi-popped	Unpopped
RSP	0.89 ± 0.12[a]	19.50 ± 0.48[a]	58.67±0.33[ab]	26.67±0.88[a]	15.00±1.15[a]
YSP	0.81±0.00[a]	17.03±0.64[a]	55.33±0.88[b]	27.33±0.88[a]	17.00±1.73[a]
WSP	0.85±0.01[a]	18.45±0.51[a]	59.67±0.33[a]	24.67±0.88[a]	15.67±2.19[a]
P value	NS (0.07)	NS(0.108)	<0.05	<0.05	NS (0.072)
CD at 5%	0.063	2.418	3.42	2.72	5.20
CV%	3.294%	5.822%	2.836%	5.251%	16.948%

Note: values are expressed as mean ± standard deviation of three determinants. Means with a column followed by a common letter do not differ significantly at ($p < 0.05$)

RSP: red sorghum pops, YSP: yellow sorghum pops, WSP: white sorghum pops

NS = Not significant ($p>0.05$)

Popped ratio and expansion ratio did not vary significantly among genotypes ($p > 0.05$), though RSP showed the highest values (0.89 ± 0.12; 19.50 ± 0.48) and YSP the lowest (0.8167±0.00; 17.03±0.64). Popping capacity differed significantly ($P < 0.05$). WSP gave the most fully popped kernels (59.67 ± 0.33) and fewer semi-popped grains, while YSP had the lowest popped yield (55.33±0.88) and most unpopped kernels (17.00±1.73). The poorer performance of YSP likely relates to a denser endosperm that limits steam buildup and starch expansion during popping (Mishra *et al.*, 2014;

Rooney, 2016). High CV% for unpopped kernels (16.95%) reflects common variability in sorghum popping due to kernel heterogeneity (Gomez and Gomez, 1984). WSP is best suited for commercial popping based on higher yield. These values are in identical with the reports published by Sharanagat *et al.*, (2019).

Functional parameters

Functional properties like water and oil binding influence how popped sorghum behaves in food formulations. Testing of WAC, WSI and OAC across genotypes showed no significant differences ($p > 0.05$), suggesting similar processing potential.

Table 5: Functional parameters of popped-sorghum

Genotype	Water absorption capacity (g/100g)	Water solubility index (%)	Oil absorption capacity (g/100g)
RSP	569.4±1.5 ^{a}	161.7±6.8^{a}	155.6±6^{a}
YSP	529.7±36.8^{a}	143.9±7.6^{a}	173.0±38.6^{a}
WSP	480±40.2^{a}	171±7.8^{a}	190.5±12.2^{a}
P Value	NS(0.34)	NS (0.199)	NS (0.677)
CD at 5%	146.85	35.29232	104.490
CV%	12.306%	9.780%	26.640%

Note: values are expressed as mean ± standard deviation of three determinants. Means with a column followed by a common letter do not differ significantly at ($p < 0.05$)
RSP: red sorghum pops, YSP: yellow sorghum pops, WSP: white sorghum pops
NS = Not significant ($p>0.05$)

Water Absorption Capacity varied from 480 ± 40.2% in WSP to 569.4±1.5% in RSP, indicating uniformly high hydration ability linked to starch-protein structure (Kaur and Singh, 2007). These values are comparable to WAI of 397.57% reported for popped sorghum (Sharma *et al.*, 2014) Water Solubility Index ranged between 143.9±7.6% for YSP and 171±7.8% for WSP, pointing to comparable starch stability (Abiodun and Adepeju, 2011). Oil Absorption Capacity was 155.6 ± 6% to 190.5±12.2%, though high CV (26.64%) showed more variability (Aremu *et al.*, 2006). The lack of statistical differences means these genotypes can be used interchangeably in products needing moisture retention or oil binding, allowing selection based on agronomic or color traits instead (Elkhalifa *et al.*, 2005).

Proximate composition

Proximate analysis determines the macronutrient quality and storage stability of popped snacks.

Table 6: Proximate composition of popped-sorghum

Genotype	Moisture (%)	Ash (g/100g)	Fat (g/100 g)	Crude fiber (g/100g)	Protein (g/100 g)	Carbohydrates (g/100g)	Energy (kcal/100g)
RSP	5.78±0.34^{a}	1.86±0.17^{a}	5.62±0.54^{a}	3.43±0.20^{a}	11.4±0.78^{a}	75.09±0.59^{b}	393.1±7.9
YSP	5.64±0.8^{a}	1.43±0.08^{a}	3.40±0.2^{b}	3.13±0.41^{a}	10.2±0.17^{ab}	79.31±0.61^{a}	388.4±3.9
YSP	6.19±0.2^{a}	1.50±0.11^{a}	3.30±0.1^{b}	3.08±0.19^{a}	9.53±0.37^{b}	79.47±0.46^{a}	385.7±1.4
P Value	NS (0.78)	NS (0.12)	<0.05	NS (0.51)	<0.05	<0.05	NS (0.64)
CD at 5%	2.24	0.47	1.48	0.83	1.39	2.63	21.06
CV%	16.83 %	13.01 %	15.93 %	11.54 %	5.92 %	1.492 %	2.38 %

Note: values are expressed as mean ± standard deviation of three determinants. Means with a column followed by a common letter do not differ significantly at ($p < 0.05$)
RSP: red sorghum pops, YSP: yellow sorghum pops, WSP: white sorghum pops
NS = Not significant ($p>0.05$)

Results showed significant genotypic differences in fat, protein and carbohydrates, while moisture, ash, fiber and energy remained uniform. Crude fat and protein varied significantly ($p < 0.05$). RSP had the highest fat (5.62%) and protein (11.40%), giving it greater nutrient density for fortification (Taylor and Duodu, 2015). WSP and YSP were richer in carbohydrates (79.47% and 79.31%; $p < 0.05$), making them better energy sources (Gomez *et al.*, 1997). Moisture (5.64-6.19%), ash (1.43-1.87%), fiber (3.09-3.43%) and energy (385.7-393.1 kcal/100g) did not differ ($p > 0.05$). All samples had safe moisture for storage (IFCT, 2017) and fiber > 3% for dietary benefit (FAO, 1995). Similar energy values suggest higher fat/protein in RSP offsets its lower carbohydrates. Low CV % for carbohydrates (1.49%) and energy (2.39%) confirmed reliability and are in the ranges studied by Tasie and Gebreyes, 2020.

Phytonutrients

Phenolic compounds and tannins affect both nutritional value and sensory quality of sorghum pops.

Table 7: Phytonutrient composition in popped-sorghum

Genotype	Phenols (mg GAE/g)	Tannins (mg/g)
RSP	31.61±1.63[a]	25.18±0.37[a]
YSP	19.93±0.23[b]	23.74±0.35[a]
WSP	17.09±0.19[b]	22.90±0.50[a]
P Value	<0.005	NS (0.06)
CD at 5%	3.94	1.88
CV%	7.61%	3.47%

Note: values are expressed as mean ± standard deviation of three determinants. Means with a column followed by a common letter do not differ significantly at ($p < 0.05$)
RSP: red sorghum pops, YSP: yellow sorghum pops, WSP: white sorghum pops
NS = Not significant ($p>0.05$)

Analysis revealed clear genotypic differences in phenols but in tannins. Total phenolic content differed significantly ($p < 0.005$). RSP had the highest level (31.61±1.63 mg GAE/g), followed by YSP (19.93 ± 0.23) and WSP (17.09 ± 0.19; CD = 3.946). Higher phenols in the red genotype align with pigmentation-related antioxidant accumulation reported in darker sorghum types (Dykes et al., 2005; Bravo, 1998). Tannin content showed no significant variation (P = 0.06), ranging from 22.90±0.50 to 25.18±0.37 mg/g with low CV (3.48%). This suggests RSP provides greater antioxidant potential without raising antinutritional tannins that affect protein digestibility (Salunkhe *et al.*, 1990).

Sensory Evaluation of popped-sorghum genotypes

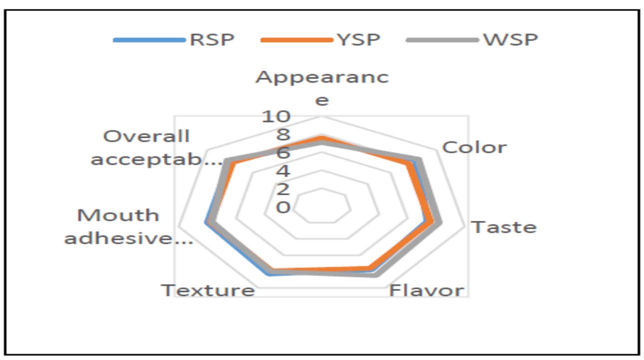

Fig. 1 : Sensory profile of popped red sorghum (RSP), yellow sorghum (YSP) and white sorghum (WSP) as evaluated by consumer panelists (n = 15). Data represent mean scores on 9-point hedonic scale.

Sensory evaluation using a 9-point hedonic scale revealed acceptable scores (> 7.0) for all popped sorghum genotypes across attributes. WSP recorded the highest scores for color (8.2), taste (8.3) and flavor (8.5), resulting in the greatest overall acceptability. RSP was rated highest for texture (8.5) and mouth adhesiveness (7.8), while YSP scored highest for appearance (7.8). Despite having the highest instrumental hardness, YSP received lower taste and flavor scores, suggesting scores (7.5-7.8) indicates all genotypes are marketable, but WSP is most suitable for commercial popping targeting flavor preference, whereas RSP offers a balance of texture and taste for product diversification (De Aguiar *et al.*, 2021)

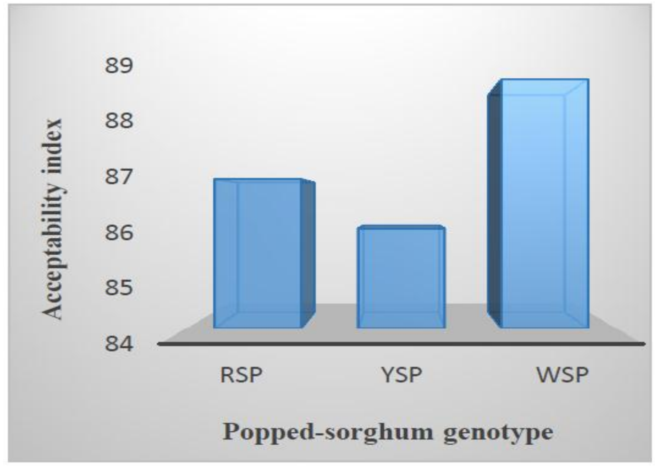

Fig. 2 : Acceptability index (%) of popped red sorghum (RSP), yellow sorghum (YSP) and white sorghum (WSP).

The acceptability index of popped-sorghum genotypes is presented in Figure 2. WSP recorded the highest acceptability index (88.8%), followed by RSP (87.0%) and YSP (86.2%). Although all genotypes showed high acceptance with indices > 85%, WSP was most preferred by panelists. The higher acceptability of WSP may be attributed to its lighter color, bland flavor and absence of tannins, which are known to impart bitterness and astringency in pigmented sorghums. This aligns with previous reports that white sorghum varieties are generally preferred for direct consumption and value-added products due to superior sensory appeal (Rooney *et al.*, 2000).

Conclusion

This study found that sorghum type really matters when making popped snacks. The genotype affected popping quality, nutrient levels and antioxidant content, but didn't change much in terms of functional behavior or taste texture. Among the three white sorghum popped the best and scored highest in taste tests. That makes it a good choice for commercial pops where crunch and flavor are key. RSP stood out nutritionally- it had more protein, fat and phenolic compounds, yet no extra tannins. So it works well for healthier, antioxidant-rich snacks. Yellow sorghum was in the middle: decent popping and balanced carbohydrates, making it a solid all-rounder. Interestingly, all three types absorbed water and oil about the same way. That means food makers can switch genotypes based on what they want better taste, more nutrition or higher antioxidants without worrying about how the pops will behave during processing. This can help companies create more kinds of ready-to-eat sorghum snacks and guide plant breeders to develop varieties specifically for popping.

Acknowledgement

The authors thank Honourable Vice Chancellor of Professor Jayashankar Telangana Agricultural University, Rajendranagar, Hyderabad for his encouragement.

References

Abiodun, O. A. and Adepeju, A. B. (2011). Functional properties of sorghum-based composite flours. *Journal of Food Science and Technology*, **48**(6), 711-715.

Aremu, M. O., Olaofe, O. and Akintayo, E. T. (2006). Functional properties of some Nigerian varieties of legume seed flours. *International Journal of Food Science & Technology*, **41**(3), 263-268.

Association of Official Analytical Chemists (AOAC) (2016). *Official Methods of Analysis* (20th ed.). AOAC International, Rockville, MD, USA.

Awika, J. M. and Rooney, L. W. (2004). Sorghum phytochemicals and their potential impact on human health. *Phytochemistry*, **65**(9), 1199-1221.

Bravo, L. (1998). Polyphenols: Chemistry, dietary sources, metabolism, and nutritional significance. *Nutrition Reviews*, **56**(11), 317-333.

De Aguiar LM, Rodrigues DS, Queiroz VAV, Melo L, Pineli LLO. 2021. Effects of white sorghum flour levels on physicochemical and sensory characteristics of gluten-free bread. Foods 10(9): 2192

Duodu, K. G., Taylor, J. R. N., Belton, P. S. and Hamaker, B. R. (2003). Factors affecting sorghum protein digestibility. *Journal of Cereal Science*, **38**(2), 117-131.

Dykes, L., Rooney, L. W., Waniska, R. D. and Rooney, W. L. (2005). Phenolic compounds and antioxidant activity of sorghum grains of varying genotypes. *Journal of Agricultural and Food Chemistry*, **53**(17), 6813-6818.

Elkhalifa, A. E. O., Bernhardt, R., Bonomi, F., Iametti, S., Pagani, M. A. and Zardi, M. (2005). Functional properties of sorghum-based flours. *Food Chemistry*, **92**(4), 757-763.

FAO (1995). *Dietary fibre: Definition and analysis*. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO (2023). *Sorghum and millets: Climate-resilient crops*. Food and Agriculture Organization of the United Nations, Rome, Italy.

Gomez, K. A. and Gomez, A. A. (1984). *Statistical Procedures for Agricultural Research* (2nd ed.). John Wiley & Sons, New York, USA.

Gomez, M. I., Obilana, A. B., Martin, D. F., Madzvamuse, M. and Monyo, E. S. (1997). *Manual of laboratory procedures for quality evaluation of sorghum and pearl millet*. ICRISAT, Patancheru, India.

ICAR-IIMR (2023). *International Year of Millets 2023 report*. ICAR-Indian Institute of Millets Research, Hyderabad, India.

IFCT (2017). *Indian Food Composition Tables*. National Institute of Nutrition, Indian Council of Medical Research, Hyderabad, India.

Kaur, M. and Singh, N. (2007). Studies on functional, thermal and pasting properties of flours from different legumes. *Food Chemistry*, **101**(3), 1034-1041.

Lopes, C., et al. (2023). Effects of thermal processing on antioxidant bioaccessibility in cereal grains. *Journal of Food Composition and Analysis*, **115**, 1049-1055.

Maisont, S., Suriya, W. and Saetan, S. (2021). Texture profile analysis of expanded snack products. *International Journal of Food Engineering*, **17**(4), 285-294.

Mishra, G., Joshi, D. C. and Panda, B. K. (2015). Popping and puffing of cereal grains: A review. *Journal of Grain Processing and Storage*, **2**(1), 1-12.

Mishra, G., Joshi, D. C., Panda, B. K. and Mohapatra, D. (2014). Popping characteristics of sorghum genotypes. *Journal of Food Science and Technology*, **51**(11), 3400-3406.

Nakade, P., Joshi, D. C. and Mishra, G. (2020). Optimization of HTST popping parameters for sorghum grains. *Journal of Agricultural Engineering*, **57**(3), 215-224.

Pathare, P. B., Opara, U. L. and Al-Said, F. A. (2012). Colour measurement and analysis in fresh and processed foods: A review. *Food and Bioprocess Technology*, **6**(1), 36-60.

Pawar, V. D., Patil, S. S. and Machewad, G. M. (2014). Microwave puffing of sorghum grains. *Journal of Ready-to-Eat Foods*, **1**(2), 45-51.

Pontieri, P., Del Giudice, A. and Mamone, G. (2021). Sorghum: A potential source of nutraceuticals. *Journal of Functional Foods*, **83**, 104-112.

Rooney, L. W. and Waniska, R. D. (2000). Sorghum food and industrial utilization. In: C. W. Smith and R. A. Frederiksen (Eds.), *Sorghum: Origin, History, Technology, and Production*. John Wiley & Sons, New York, USA, pp. 689-729.

Rooney, W. L. (2016). Sorghum genotype and grain quality interactions. *Cereal Foods World*, **61**(4), 145-152.

Rybak-Chmielewska, H. (2003). Methods for evaluating physical properties of cereal grains. *Journal of Apicultural Science*, **47**(1), 85-92.

Saballos, A. (2008). Development and utilization of sorghum as a bioenergy crop. In: W. Vermerris (Ed.), *Genetic Improvement of Bioenergy Crops*. Springer, New York, USA, pp. 211-248.

Sadasivam, S. and Manickam, A. (2018). *Biochemical Methods* (4th ed.). New Age International Publishers, New Delhi, India.

Sairam, S., Gopala Krishna, A. G. and Urooj, A. (2011). Functional and physicochemical properties of cereal flours. *Journal of Food Science and Technology*, **48**(4), 498-504.

Salunkhe, D. K., Chavan, J. K. and Kadam, S. S. (1990). *Dietary Tannins: Consequences and Remedies*. CRC Press, Boca Raton, FL, USA.

Shahabi, M., et al. (2014). Color measurement methods for processed cereal products. *Journal of Food Quality*, **37**(3), 189-198.

Sharanagat, V. S., Suri, S., Kumar, A., Singh, L., Mann, S. and Nema, P. K. (2019). Physico-chemical, functional and sensory characterization of sorghum. *Journal of Food Science and Technology*, **56**(3), 1211-1221.

Sharma, S., Bhat, J. I. and Riar, C. S. (2004). Functional properties of cereal grains. *Journal of Agricultural Sciences*, **12**(2), 89-97.

Sharma, S., Saxena, D. C. and Riar, C. S. (2014). Functional and physicochemical properties of popped sorghum. *International Journal of Food Properties*, **17**(7), 1502-1515.

Singh, A., Sharma, S. and Singh, B. (2022). Ready-to-eat snack development from millets: Trends and opportunities. *Critical Reviews in Food Science and Nutrition*, **62**(14), 3891-3907.

Svegrova, A., Mickova, K. and Pribyl, J. (2016). Gluten-free cereals and consumer health trends. *Czech Journal of Food Sciences*, **34**(5), 412-420.

Tasie MM, Gebreyes BG. 2020. Characterization of nutritional, antinutritional, and mineral contents of thirty-five sorghum varieties grown in Ethiopia. Food Sci Nutr 8(9): 4784-4795.

Taylor, J. R. N. and Duodu, K. G. (2015). Effects of processing sorghum and millets on their phenolic phytochemicals and the implications of this to the health-enhancing properties of sorghum and millet food and beverage products. *Journal of the Science of Food and Agriculture*, **95**(2), 225-237.

Tran, T. L., Vidal-Valverde, C. and Hawkins, W. E. (1999). Popping characteristics of cereal grains. *Cereal Chemistry*, **76**(5), 623-629.