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Roasted Sorghum and Flower Powder-Enriched Edible Cutlery: Evaluating Nutritional, Sensory, and Textural Properties as a Sustainable Alternative to Single-Use Cutlery

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ABSTRACT

Background: The widespread use of disposable cutlery, driven by rapid industrialization and population growth, has led to an escalation of solid waste and environmental damage. The research projects a sustainable solution: edible sorghum-based cutlery enriched with roasting the millet and antioxidant-rich flower incorporation providing an eco-friendly alternative to single-use plastic cutlery. **Methods:** Proximate analysis was used and antinutritional factor and antioxidant activity of sorghum cutlery were investigated through standardized procedures. Sensory evaluation was done by 30 semi-trained panelists, on a nine-point hedonic scale, while texture analysis was performed using a Shimadzu EZ-XS texture analyzer. To assess structural integrity, the cutlery was subjected to 29 °C, 80 °C, and 4 °C, and shelf life stability by monitoring changes in microbial count and weight over 120 days. **Results:** The sorghum cutlery, circular shaped, 10 cm x 2 cm x 2 mm (diameter, height, thickness), with a weight of 18 g, showed significant results in optical, sensory, and functional properties when hibiscus and rose flower powders were incorporated. Edible flowers and Roasted Sorghum Cutlery (SRK) resulted in enhanced antioxidant activity. Cutlery withstands cold and dry food for 60 minutes and hot food or beverages for 45 minutes without losing structural integrity. It demonstrated microbial stability with a shelf life of up to 120 days, maintaining a total plate count of 10-12 x 10^1 CFU/g. **Conclusion:** The sorghum edible cutlery provides a nutritious and eco-friendly alternative to plastic cutlery, meeting the increasing consumer demand for sustainable and less toxic food packaging solutions. Their adoption in food industry could significantly reduce plastic waste and promote environmentally responsible consumption practices.

Introduction

Plastic pollution is a significant global issue, with over 380 million tons of plastic produced annually, only about 9% of this material is recycled (Moshood *et al.*, 2022). Single-use plastics, account for nearly 40% of this production, and contribute around 8 million tons of waste to oceans yearly, harming marine life, ecosystems, and human health (Kibria *et al.*, 2023, Kumar *et al.*, 2021). This pollution threatens ecosystem services, with microplastics even found in drinking water and food chains, posing significant health risks and impeding the achievement of several sustainable

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development goals (SDGs). Although biodegradable plastics offer an alternative, their specific degradation conditions, and high production costs make them less effective in combating plastic pollution (Moshood *et al.*, 2022). These challenges emphasize the urgency for sustainable solutions (Kumar *et al.*, 2021). Consequently, there is a rising interest in sustainable, affordable, and eco-friendly packaging solutions such as edible and compostable materials (Kibria *et al.*, 2023, Moshood *et al.*, 2022).

Edible containers and cutlery are gaining traction, reducing plastic waste while promoting health and entrepreneurship (Chowdhury *et al.*, 2021, Kabir *et al.*, 2022, Narvekar, 2022). Edible cutlery made from millets, cereals, soy protein isolate, brewers' spent grain, and fruit peels has been successfully developed using traditional baking methods (Choeybundit *et al.*, 2022, Jaspal *et al.*, 2024, Nehra *et al.*, 2024, Wulandari *et al.*, 2023). Innovations like sorghum-based edible cutlery provide a nutritious, non-toxic, and sustainable alternative to plastic, meeting the growing consumer demand for eco-friendly products. Sorghum (*Sorghum bicolor L.* Moench), known for its resilience to temperature and water stress, low production costs, and high net revenue potential, is emerging as a sustainable crop for future food systems (Hossain *et al.*, 2022, Stamenković *et al.*, 2020, Teferra and Awika, 2019). It is rich in health-promoting phytochemicals such as phytosterols, policosanols, phenolic compounds, and bioactive substances, offering protective benefits against chronic diseases (Khoddami *et al.*, 2023, Teferra and Awika, 2019). Sorghum flour can replace wheat in various food products like bread, cookies, and noodles, making it versatile. Roasting sorghum further enhances its nutritional profile, flavour, and sensory attributes, making it ideal for edible packaging, especially in cutlery applications (Batariuc *et al.*, 2023). Roasting helps reduce antinutritional factors and enhance mineral bioavailability (Meena *et al.*, 2024) by inactivating heat-labile antinutritional compounds (Sharanagat *et al.*, 2024). In sorghum, roasting leads to an increase in ash, carbohydrate, iron, calcium, and protein content, while fat and dietary fiber decrease due to chemical composition changes (Latha Ravi and Rana, 2024, Manivel *et al.*, 2025).

This research focuses on the formulation and standardization of sorghum cutlery, enhanced by roasting sorghum and the incorporation of antioxidant-rich edible flower powders like hibiscus (*Hibiscus rosa-sinensis* L.) and rose (*Rosa damascena* Mill.). Despite growing interest in sustainable alternatives, the integration of edible flowers and roasting of sorghum into edible, eco-friendly cutlery has yet to be investigated, presenting a significant avenue for research. Incorporating functional ingredients enhances the properties of cutlery, aligning with eco-innovation and health trends by offering aesthetic, sensory, and health benefits (Srivastava and Siddiqui). Hibiscus, known for its anti-inflammatory, antibacterial, and circulatory-boosting properties, and rose, renowned for its antioxidant-rich phenolic compounds like quercetin and epicatechin, add therapeutic and dietary value (Hegde *et al.*, 2022, Ngan *et al.*, 2021, Rengarajan *et al.*, 2020). The novelty of this research lies in the formulation and standardization of sorghum edible cutlery, enhanced through roasting the sorghum and the incorporation of shade dried, antioxidant-rich flower powder, such as hibiscus and rose. This approach amplifies the aesthetic, sensory, and health benefits and offers a sustainable, eco-friendly alternative to single-use plastics in various sectors.

Materials and Methods

Selection and processing of raw materials

Sorghum grains were sourced from a local departmental store and were cleaned, sorted, and milled to prepare them for further processing. Edible flowers, specifically hibiscus (*Hibiscus rosa-sinensis*) and rose (*Rosa damascena*), were chosen for their potential to enhance the nutritive value, antioxidant activity, palatability, appearance, and functional properties of the sorghum cutlery. The flowers were collected from farms in Karur district, Tamil Nadu during the first quarter of

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2023. The petals were carefully separated, shade-dried for 48 hours at room temperature, and kept in airtight containers.

Standardization and formulation of sorghum cutlery

The formulation of sorghum cutlery involved experimenting with various ratios to achieve the optimal structure and temperature tolerance. The final standardized cutlery consisted of 14 grams of unprocessed or roasted sorghum flour, 3 grams of wheat flour, and 3 grams of jaggery, with jaggery serving as a flavour and wheat flour acting as a binder. Additionally, 3 g of edible flower powder was incorporated into sorghum cutlery to enhance its antioxidant and functional properties. The cutlery was baked using a circular mold in an eco-friendly cutlery-making machine at 80 °C for 12 minutes at 1500 psi hydraulic pressure (**Figure 1**). Increasing the amount of wheat flour in edible cups enhances structural sturdiness and utility (Matheswari and Arivuchudar, 2024). The final products were coded as Unprocessed Sorghum Cutlery (SUK), Unprocessed Sorghum Hibiscus Incorporated Cutlery (SUHK), Unprocessed Sorghum Rose incorporated Cutlery (SURK), Roasted Sorghum Cutlery (SRK), Roasted Sorghum Hibiscus Incorporated Cutlery (SRHK), and Roasted Sorghum Rose incorporated Cutlery (SRRK (**Figure 2**).

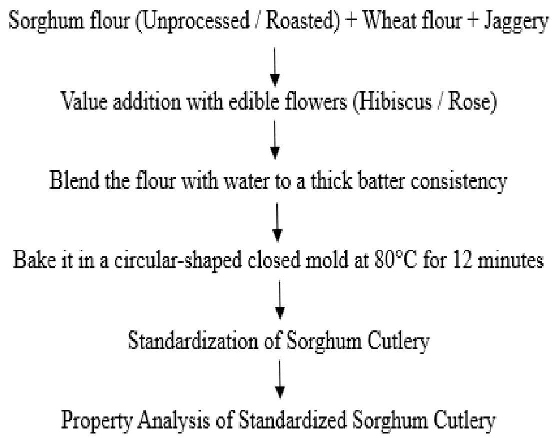

Figure 1. Flowchart of sorghum cutlery standardization.

Physical and optical properties of sorghum cutlery

Physical properties such as height, weight, length, and thickness of sorghum cutlery were measured using a vernier caliper (Mitutoyo, with 0.02 mm calibration). Optical properties were analyzed using a laboratory-scale food color reader. L* value indicates lightness, while a* and b* values denote red-green and yellow-blue color spectrums, respectively and ΔE measures the overall color difference (Devatha and Raajeswari, 2023, Hernández-Nava *et al.*, 2023, Yodkum and Yokesahachart, 2024)

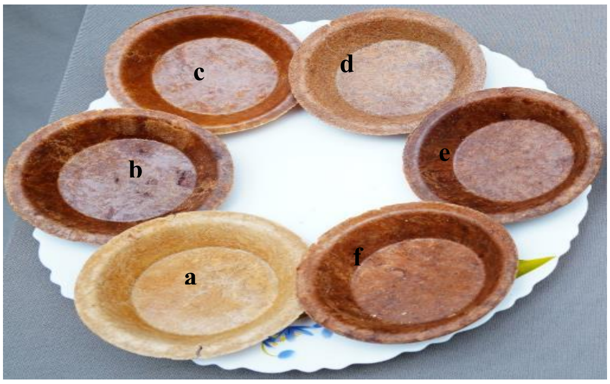

Figure 2. a: SUK, b: SUHK, c: SURK, d: SRK, e: SRHK, f: SRRK.

Nutrient analysis of sorghum cutlery

Nutrient analysis was performed using standard procedures, moisture, ash, protein, fat, and crude fiber by AOAC standards, while the anthrone method determined carbohydrates. Vitamin C, iron, calcium, and phosphorus were quantified using ascorbic acid volumetric method, Folin-Ciocalteu reagent method, and titration with $KMnO_4$ (Cunniff and Washington, 1997, Sadasivam, 1992).

Antioxidant activity of sorghum cutlery

Antioxidant activity was assessed using 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging assay. IC50 values, representing the concentration required to inhibit 50% of DPPH radicals, were determined through linear regression. Antioxidant potency was categorized as strong (IC50 between 10 and 50 mg/ml), moderate (IC50 between 50 and 100 mg/ml), or weak (IC50 above 100 mg/ml) (Salamatullah *et al.*, 2024).

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Total phenolic content of sorghum cutlery

Total phenolic content of the sample was measured by Folin-Ciocalteu reagent method (Sadasivam, 1992).

Antinutritional factors of sorghum cutlery

Antinutritional factors, including tannins, and phytic acid levels, were measured using standard methods: tannins by Folin-Denis spectrophotometric method, and phytic acid via spectrophotometry calibrated against ferric nitrate (Sadasivam, 1992).

Sensory evaluation of sorghum cutlery

Sensory evaluation was conducted using a nine-point hedonic scale, where 30 semi-trained panelists rated attributes such as appearance, color, taste, flavor, texture, and overall acceptability. Scores ranged from 1 (dislike extremely) to 9 (like extremely) to provide valuable insights into consumer preferences to refine future formulations (Hnin *et al.*, 2021).

Exposure test and drop test of sorghum cutlery

To test durability, sorghum cutlery samples were subjected to different temperature conditions: ambient (29 °C), hot (80 °C), and cold (4 °C), simulating typical usage in food industry. The cutlery was kept in these conditions for one hour to observe temperature stabilization. A drop test was conducted from 10 to 150 cm heights to evaluate the resistance to accidental falls (Devatha and Raajeswari, 2023, Wulandari *et al.*, 2023).

Texture analysis of sorghum cutlery

The textural properties, specifically hardness and break force, were evaluated using a texture analyzer (Shimadzu EZ-SX) equipped with a 36 mm diameter cylindrical jig, employing a three-point bending test. The test recorded force (N) against displacement (mm) to create a force-displacement curve. Hardness force indicates the maximum pressure required for compression, while elasticity measures the ability to deform and recover (Devatha and Raajeswari, 2023, Razack *et al.*, 2020).

Shelf life analysis of sorghum cutlery

The shelf life was evaluated through total plate count and weight change, over 120 days. Samples were incubated at 35 °C for 48 hours, and microbial counts were taken using serial dilutions with sterile peptone water. Weight change was monitored for 120 days to assess the cutlery response to atmospheric conditions and shelf stability (Devatha and Raajeswari, 2023, Razack *et al.*, 2020).

Ethical considerations

The study was conducted with approval from the Institutional Human Ethical Committee (AUW/IHEC/FSN-21-22/XPD-31), and the plants were authenticated by Rapinat Herbarium, St. Joseph College, Tiruchirappalli, Tamil Nadu.

Data analysis

All experiments were performed in triplicate for reliability and reproducibility. The data were analyzed for mean values and standard deviations, with a one-way analysis of variance (ANOVA) to determine significant differences among samples using SPSS Statistics Software (Version 25 IBM Corp., USA) in triplicate experiments. Duncan's multiple range test was used to compare mean values at the significance level of P-value < 0.05. Graphs and figures were plotted through Microsoft Excel (MS Excel Version 2021).

Results

Physical and optical properties of sorghum cutlery

The average weight of sorghum cutlery is 18 g, with a 2 mm thickness and a circular shape (10 cm in diameter and 2 cm in height), making it suitable for serving ice cream, snacks, and savories in food, entertainment sectors, and households. The optical properties (**Table 1**) of sorghum cutlery vary significantly in terms of lightness (L*), redness (a*), yellowness (b*), and overall color difference (ΔE). SUK has the highest lightness (19.27), indicating a lighter color, along with high yellowness (11.79) and redness (2.45), leading to the greatest overall color difference (ΔE of 15.3). In contrast, SUHK shows the darkest hue with the lowest L* (10.68) and redness (a* of 0.12), as well as the lowest ΔE (5.87), reflecting a more stable color. SURK, while having high lightness (L* of 18.51) and

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yellowness (b* of 10.39), has a lower color difference (ΔE of 13.33) than SUK. SRK shows moderate lightness (L* of 15.43) and reduced ΔE (10.86), attributed to the effects of roasting. SRHK displays intermediate lightness (L* of 12.91) and redness (a* of 1.1), with a lower ΔE (7.10), indicating greater color stability. SRRK retains high lightness (L* of 19.36) similar to SUK but with moderately lower ΔE (13.59), reflecting balanced color changes post-roasting. These findings suggested that roasting and incorporating flower powder significantly affected the optical properties of the sorghum cutlery.

Nutrient analysis of sorghum cutlery

The nutritive analysis of sorghum cutlery reveals significant differences in their nutritional content (**Table 2**). The highest moisture content was in SUHK (3.87%), while the lowest was observed in SRK (2.93%). Ash content was generally stable across samples, with minor variations. The carbohydrate content was slightly higher in roasted variants (SRHK, SRRK, 15.83 g), indicating starch gelatinization and enhanced digestibility. Protein content increased with roasting, peaking in SRHK (2.98 g), highlighting protein denaturation and improved availability. Fat content remained relatively consistent across samples. Fiber content showed minor differences, suggesting that hibiscus and rose incorporation did not significantly affect the fiber profile. The highest Vitamin C content was notably in SRRK (0.20 mg), likely due to the antioxidant properties of flowers. Iron content varied considerably, while calcium and phosphorus levels were relatively uniform across all cutlery. Roasting and flower powder incorporations enhanced certain nutritional aspects, particularly protein and vitamin C, potentially providing added health benefits. The incorporation of 3 g of edible flower powder like hibiscus and rose in sorghum cutlery was significantly similar except for phosphorous which can be increased by adding more quantity of edible flower powder.

Antioxidant activity of sorghum cutlery

The antioxidant activity of different sorghum cutlery was evaluated using DPPH scavenging, with varying effectiveness at sorghum concentrations between 10 and 750 µl (**Figure 3**). IC_{50}, the concentration of the sample required for 50% inhibition, was calculated from the percentage of inhibition. SUHK showed the highest inhibition, reaching 95.12% at 350 µl, while SRHK and SRRK also displayed strong inhibition, with IC_{50} values of 87.96 µl. SURK performed well with an IC_{50} of 87.96 µl. SUHK and SRK exhibited greater inhibition at lower concentrations (10 µl and 50 µl). Overall, the antioxidant properties improved with increasing concentration, with all samples showing excellent inhibition at 750 µl. The lower IC_{50} values of SUHK and SURK indicated superior antioxidant activity, suggesting that adding antioxidant-rich ingredients like hibiscus and rose to sorghum cutlery significantly increased their scavenging ability, enhancing both their eco-friendliness and nutritional value.

Total phenolic content of sorghum cutlery

The highest amounts of total phenols, which are beneficial antioxidants but can also act as antinutritional factors, were in SURK [80.88 mg/100 g Garlic Acid Equivalent (GAE)] and SUHK (80.61 mg/100 g GAE) and significantly lower in SRK (66.33 mg/100 g GAE). Tannins were more prevalent in SUK (8.33 mg/100 g TAE) and decreased substantially after roasting, particularly in hibiscus and rose-incorporated cutlery [3.92 mg/100 g Tannic Acid Equivalent (TAE)], likely due to heat-induced degradation. **Table 2** depicts total phenol content of sorghum cutlery.

Antinutritional factors in sorghum cutlery

Antinutritional constituents in sorghum cutlery indicated significant variations in total phenols, tannins, and phytic acid content (**Table 2**). Phytic acid, which chelates essential minerals and affects their bioavailability, was slightly higher in SURK (30.11 mg/100 g) compared to SRK (26.44 mg/100 g). The findings showed that roasting significantly reduced tannins and total phenolic content,

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enhancing the nutritional profile by lowering antinutritional factors. Hibiscus and rose incorporation contributed to higher phenolic content, which may provide added antioxidant benefits despite the slight increase in antinutritional components.

Table 1. Optical properties of sorghum cutlery.

Optical property	L*	a*	b*	Δ E
Unprocessed sorghum cutlery (SUK)	19.27 ± 0.55^{e}	2.45 ± 0.43^{c}	11.79 ± 0.54^{c}	15.3 ± 0.79^{e}
Unprocessed sorghum hibiscus incorporated cutlery (SUHK),	10.68 ± 0.32^{a}	0.49 ± 0.12^{a}	5.87 ± 0.61^{a}	5.87 ± 0.61^{a}
Unprocessed sorghum rose incorporated cutlery (SURK)	18.51 ± 0.20^{d}	0.90 ± 0.28^{ab}	10.39 ± 0.44^{b}	13.33 ± 0.39^{d}
Roasted sorghum cutlery (SRK)	15.43 ± 0.24^{c}	0.78 ± 0.09^{ab}	10.42 ± 0.55^{b}	10.86 ± 0.48^{c}
Roasted sorghum hibiscus incorporated cutlery (SRHK)	12.91 ± 0.25^{b}	1.1 ± 0.05^{ab}	5.99 ± 0.56^{a}	7.10 ± 0.66^{b}
Roasted sorghum rose incorporated cutlery (SRRK)	19.36 ± 0.48^{e}	1.21 ± 0.56^{b}	9.69 ± 0.67^{b}	13.59 ± 0.71^{d}
F-value	289.83	13.58	57.56	103.47
P-value	0.01	0.01	0.01	0.01

The results are displayed as mean ± SD; Values in superscript in each column denote the significant difference (P<0 05) through One-way ANOVA *and Duncan's multiple range test.*

Table 2. Nutrient analysis, total phenol and Antinutritional factors content of sorghum cutlery.

Variable	SUK	SUHK	SURK	SRK	SRHK	SRRK	P-value)
Moisture (%)	3.44±0.12^{c}	3.87±0.05^{e}	3.72±0.03^{d}	2.93±0.02^{a}	3.22±0.01^{b}	3.42±0.01^{c}	0.01
Ash (%)	3.28±0.04^{a}	3.43±0.10^{b}	3.44±0.04^{b}	3.33±0.01^{ab}	3.37±0.02^{ab}	3.37±0.04^{ab}	0.04
Carbohydrate (g)	15.75±0.08^{ab}	15.70±0.06^{a}	15.73±0.03^{a}	15.75±0.03^{ab}	15.83±0.02^{b}	15.83±0.04^{b}	0.03
Protein (g)	2.74±0.11^{a}	2.65±0.13^{a}	2.79±0.05^{ab}	2.91±0.02^{bc}	2.98±0.02^{c}	2.93±0.01^{c}	0.01
Fat (g)	0.56±0.05^{a}	0.58±0.05^{b}	0.52±0.01^{a}	0.51±0.02^{a}	0.59±0.03^{b}	0.52±0.01^{a}	0.08
Fiber (g)	2.79±0.07^{a}	2.82±0.02^{a}	2.76±0.01^{a}	2.78±0.03^{a}	2.86±0.06^{b}	2.78±0.05^{a}	0.21
Vitamin C (mg)	0.11±0.06^{bc}	0.13±0.02^{a}	0.12±0.01^{ab}	0.10±0.01^{a}	0.12±0.01^{ab}	0.20±0.01^{c}	0.01
Iron (mg)	1.11±0.11^{ab}	1.23±0.02^{b}	0.12±0.01^{ab}	1.07±0.12^{a}	1.12±0.04^{ab}	1.15±0.02^{ab}	0.16
Calcium (mg)	7.04±0.15^{b}	7.05±0.05^{b}	6.91±0.06^{ab}	6.86±0.08^{a}	6.97±0.06^{ab}	6.90±0.03^{ab}	0.08
Phosphorous (mg)	55.43±0.12^{ab}	55.74±0.11^{c}	55.43±0.03^{ab}	55.25±0.07^{a}	55.42±0.11^{ab}	55.46±0.11^{b}	0.01
Total phenols (mg /100 g GAE)	77.02±2.28^{c}	80.61±1.02^{d}	80.88±1.54^{d}	66.33±1.25^{a}	69.68±2.22^{b}	71.91±2.06^{b}	0.01
Tannin (mg /100 g TAE)	8.33±0.11^{c}	8.61±0.13^{d}	8.75±0.09^{d}	4.78±0.19^{b}	3.92±0.10^{b}	3.97±0.06^{b}	0.01
Phytic acid (mg/100g)	28.89±0.78^{bcd}	29.95±0.13^{cd}	30.11±0.13^{d}	26.44±2.08^{a}	28.14±0.87^{abc}	27.46±0.30^{ab}	0.01

The results are displayed as mean ± SD; Values in superscript in each column denote the significant difference (P<0 05) through One-way ANOVA *and Duncan's multiple range test;* ***SUK****: Unprocessed Sorghum Cutlery;* ***SUHK****: Unprocessed Sorghum Hibiscus Incorporated Cutlery;* ***SURK****: Unprocessed Sorghum Rose incorporated Cutlery;* ***SRK****: Roasted Sorghum Cutlery;* ***SRHK****: Roasted Sorghum Hibiscus Incorporated Cutlery, and* ***SRRK****: Roasted Sorghum Rose incorporated Cutlery; TAE: Tannic acid equivalent..*

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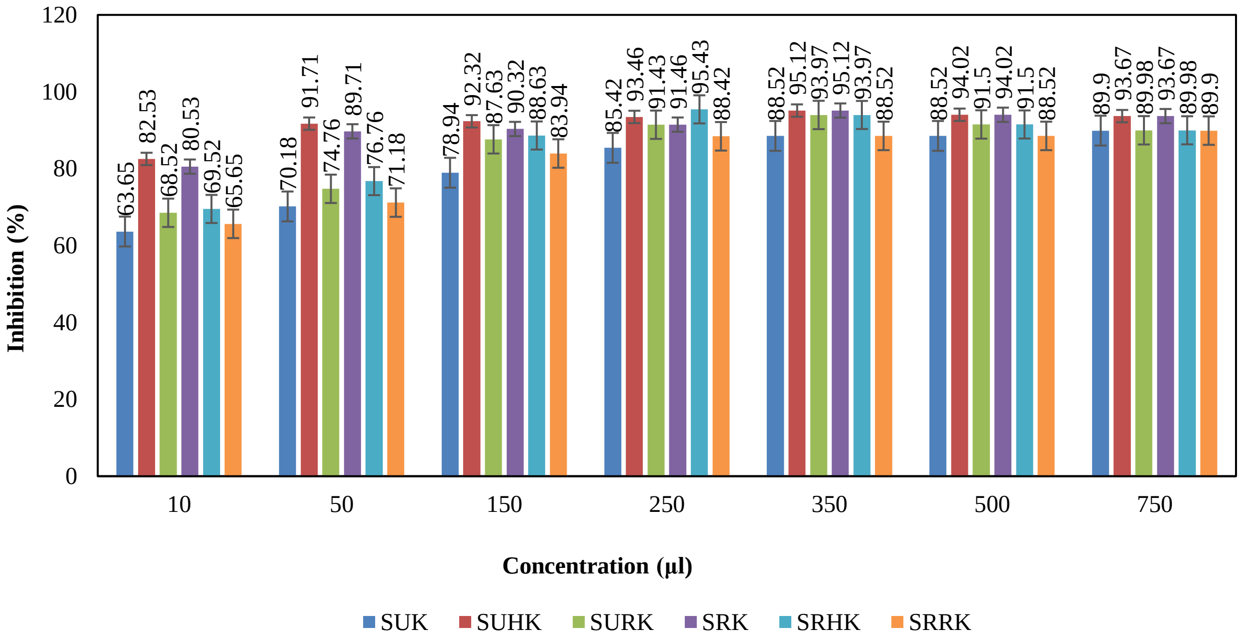

Figure 3. Antioxidant activity of sorghum cutlery.
***SUK**: Unprocessed Sorghum Cutlery; **SUHK**: Unprocessed Sorghum Hibiscus Incorporated Cutlery; **SURK**: Unprocessed Sorghum Rose incorporated Cutlery; **SRK**: Roasted Sorghum Cutlery; **SRHK**: Roasted Sorghum Hibiscus Incorporated Cutlery, and **SRRK**: Roasted Sorghum Rose incorporated Cutlery.*

Sensory evaluation of sorghum cutlery

The sensory evaluation of sorghum cutlery, conducted by 30 semi-trained panelists, revealed a range of scores across various attributes (**Figure 4**). Shape and appearance scores ranged from 8.2 to 8.8, with SRRK achieving the highest score, showing that edible flowers enhanced visual appeal. Color scores varied from 8.2 to 8.6, with SRK receiving the highest score due to Maillard reaction from roasting, which improved color. Taste scores ranged from 7.0 to 7.9, with SRK showing the highest (7.9), indicating that roasting enhanced flavor. The maximum crispiness was in SRRK, scoring 8, reflecting the improved texture from roasting. Overall acceptability scores ranged from 7.6 to 8.0, with SRK slightly ahead, highlighting that roasting and the inclusion of hibiscus, and rose flower powder improved both visual and sensory appeal.

Exposure test of sorghum cutlery

The exposure test of the sorghum cutlery was done at three different temperatures (at 29 °C, 80 °C, and 4 °C) for one hour and changes in structure and physical attributes were constantly observed (**Figure 5**). The observations showed that sorghum cutlery withstood temperature fluctuations between 29 °C and 4 °C without undergoing any noticeable changes in its structure or appearance for 40 minutes. The cutlery tended to absorb the moisture at corners and base when exposed for more than 40 minutes and became soggy at the end of one hour. At 80 °C, sorghum cutlery resisted for 25 minutes without any absorption, gradual moisture absorption at margins at 45 minutes, and total structural disruption at 60 minutes. All six-sorghum cutlery exhibited the same exposure property, proving that incorporating flowers and roasting sorghum did not show any difference or changes in its structural changes during exposure at 29 °C, 80 °C, and 4 °C. The exposure test of sorghum cutlery showed that it is suitable for individual servings, side dishes, or snacks at cold, dry, and ambient temperatures for 40 minutes and hot food and beverages for 25 minutes without any change in its structural integrity and absorption of moisture.

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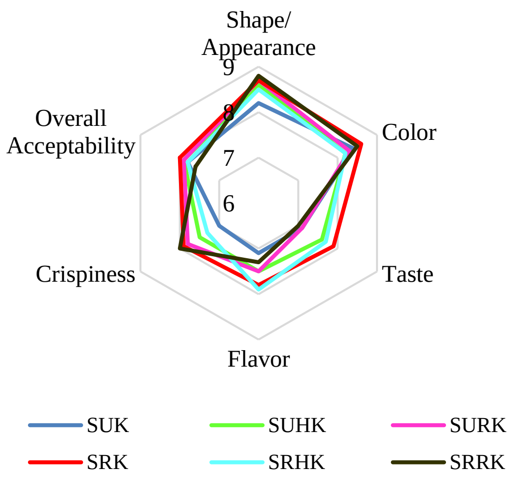

Figure 4. Sensory evaluation of sorghum cutlery.

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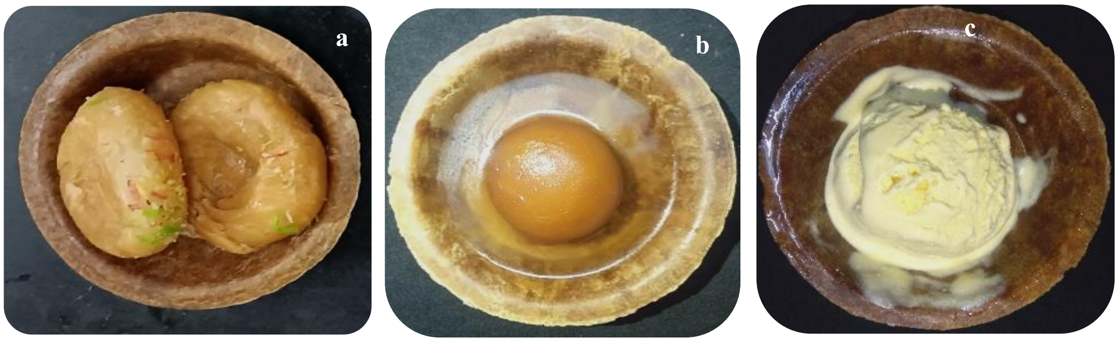

Figure 5. Exposure test of sorghum cutlery a. dry sweet, b. hot sweet with sugar syrup, c. ice cream.

Drop test of sorghum cutlery

Sorghum cutlery was dropped from 70 cm to 150 cm to measure the simulated accidental drops or falls that could happen during handling or serving on a levelled hard surface (**Table 3**), noting any deformation, cracking, or breaking and its ability to retain its structural integrity. At 110 cm, SUK did not exhibit any deformation, cracking, or breaking; at 130 cm, the corners began to crack, and at 150 cm, the cutlery broke entirely. While SRK showed no evidence of damage until 90 cm, its first crack appeared at 130 cm, and broke fully at 150 cm, SUHK, SURK, SRHK, and SRRK showed no deformations until 90 cm and were shattered into pieces at 130 cm. Drop tests of sorghum cutlery showed that SRK had high resistance to free fall impact and edible flower powder incorporated cutlery exhibited milder impact than SUK and SRK.

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Table 3. Drop test of sorghum cutlery.

Drop test	70 cm	90 cm	110 cm	130 cm	150 cm
SUK	No Damages	No Damages	No Damages	Corners cracked	Broken into pieces
SUHK	No Damages	No Damages	First crack	Corners cracked	Broken into pieces
SURK	No Damages	No Damages	First crack	Corners cracked	Broken into pieces
SRK	No Damages	No Damages	No Damages	No Damages	Corners cracked
SRHK	No Damages	No Damages	First crack	Corners cracked	Broken into pieces
SRRK	No Damages	No Damages	First crack	Corners cracked	Broken into pieces

***SUK**: Unprocessed Sorghum Cutlery; **SUHK**: Unprocessed Sorghum Hibiscus Incorporated Cutlery; **SURK**: Unprocessed Sorghum Rose incorporated Cutlery; **SRK**: Roasted Sorghum Cutlery; **SRHK**: Roasted Sorghum Hibiscus Incorporated Cutlery, and **SRRK**: Roasted Sorghum Rose incorporated Cutlery.*

Texture analysis of sorghum cutlery

The texture analysis of functionally enhanced sorghum cutlery showed significant differences in mechanical properties (**Table 4**). The maximum hardness, indicating the force required to break the cutlery, was in SRHK (76.27 N), suggesting that roasting combined with hibiscus improved structural integrity, followed by SUHK (64.56 N). SURK had the lowest hardness (39.6 N), showing a softer, and more delicate texture. The increase in hardness for roasted samples was linked to Maillard reaction and starch gelatinization, which strengthen the cutlery matrix (Latha Ravi and Rana, 2024, Manivel *et al.*, 2025). SRHK also displayed the highest elastic force (100.51 N/mm²), reflecting greater resistance to deformation and a firmer texture, ideal for crunchy products. SURK, with the lowest elastic force (38.18 N/mm²), correlated with its softness. These variations were due to effects of roasting and distinct structural impacts of hibiscus and rose incorporations, influenced by their unique phytochemical compositions.

Table 4. Texture analysis of sorghum cutlery.

Texture analysis	Hardness and break force (N)	Elastic force (N/mm2)
Unprocessed sorghum cutlery (SUK)	47.84 ± 0.3^{b}	55.58 ± 0.82^{c}
Unprocessed sorghum hibiscus incorporated cutlery (SUHK),	64.56 ± 0.74^{d}	53.1 ± 3.84^{c}
Unprocessed sorghum rose incorporated cutlery (SURK)	39.6 ± 0.51^{a}	38.18 ± 1.09^{a}
Roasted sorghum cutlery (SRK)	49.32 ± 1.04^{b}	70.47 ± 2.15^{d}
Roasted sorghum hibiscus incorporated cutlery (SRHK)	76.27 ± 2.00^{e}	100.51 ± 2.41^{e}
Roasted sorghum rose incorporated cutlery (SRRK)	56.26 ± 1.15^{c}	47.68 ± 2.07^{b}
F-value	422.54	279.32
P-value)	0.01	0.01

The results are displayed as mean ± SD; Values in superscript in each column denote the significant difference (p < 0 05) through One-way ANOVA *and Duncan's multiple range test.*

Shelf life analysis of sorghum cutlery

The microbial load analysis of sorghum cutlery over 120 days showed that unroasted cutlery (SUK, SUHK, SURK) had higher microbial growth compared to roasted variants. SUK reached 10 x 10^{1} CFU/g by Day 120, while SUHK and SURK peaked at 12 x 10^{1} and 11 x 10^{1} CFU/g, respectively (**Table 5**). Roasted cutlery (SRK) exhibited the lowest microbial load, increasing from 0 x 10^{1} CFU/g at Day 30 to only 4 x 10^{1} CFU/g by Day 120. Roasted cutlery with added powders (SRHK, SRRK) showed similarly lower microbial loads, peaking at 6 x 10^{1} and 5 x 10^{1} CFU/g, respectively. The findings suggested that roasting helped reduce microbial growth, while adding edible flower powders slightly increased bacterial load, slightly reducing the cutlery shelf life.

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Table 5. Total microbial load of sorghum cutlery.

Total microbial load	Day 30 (CFU/g)	Day 60 (CFU/g)	Day 90 (CFU/g)	Day 120 (CFU/g)
Unprocessed sorghum cutlery (SUK)	1 x 10^1	4 x 10^1	7 x 10^1	10 x 10^1
Unprocessed sorghum hibiscus incorporated cutlery (SUHK),	3 x 10^1	5 x 10^1	8 x 10^1	12 x 10^1
Unprocessed sorghum rose incorporated cutlery (SURK)	2 x 10^1	4 x 10^1	9 x 10^1	11 x 10^1
Roasted sorghum cutlery (SRK)	0 x 10^1	1 x 10^1	2 x 10^1	4 x 10^1
Roasted sorghum hibiscus incorporated cutlery (SRHK)	2 x 10^1	3 x 10^1	4 x 10^1	6 x 10^1
Roasted sorghum rose incorporated cutlery (SRRK)	1 x 10^1	2 x 10^1	3 x 10^1	5 x 10^1

The weight change of sorghum cutlery over 120 days showed a gradual increase in weight, reflecting moisture absorption (**Figure 6**). On day 1, SUK, SUHK, and SURK had initial weights of 19.35 g, 18.3 g, and 18.87 g, respectively, and by day 120, their weights increased by approximately 0.30 g. The weight increase for all cutlery samples was between 0.07 g and 0.09 g every 30 days, with SRRK showing the highest overall weight gain by day 120, while SRK had the least. The rate of weight gain slowed over time, indicating reduced moisture absorption as the samples aged. The results suggested that moisture absorption varied based on cutlery composition, with roasted variants and flower powder incorporation affecting weight changes differently.

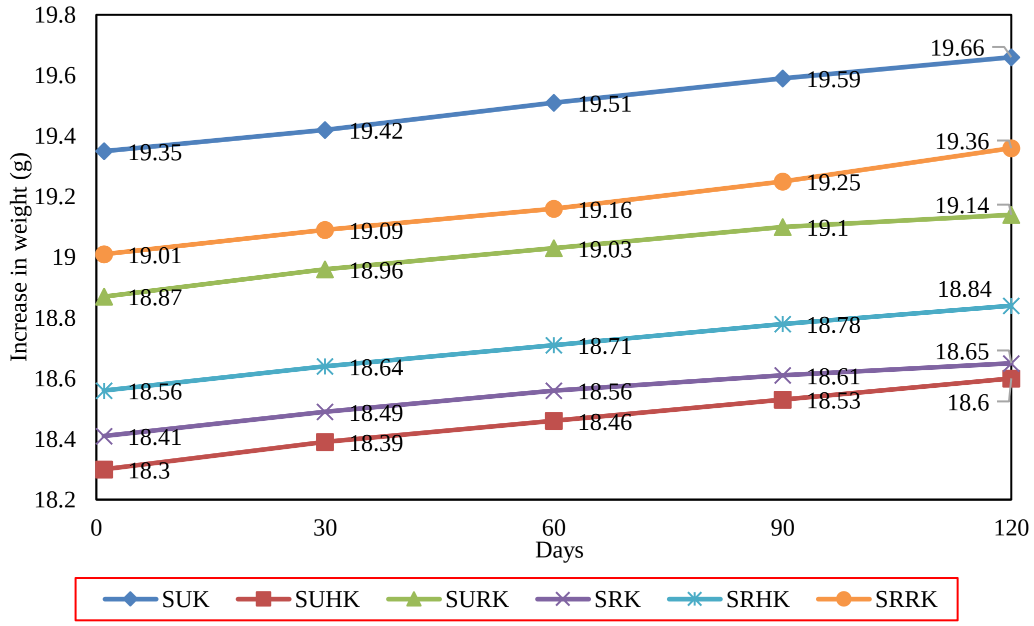

Figure 6. Change in weight (g) of sorghum cutlery.

***SUK**: Unprocessed Sorghum Cutlery; **SUHK**: Unprocessed Sorghum Hibiscus Incorporated Cutlery; **SURK**: Unprocessed Sorghum Rose incorporated Cutlery; **SRK**: Roasted Sorghum Cutlery; **SRHK**: Roasted Sorghum Hibiscus Incorporated Cutlery, and **SRRK**: Roasted Sorghum Rose incorporated Cutlery.*

Discussion

Physical and optical properties of sorghum cutlery

Roasting and the incorporation of flower powders significantly enhanced color properties of sorghum cutlery. Roasting reduced brightness while increasing overall color change due to browning (Rashwan *et al.*, 2021). Freeze-dried rose flower powder, known for its superior L*, a*, and h values, enhanced optical properties

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compared to microwave or vacuum drying (Qiu *et al.*, 2020). Low-temperature drying promoted uniformity, further improving optical qualities. Hibiscus, rich in red anthocyanins, acts as a natural food colorant (Weerasingha *et al.*, 2021). Products like biscuits with 10-15% rose calyx powder show a reddish hue and reduced brightness, especially with higher rose content (Hernández-Nava *et al.*, 2023). Ingredients rich in bioactive compounds and pigments enhance red and yellow tones in edible cutlery (Siddiqui *et al.*, 2023, Yodkum and Yokesahachart, 2024). Color changes can be attributed to chemical reactions occurring in cereal-based products under high temperatures, including Maillard reaction, moisture absorption, and starch gelatinization, which contribute to darkening. Moreover, the pronounced red, yellow, and total color variations likely result from pigment leaching and polyphenol oxidation, both of which are characteristics of heat treatment processes (Manivel *et al.*, 2025, Mashau *et al.*, 2024).

Nutritive analysis of sorghum cutlery

Roasting and flower incorporation enhanced the nutrient profile of sorghum cutlery. Sorghum-based edible cutlery contained 2.68% moisture, 1.75% ash, 1.82% crude fat, 4.7% crude protein, and 0.8% crude fiber (Iqbal *et al.*, 2022). Roasting increased the ash content in sorghum from 1.73% to 1.89% (Tamilselvan and Kushwaha, 2020). Multi-millet edible bowls offered higher dietary fiber and protein but lower calories, fat, and moisture (Jaspal *et al.*, 2024). Fresh hibiscus and rose flowers had around 86% moisture, with dry flowers high in carbohydrates (60-80%), protein (12.14 g), and crude fat (3.28 g) (Hegde *et al.*, 2022). The addition of hibiscus and rose hips to food products enhanced taste while boosting protein, fiber, and essential nutrients (Antarkar *et al.*, 2019, Weerasingha *et al.*, 2021). The incorporation of edible flowers into edible sorghum bowls significantly enhanced their micronutrient and macronutrient content, except for carbohydrates (Manivel *et al.*, 2025). The nutrient content of roasting sorghum increased due to alter in its chemical composition (Latha Ravi and Rana, 2024).

Antioxidant properties of sorghum cutlery

The antioxidant activity of roasted and flower-incorporated sorghum cutlery increased compared to SUK. Hibiscus flowers are known for their phytochemical content, contributing to strong antioxidant activity by scavenging free radicals that may cause DNA damage (Weerasingha *et al.*, 2021). Oven-dried rose petals exhibited the highest DPPH scavenging activity at 60.30%, outperforming sun-dried and shade-dried counterparts (Salamatullah *et al.*, 2024). Brewer's spent grain in edible bowls significantly enhanced antioxidant activity with increased grain content (Nehra *et al.*, 2024). Foxtail millet cutlery containing catechins, ferulic acid lignin, saponin, and betacyanin also demonstrated notable antioxidant properties (Mukherjee and Raju, 2023).

Total phenolic content and antinutritional factors in sorghum cutlery

Among sorghum cutlery, roasting significantly reduced tannins and total phenolic content, enhancing its nutritional profile by lowering antinutritional factors. The addition of hibiscus and rose powders increased phenolic content, providing antioxidant benefits, despite a slight rise in antinutritional components. Studies have shown that traditional sorghum processing lowers phenolics from 92.62 mg GAE/100 g to 48.40 mg GAE/100 g, with similar reductions in tannins (Tamilselvan and Kushwaha, 2020). Heat treatments help release phenolics and break down tannins into smaller bioactive compounds (Gwekwe *et al.*, 2024, Rashwan *et al.*, 2021). For instance, adding 15% rose calyx powder increased phenolic content in biscuits from 3 mg GAE/100 g to 76 mg GAE/100 g (Hernández-Nava *et al.*, 2023). Rose petals, depending on drying methods, showed phenolic content ranging from 15.6 mg to 34.24 mg GAE/g (Salamatullah *et al.*, 2024).

Sensory evaluation of sorghum cutlery

Edible cutlery made from composite flours scored between 7 and 8 for sensory attributes (Matheswari and Arivuchudar, 2024). Sorghum,

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rice, and wheat flour cutlery received mean sensory scores of 6 to 8 (Iqbal *et al.*, 2022). Incorporation of five percent rose calyx powder in biscuits showed higher acceptability than ten to fifteen percent level of incorporation (Hernández-Nava *et al.*, 2023, Hnin *et al.*, 2021).

Exposure test and drop test of sorghum cutlery

Sorghum-based cutlery absorbs up to 12% water in 30 minutes at ambient temperature, with varying water-holding capacities depending on the composition of sorghum, wheat, and rice (Kabir *et al.*, 2022). The water-holding capacities of rice, wheat, and sorghum-based edible cutlery ranged from 44.33 to 47.70 (Iqbal *et al.*, 2022). Multi-millet edible bowls demonstrated lower water absorption and a thicker, harder surface (Jaspal *et al.*, 2024). A bowl made from papaya skin and peel withstands for 30 minutes at 25 °C and 18 minutes at 90 °C (Wulandari *et al.*, 2023). Brewer's spent grain incorporated into edible bowls reduced water absorption and increased sogginess after 30 minutes (Nehra *et al.*, 2024). Sorghum cutlery exposure properties were superior due to its composition and baking method in a closed mold, improving water resistance and durability.

Texture analysis of sorghum cutlery

Sorghum cups showed a break force of 41 N and an adhesive force of 0.03 (Devatha and Raajeswari, 2023) and sorghum bowls with roasting millet and hibiscus or rose flower incorporation had a break force between 230 N to 310 N (Manivel *et al.*, 2025). The increased hardness may result from the partial degradation of starch integrity and a weakened gluten-starch network. This could also be attributed to enhanced interactions between gelatinized starch and gluten (Sharanagat *et al.*, 2024). Roasting and flower nanoparticle enhancement, such as hibiscus iron oxide nanoparticles in wheat biscuits, improved texture properties like hardness and fracturability (Razack *et al.*, 2020). Similarly, edible bowls with higher concentrations of brewer's spent grain displayed increased stiffness and hardness (Nehra *et al.*, 2024). The flexural and izod impact strength of rice flour spoons improved with higher proportions of defatted rice bran, likely due to its reinforcing effects (Yodkum and Yokesahachart, 2024).

Shelf life analysis of sorghum cutlery

The standardized edible sorghum cutlery, enriched with edible flowers, exhibited a lower microbiological count (0×10^1 to 12×10^1 CFU/g) compared to the International Microbiological Standards Recommendation for dry and ready-to-eat foods, which allows 10^3–10^2 CFU/g for coliforms and <10^3 CFU/g for total heterotrophic bacteria (Sharanagat *et al.*, 2024). The standardized sorghum cutlery had a shelf life of 120 days as the research par with, composite edible cutlery had a shelf life of 120 days when stored in air-tight packaging (Matheswari and Arivuchudar, 2024). The incorporation of iron oxide nanoparticles from hibiscus in wheat biscuits enhanced the shelf life by inhibiting microbial growth and acting as an antimicrobial agent (Razack *et al.*, 2020).

Limitation and Recommendation

The cutlery was tested at three different temperatures (29 °C, 80 °C, and 4 °C); however, a wider range of temperature may be included in subsequent research. Over a period of 120 days, the microbial load was observed in a controlled temperature environment, which can be extended to varied environmental settings. The nutritional content and sensory qualities of the cutlery may also be enhanced by exploring alternative regional, environmentally friendly functional food products.

Conclusion

Sorghum cutlery offered a nutritious, eco-friendly alternative to single-use plastics, appealing to consumers of all ages while innovatively promoting the consumption of nutri-cereals. It provided a sustainable solution for serving meals, snacks, and beverages in various settings, reducing ecological impact and encouraging sustainable practices. The addition of hibiscus and rose powders significantly enhanced their nutritional, antioxidant, and sensory qualities, improving appearance, palatability, and functionality. Roasting sorghum further enhanced the texture, flavor, and structural integrity while bioactive

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compounds in sorghum contribute to potential health benefits. With a long shelf life, robust antioxidant properties, and strong sensory qualities, sorghum cutlery presented a promising edible alternative to traditional tableware. Their adoption promoted responsible consumption, advancing a sustainable food system by reducing plastic waste, and aligned with SDGs such as zero hunger, good health, and environmental conservation.

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Authors' contributions

Devatha SM conceptualized, designed, and conducted the research and wrote the first draft of the manuscript. Raajeswari P supervised the experiment and revised the manuscript. All authors read and approved the final manuscript.

Conflicts of Interest

The authors declared no conflict of interest.

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