CHAPTER IV

RESULTS AND DISCUSSION

The study entitled "**Sustainable Solutions: Edible Millet Tableware as a Substitute for Single-Use Cutleries in the Food Service Sector**" is discussed under five phases,

PHASE - I

4.1 PROPERTY ANALYSIS OF SELECTED MAJOR MILLET

4.1.1 Physical Properties of Millet

4.1.2 Physicochemical Properties of Millet Flour

4.1.3 Total Phenolic Content of Millet Flour

4.1.4 Antinutritional Factors of Millet Flour

4.1.5 Functional Properties of Millet Flour

PHASE - II

4.2 CHARACTERISATION OF STANDARDISED MILLET TABLEWARE

4.2.1 Physical Properties of Standardised Millet Tableware

4.2.2 Proximate and Nutrient Analysis of Standardised Millet Tableware

4.2.3 Sensory Evaluation of Standardised Millet Tableware

4.2.4 Functional Properties of Standardised Millet Tableware

4.2.5 Texture Analysis of Standardised Millet Tableware

PHASE - III

4.3 PROPERTY ANALYSIS OF NATIVE EDIBLE FLOWER

4.3.1 Nutrient Analysis of Selected Edible Flower Powder

4.3.2 Phytochemical Screening of Selected Edible Flower Powder

4.3.3 Antioxidant Activity of Selected Edible Flower Powder

4.3.4 Optical Property of Selected Edible Flower Powder

PHASE - IV

4.4 CHARACTERISATION OF STANDARDISED FLOWER-ENRICHED MILLET TABLEWARE

4.4.1 Proximate and Nutrient Analysis of Flower-Enriched Millet Tableware

4.4.2 Antioxidant Activity of Flower-Enriched Millet Tableware

4.4.3 Optical Property of Flower-Enriched Millet Tableware

4.4.4 Sensory Evaluation of Flower-Enriched Millet Tableware

PHASE V

4.5 ANALYSIS OF SHELF LIFE, TOXICITY, AND BIODEGRADABILITY OF MILLET TABLEWARE

PHASE - I

4.1 PROPERTY ANALYSIS OF SELECTED MAJOR MILLET

4.1.1 PHYSICAL PROPERTIES OF MILLET

i. Quality of Pearl millet and Sorghum grain

Physical properties of unprocessed, germinated and roasted pearl millet and sorghum grains were carried out by measuring its length, breadth, length/breadth ratio, thickness, thousand grain weight, and thousand grain volume and is given in Table VIII.

Table VIII
Quality of Pearl millet and Sorghum grain

S. No	Parameters	Pearl Millet			Sorghum			F value
		PMUG	PMGG	PMRG	SUG	SGG	SRG	
1	Length (mm)	0.47 ± 0.01	0.34 ± 0.01	0.44 ± 0.03	0.61 ± 0.01	0.56 ± 0.04	0.59 ± 0.01	58.48*
2	Breadth (mm)	0.25 ± 0.02	0.21 ± 0.01	0.20 ± 0.02	0.69 ± 0.02	0.61 ± 0.02	0.7 ± 0.04	252.21*
3	Length / Breadth ratio(mm)	1.88 ± 0.19	1.58 ± 0.13	2.19 ± 0.28	0.87 ± 0.05	0.90 ± 0.11	0.85 ± 0.06	40.06*
4	Thickness (mm)	0.21 ± 0.02	0.19 ± 0.02	0.18 ± 0.01	0.58 ± 0.05	0.53 ± 0.02	0.58 ± 0.05	106.31*
5	Thousand Grain Weight (g)	8.86 ± 0.01	8.40 ± 0.03	8.6 ± 0.03	29.43 ± 0.12	23.24 ± 0.08	26.48 ± 0.06	63266.87*
6	Thousand Grain Volume (ml)	16 ± 0.57	26.04 ± 0.15	29.11 ± 0.13	36.05 ± 0.07	44.63 ± 0.08	41.06 ± 0.07	5007.57*

*Significant, **Not Significant, Values in superscript within each column denote the significant difference, $p<0.05$, PMUG - Unprocessed Pearl millet Grain, PMGG - Germinated Pearl millet Grain, PMRG - Roasted Pearl millet Grain, SUG - Unprocessed Sorghum Grain, SGG - Sorghum Germinated Grain, SRG - Roasted Sorghum Grain

Germination and roasting of pearl millet and sorghum grain showed a significant decrease in length, breadth, length/breadth ratio and thickness as compared to its unprocessed variants. PMGG exhibited a length of 0.34 ± 0.01 mm and 0.44 ± 0.03 mm in PMRG which was less as 0.47 ± 0.01 mm in PMUG, while sorghum grains exhibited longer length as compared to pearl millet where SGG, and SRG exhibited 0.56 ± 0.04 mm, and 0.59 ± 0.01 mm length whereas SUG with 0.61 ± 0.01 mm. Breadth of sorghum exhibited significantly broader grains, 0.69 ± 0.02 mm in SUG compared to pearl millet, 0.25 ± 0.02

mm in PMUG. The length-to-breadth ratio was higher in PMRG, whereas sorghum grains showed lowest ratio. Grains thickness was the lowest in pearl millet, with values around 0.18 mm to 0.21 mm, and the highest in sorghum ranging from 0.53 to 0.58 mm.

Thousand-grain weight and volume highlighted the significant difference between pearl millet and sorghum. Sorghum showed higher thousand grain weight, ranging from 23.24 ± 0.08 g (SGG) to 29.43 ± 0.12 g (SUG), compared to pearl millet, which ranged from 8.40 ± 0.03 g (PMGG) to 8.86 ± 0.01 g (PMUG). Similarly, sorghum exhibited higher grain volume, with values peaking at 44.63 ± 0.08 ml (SGG), whereas pearl millet volumes were lower, ranging from 16 ± 0.57 ml (PMUG) to 29.11 ± 0.13 ml (PMRG). The F-value for all parameters showed significant difference between the unprocessed and processed millet grain that indicated processing methods had an impact on grain quality. The result of the present study is supported by the findings of, Garud *et al*. (2022), has stated that, thousand grain volume and weight was directly proportional to the size of the kernel and also found that, the thousand grain weight of pearl millet was approximately 10 to 15 g, which was significantly lower than the grain weight of pearl millet in the present study.

ii. Flour yield of Pearl millet and Sorghum

500 g of pearl millet and sorghum grains were taken, cleaned and sorted. Preliminary processing like germination and roasting of millet were done. It was then, milled, ground and its flour yield is given in Figure - 3.

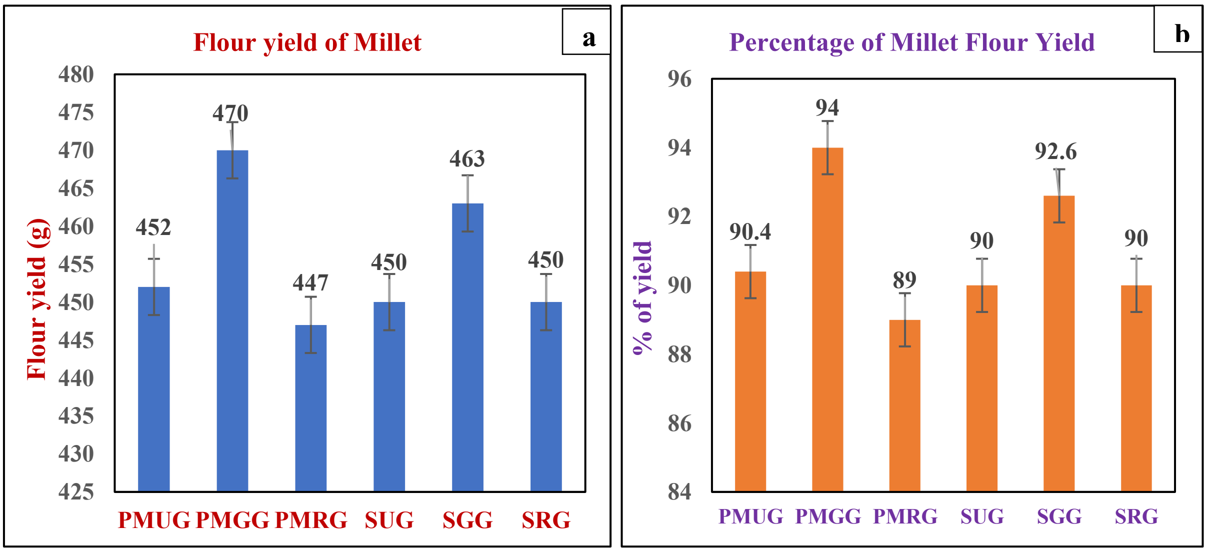


Figure - 3
Flour yield of Pearl millet and Sorghum, a. Flour yield of millet, b. Percentage of millet flour yield
(PMUG - Unprocessed Pearl Millet Grain, PMGG - Germinated Pearl Millet Grain, PMRG-Roasted Pearl Millet Grain, SUG - Unprocessed Sorghum Grain, SGG - Sorghum Germinated Grain, SRG - Roasted Sorghum Grain)

The PMUG yielded 452 grams of flour from 500 g, resulting in a 90.4 per cent yield whereas PMGG yielded 470 g (94%), and PMRG yielded the least, 447 g (89%). Similarly, for sorghum, SUG yielded 450 g (90%), while SGG yielded 463 g (92.6%), and SRG with 450 g (90%) of yield. Germinated millet resulted in higher yields due to improved water retention property whereas roasted millet produced lower yields due to moisture loss and structural changes during roasting when compared to unprocessed pearl millet and sorghum. The result is similar with the findings of Anjitha *et al*. (2021) on millet yield percentage.

4.1.2 PHYSICOCHEMICAL PROPERTIES OF MILLET FLOUR

The physicochemical properties like bulk density, swelling capacity, water absorption capacity, oil absorption capacity, moisture and ash content of the unprocessed, germinated, and roasted pearl millet and sorghum were measured and is given in Table IX.

Table IX

Physicochemical Properties of Millet Flour

S. No	Parameters	Pearl Millet			Sorghum			F value
		PMUF	PMGF	PMRF	SUF	SGF	SRF	
1	Bulk Density (g/ml)	0.19 ± 0.01	0.13 ± 0.02	0.14 ± 0.03	0.19 ± 0.02	0.12 ± 0.01	0.18 ± 0.02	6.12*
2	Swelling Capacity (%)	2.84 ± 0.03	2.32 ± 0.1	3.25 ± 0.04	3.59 ± 0.03	2.40 ± 0.03	3.27 ± 0.04	288.87*
3	Water Absorption Capacity (ml/g)	1.48 ± 0.03	1.75 ± 1.10	1.40 ± 0.04	1.27 ± 0.04	1.49 ± 0.04	1.85 ± 0.09	93.27*
4	Oil Absorption Capacity (ml/g)	0.84 ± 0.05	0.40 ± 0.24	0.98 ± 0.02	0.87 ± 0.02	1.34 ± 0.04	0.96 ± 0.03	24.53*
5	Moisture (%)	8.54 ± 0.10	14.33 ± 1.52	9.52 ± 0.05	10.38 ± 0.04	19.75 ± 0.05	9.37 ± 0.02	142.69*
6	Ash (%)	19.46 ± 0.05	19.75 ± 0.10	19.03 ± 1.65	19.55 ± 0.08	20.13 ± 0.08	20.46 ± 0.06	1.67**

*Significant, **Not Significant (*p<0.05*), PMUF - Unprocessed Pearl millet Flour, PMGF - Germinated Pearl millet Flour, PMRF - Roasted Pearl millet Flour, SUF – Unprocessed Sorghum Flour, SGF – Sorghum Germinated Flour, SRF – Roasted Sorghum Flour

The bulk density ranged from 0.13 ± 0.02 g/ml (PMGF) to 0.19 ± 0.01 g/ml (PMUF) for pearl millet and from 0.12 ± 0.01 g/ml (SGF) to 0.19 ± 0.02 g/ml (SUF) for sorghum.

Unprocessed pearl millet and sorghum flour exhibited the highest bulk density whereas, lowest was observed in germinated variations. The swelling capacity was highest for SUF at 3.59 ± 0.03 per cent, while the lowest value was found in PMGF at 2.32 ± 0.1 per cent. Sorghum flour exhibited superior swelling capacity as compared to pearl millet flour. The result of the present study is supported by the findings of, Dias-Martins *et al.* (2024) who stated that, processing of millet reduced bulk density as compared to its unprocessed variations. Garud *et al*. (2022), found that, higher bulk density indicated the close packing of starch and dense grains.

The water absorption capacity was the highest in SRF at 1.85 ± 0.09 ml/g, whereas SUF exhibited the lowest value at 1.27 ± 0.04 ml/g. Sorghum exhibited higher water absorption capacity than pearl millet in roasted forms. The findings align with the results of, Dias-Martins *et al.* (2024) who found that, the alternation in water absorption capacity was due to the action of amylase on the starch granules and also exhibited anti-microbial activity. SGF showed the highest value (1.34 ± 0.04 ml/g) and PMGF exhibited the lowest (0.4 ± 0.24 ml/g) oil absorption capacity due to protein solubilization and dissociation. Moisture content was notably higher in germinated flour, SGF had the highest moisture content of 19.75 per cent, while roasted flour generally showed reduced moisture levels, PMRF exhibited 9.52 per cent and SRF had 9.37 per cent. Ash content remained relatively consistent across all the variations, ranging from 19.03 per cent (PMRF) to 20.46 per cent (SRF), and no significant differences were observed (F = 1.67, not significant). The study found that germination significantly reduced the bulk density and enhanced the moisture content which negatively affected water and oil absorption capacities. Roasted millet had, improved water and oil absorption properties because of lower moisture levels and also sorghum showed higher swelling and absorption properties than pearl millet. The result is on par with the findings of the previous studies by Sharma & Anurag (2023) stated that, higher oil absorption capacity increased the sensory attributes and improved lipophilicity that suits to produce bakery goods. Germinated and roasted sorghum flour exhibited better technological properties as compared to other major millet (Khatoniar & Das, 2020). Moisture content in germinated pearl millet and sorghum has significantly higher than its unprocessed variants (Gwekwe *et al*., 2024).

4.1.3 TOTAL PHENOLIC CONTENT OF MILLET FLOUR

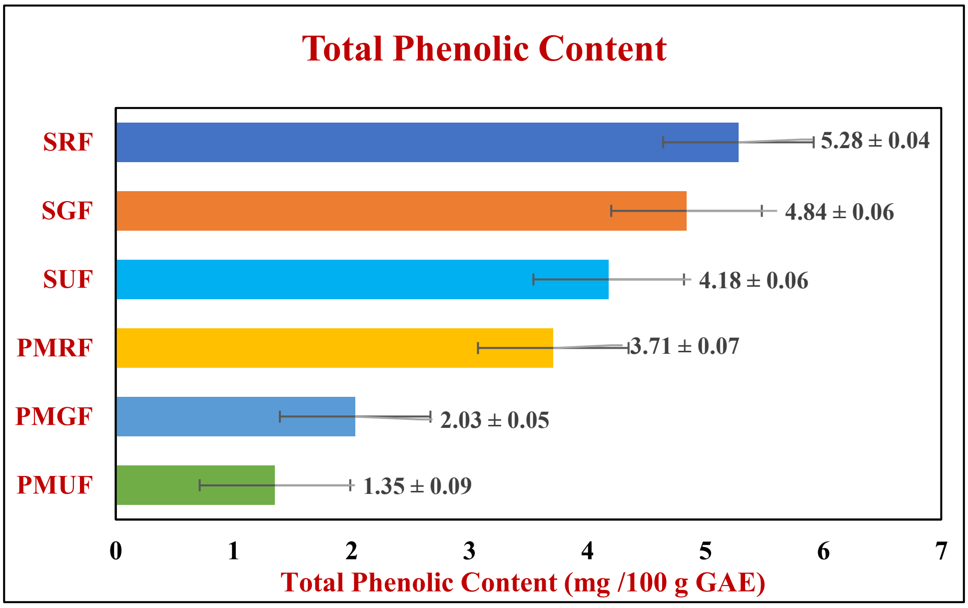


Figure – 4

Total Phenolic Content of Millet Flour

(PMUF - Unprocessed Pearl millet flour, PMGF – Germinated Pearl millet flour, PMRF – Roasted Pearl millet flour, SUF – Unprocessed Sorghum flour, SGF – Sorghum Germinated flour, SRF – Roasted Sorghum flour)

Sorghum flour exhibited highest phenolic content than pearl millet in all three forms (unprocessed, germinated and roasted). Roasted sorghum (5.28 ± 0.04 mg/100 g GAE) and pearl millet (PMRF, 3.71 ± 0.07 mg GAE/100 g) flour, exhibited increased phenolic content when compared to its unprocessed flour (PMUF, 1.35 ± 0.09 mg/100 g GAE and SUF, 4.18 ± 0.06 mg GAE/100 g, respectively), due to the release of bound phenolic compounds during heat treatment. The total phenolic content was statistically significant at $p<0.05$ with 1620.48 F value. Germination also enhanced total phenolic content, to a slight extent than roasting. Similar results are obtained by, Sunil *et al.* (2024) who found that, total phenolics in germinated sorghum was increased due to enzymatic activity and release of phenolics due to breakdown of phenolic compounds and macromolecules. Adhikari (2024) reported that germinated sorghum showed 49.85 per cent increase, followed by popping and soaking. Sharma & Anurag (2023), also proved that germination increased the total phenolic content in pearl millet as compared to raw variants due to activation of cell wall degrading enzymes and synthesis of new bioactive compounds.

4.1.4 ANTINUTRITIONAL FACTORS OF MILLET FLOUR

Phytic acid, tannin and saponin was quantitatively measured and given in Table X. Phytic acid content decreased significantly after germination where, PMGF and SGF exhibited 3.54 ± 0.06 mg/g, and 2.87 ± 0.05 mg/g respectively due to enzymatic degradation of phytic acid during germination. Conversely, roasting led to a moderate reduction in phytic acid due to thermal breakdown. Unprocessed pearl millet and sorghum flour showed the highest phytic acid levels. The results confirmed that processing (germination and roasting), reduced the phytic acid content. The antinutritional factors were reduced due to the phytase enzyme that increased the hydrolytic activity during germination (Rahman *et al*., 2023).

Table X

Antinutritional Factors of Millet Flour

S. No	Parameters	Pearl Millet			Sorghum			F value
		PMUF	PMGF	PMRF	SUF	SGF	SRF	
1	Phytic acid (mg/g)	7.39 ± 0.07	3.54 ± 0.06	4.16 ± 0.05	5.18 ± 0.05	2.87 ± 0.05	3.78 ± 0.08	108.62*
2	Tannin (mg /g TAE)	2.15 ± 0.06	1.54 ± 0.06	1.73 ± 0.04	3.77 ± 0.04	1.8 ± 0.04	2.05 ± 0.05	733.31*
3	Saponin (mg/g)	0.97 ± 0.05	0.59 ± 0.07	0.70 ± 0.09	2.98 ± 0.04	2.03 ± 0.06	2.68 ± 0.03	836.96*

*Significant, **Not Significant (*p<0.05*), L* Lightness (0 black to 100 White); a* (+60 red to -60 green); b* (+60 yellow to -60 blue); PMUF - Unprocessed Pearl millet flour, PMGF – Germinated Pearl millet flour, PMRF – Roasted Pearl millet flour, SUF – Unprocessed Sorghum flour, SGF – Sorghum Germinated flour, SRF – Roasted Sorghum flour

Similarly, the tannin content was the highest in SUF (3.77 ± 0.04 mg/g) and the lowest was observed in PMGF (1.54 ± 0.06 mg/g). Tannin content decreased significantly in germinated pearl millet and sorghum flour due to enzymatic degradation and leaching of tannin molecules. Roasted millet flour also showed a moderate reduction in tannin content as supported by the findings of Rahman *et al*. (2023). Saponin content was the highest in SUF (2.98 ± 0.04 mg/g) and the lowest in PMGF (0.59 ± 0.07 mg/g). Roasting appeared to enhance saponin levels in sorghum, possibly due to thermal release, while germination reduced saponin content in both grains. The reduction in saponin content was due to solubilization and leaching during soaking (Sunil *et al.,* 2024).

Germination generally reduces antinutritional factors like phytic acid, tannins, and saponins. Similar studies by Gwekwe *et al*. (2024), Adhikari (2024) and Dube *et al*. (2021) proved that, processing of sorghum and pearl millet (soaking, germination and popping) improved its functional and nutritional attributes and significantly decreased the antinutritional factors including phytate, tannin and oxalates.

4.1.5 FUNCTIONAL PROPERTIES OF MILLET FLOUR

4.1.5.1 FTIR OF MILLET FLOUR

Fourier Transform Infrared (FTIR) spectroscopy was utilized to analyse the functional properties of unprocessed, germinated, and roasted pearl millet and sorghum flour within the wavenumber range of 4000–450 cm^{-1}.

i. FTIR of Pearl millet flour

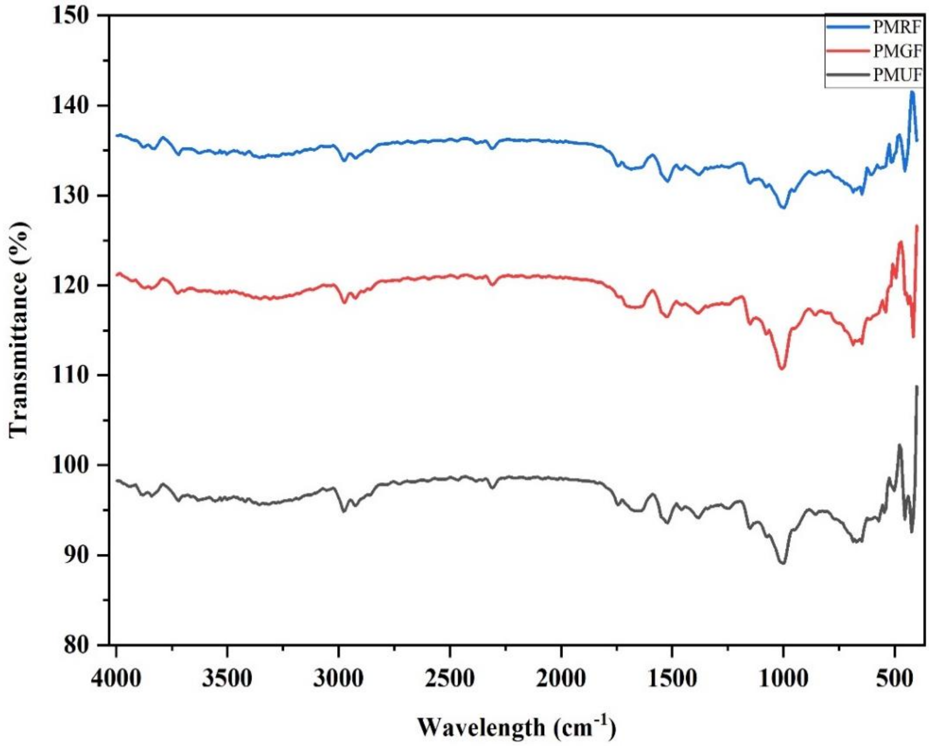


Figure – 5
FTIR of Pearl millet Flour

The FTIR spectra of unprocessed, germinated and roasted pearl millet flour revealed that, PMUF showed absorbance peaks over the 4000–400 cm^{-1} range, with notable signals at 3842 cm^{-1} and 3718 cm^{-1} (O–H stretching from hydroxyl groups), 3356 cm^{-1} (N–H stretching from amines or amides), and 2978 cm^{-1} and 2924 cm^{-1} (C–H stretching from aliphatic hydrocarbons). A strong absorption at 1743 cm^{-1} suggested C=O stretching in esters or aldehydes. Comparatively, the spectra of PMRF and PMGF highlighted the distinct differences, and displayed broad peaks in the 3600 cm^{-1} – 3000 cm^{-1} region for O–H stretching, with PMRF showed broader peaks, indicated the presence of higher hydroxyl content or stronger hydrogen bonding. In the fingerprint region (1500 cm^{-1} – 500 cm^{-1}), PMRF exhibited defined peaks at 995.27, 856.39, and 648.08 cm^{-1}, suggested the presence of functional groups, while PMGF showed sharper peaks at 1080.14 and 439.77 cm^{-1}, exhibited differing molecular arrangements or functional group intensities. The variations in peaks of PMUF, PMGF and PMRF emphasized the distinct molecular characteristics and structural organization. PMRF exhibited stronger hydroxyl group interactions and a slightly different arrangement of molecular vibrations in the lower wavenumber region, while PMGF showed sharper, distinct peaks that reflected a unique structural composition. The finding is on par with the study by Paliwal & Sharma (2022), Lin *et al.* (2021), and Olamiti *et al*. (2020), who found similar peaks in raw and processed pearl millet flour.

ii. FTIR of Sorghum Flour

In unprocessed sorghum flour, medium O–H peaks were observed between 3873.06 cm^{-1} and 3718.76 cm^{-1}, alongside weak C–H bands from 3502.08 to 3363.86 cm^{-1}. Germinated sorghum flour exhibited strong O–H peaks at 3834.40 cm^{-1}, while roasted flour displayed medium peaks between 3718.76 and 3834.40 cm^{-1}, indicative of vibrational peaks due to bound water and moisture content (Olamiti *et al*., 2020). All three-flour showed medium C–H peaks in the 2306.86–2970.38 cm^{-1} region. A medium carbonyl stretch peak (1697–1643 cm^{-1}) was present in unprocessed flour, along with a weak peak at 1689 cm^{-1}, which suggested the presence of lipids. Germinated sorghum flour lacked carbonyl stretch peaks. Strong C=C stretching peaks were noted at 1519 cm^{-1} in unprocessed flour and 1527 cm^{-1} in germinated and roasted flour, attributed to amide II from N–H bend, that confirmed the presence of proteins.

Unprocessed sorghum flour (SUF) displayed strong peaks at 1519 cm^{-1} and weak peaks between 1080 and 1458 cm^{-1}, associated with O–H, C–O, and C–C bonds, which form part of a saturated primary alcohol ring structure. Germinated and roasted flour exhibited fewer weak peaks between 1520 - 1400 cm^{-1}, that showed the denaturation of organic compounds. SUF showed more peaks between 416 and 995 cm^{-1}, SGF exhibited peaks from 416 to 725 cm^{-1}, and SRF showed, peaks ranged from 424 to 810 cm^{-1}, that confirmed the presence of amylose and amylopectin. Additionally, a medium peak at 1743.65 cm^{-1} in unprocessed flour indicated the presence of tannins, while germinated and roasted flour showed no peaks in the 1700 cm^{-1} –1400 cm^{-1} region, that confirmed the absence of tannins (Lin *et al*., 2021). Steeping and fermentation processes showed minimal impact on the structural properties of sorghum flour and reduced phytic acid and tannin content by 21–52 per cent through first-order degradation kinetics (Paliwal & Sharma, 2022).

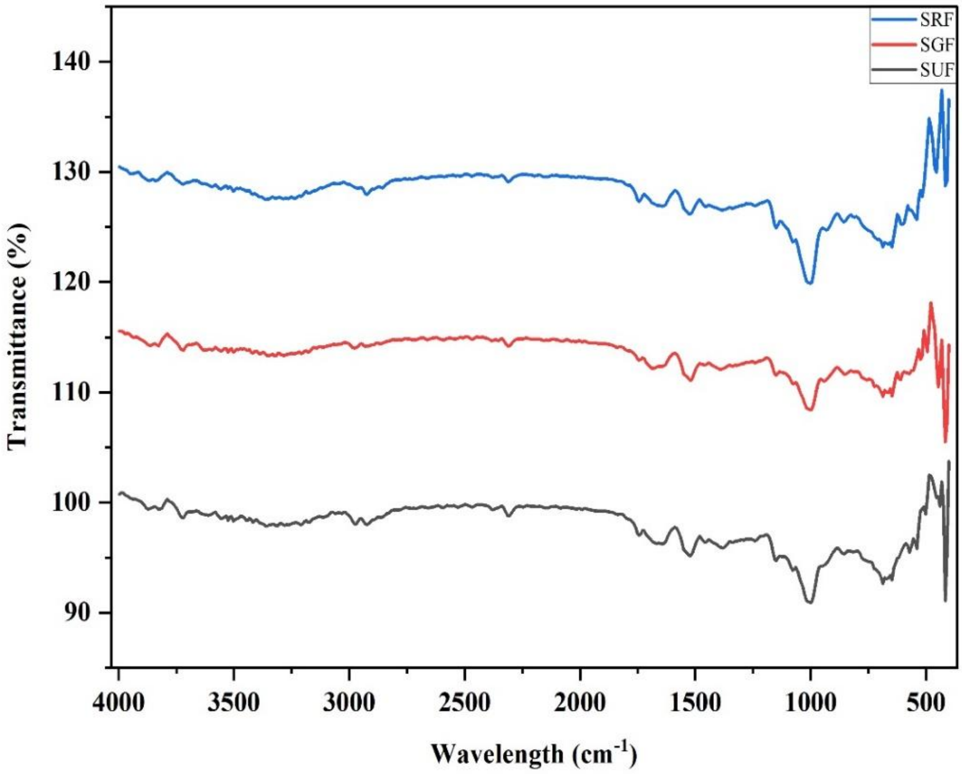


Figure – 6

FTIR of Sorghum Flour

4.1.5.2 XRD OF MILLET FLOUR

The crystalline nature and crystal size of processed and unprocessed pearl millet and sorghum flour were analysed using X-Ray diffraction (XRD).

i. XRD of Pearl millet Flour

The unprocessed pearl millet flour (PMUF) exhibited sharp peaks with 2θ values ranging from 11.86° to 62.98°, peak intensities of 40.93–1294.89 counts (cts), and FWHM values between 0.05° and 0.8°, that indicated a crystalline structure with an average crystallite size of 77.51 nm. Germinated flour (PMGF) showed peaks at 2θ values of 11.85°–55.60° with reduced intensities (24.94–708.16 cts) and FWHM values of 0.05°–0.08°, that exhibited partial crystalline disruption due to germination, with an average crystallite size of 78.34 nm. Roasted pearl millet flour (PMRF) exhibited peaks between 11.88° and 40.62° 2θ, with sharper intensities (up to 729 cts) and FWHM values of 0.05°–0.66°, which exhibited enhanced crystallinity with a crystallite size of 94.70 nm. The structural alterations suggested that, the crystallinity of roasted pearl millet flour was increased and the same was decreased in germinated pearl millet flour. The result of the present study is supported by the findings of Sharma & Sharma (2022), stating that the crystallinity index of pearl millet decreased after soaking and germination due to swelling and water absorption properties.

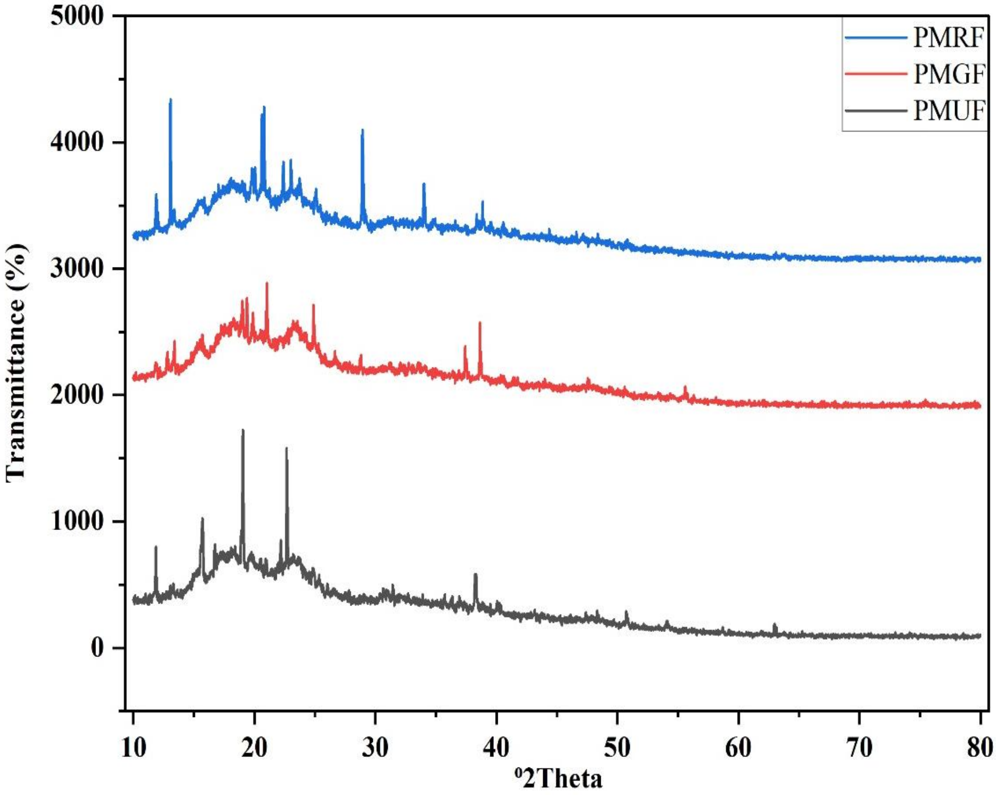


Figure – 7

XRD of Pearl millet Flour

ii. XRD of Sorghum Flour

Unprocessed sorghum flour exhibited primary reflections at 2θ values of 11.8°, 13.6°, 15.38°, 16.1°, 19.1°, 20.9°, 21.3°, 22.7°, 23.7°, 25.1°, 31.2°, 38.7°, 40.6°, 41.7°, 44.0°, 60.8°, and 61.0°, with sharp peaks indicating a well-defined crystalline structure. The crystal size was 88.92 nm, which was calculated using the Debye-Scherrer formula. Germinated sorghum flour displayed peaks at 2θ values of 12.0°, 15.3°, 19.1°, 21.1°, 22.4°, 24.9°, 25.5°, 27.6°, 31.3°, 32.1°, 36.3°, 38.5°, and 54.3°, with a crystal size of 55.91 nm. The peaks were less intense and more diffused, due to crystalline disruption of double helices, which influenced the structural characteristics of millet flour. Roasted sorghum flour exhibited prominent peaks at 2θ values of 13.1°, 15.6°, 16.8°, 19.8°, 22.3°, 24.7°, 25.3°, 32.0°, 38.4°, 40.4°, 43.6°, and 40.1°, with a crystal size of 65.25 nm. The alterations in diffraction patterns were consistent with structural change observed during fermentation and malting of sorghum and pearl millet, as reported by Olamiti *et al*. (2020). Similarly, the water and other raw material incorporation influenced the particle size of the flour, as smaller particle sizes enhanced the water absorption properties (Akinola *et al*., 2017). The unprocessed pearl millet and sorghum flour had the highest crystallinity with sharp peaks, whereas germinated pearl millet and sorghum flour exhibited reduced crystallinity due to structural disruption of double helices shape. Roasted pearl millet and sorghum flour increased the crystallinity, resulting in intermediate crystal sizes and sharper peaks than germinated millet flour and it confirmed that germinated millet flour exhibited lesser structural changes than roasted forms. The result of the present study is on par with the findings of Olamiti *et al*. (2020).

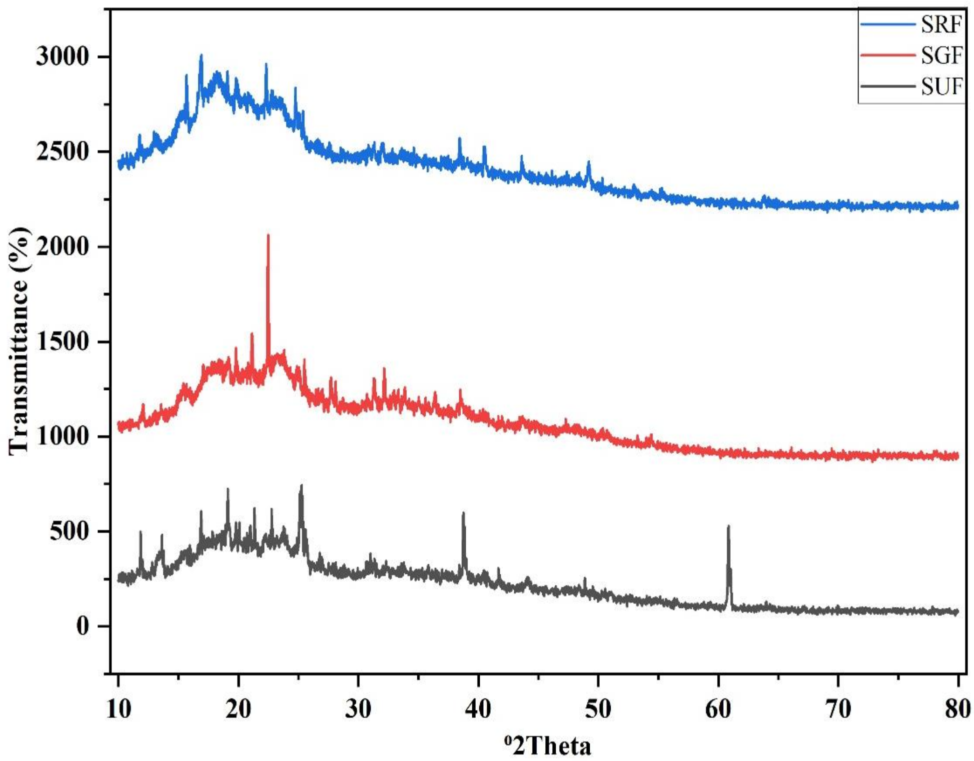


Figure – 8

XRD of Sorghum Flour

The results of Phase I showed that, conventional processing like germination and roasting of pearl millet and sorghum showed significant differences in terms of physical, technological, and functional properties. Grain size, grain volume, length and bulk density of millet were decreased during germination with reduced water and oil absorption capacities. Roasting millet, improved water and oil absorption with lower moisture levels. Sorghum showed higher swelling and absorption properties than pearl millet. Germination and roasting of pearl millet and sorghum increased total phenolic content and decreased anti-nutritional factors like phytic acid, saponin and tannin. FTIR showed sharp peaks between amylose and amylopectin region and XRD showed decreased crystalline size after processing. The result obtained from physical, technological and functional properties of unprocessed, germinated and roasted pearl millet and sorghum flour aided in the formulation of thick batter for millet tableware standardisation with varying proportions of millet flour and binder.

PHASE - II

4.2 CHARACTERISATION OF STANDARDISED MILLET TABLEWARE

4.2.1 PHYSICAL PROPERTIES OF STANDARDISED MILLET TABLEWARE

Length, breadth, height and weight of the millet tableware including cup, bowl, katori, spoon and plate was discussed in Table XI.

Table XI

Physical Properties of Millet Tableware

S. No	Millet Tableware	Measurement	Size (cm)	Average Weight (g)	Thickness (mm)
1	Cup	b x h	3.8 x 5.8	15.14 ± 3.19	2
2	Bowl	l x b x h	10 x 10 x 2	20.87 ± 3.58	2.5
3	Katori	l x b x h	10 x 10 x 2	19.20 ± 2.35	2.5
4	Spoon	l (bowl, handle) x b	3.2, 1.2 x 12.5	8.51 ± 1.29	1.5
5	Quarter Plate	l x b x h	15 x 15 x 2	42.32 ± 4.69	2.5

The millet tableware was done in a closed mold and the measurements were discussed. The weight of the standardised millet tableware varied, and processing (unprocessed, germinated and roasted) of millet played a vital role. The average weight of the cup, bowl, katori, spoon and plate were 15.14 ± 3.19 g, 20.87 ± 3.58 g, 19.20 ± 2.35 g, 8.51 ± 1.29 g and 42.32 ± 4.69 g, respectively.

Different permutation and combinations were trailed and only one proportion was standardised for further characterisation and enrichment. The best selected standardised variation for the formulation of cup, bowl, katori, spoon, and plate were Variation IV in unprocessed and roasted pearl millet and sorghum flour, as well as Variation V in germinated pearl millet and sorghum. Nutrient analysis, optical property, sensory evaluation, functional and mechanical properties of the finalized variations were discussed in Phase - II.

4.2.2 PROMIXATE AND NUTRIENT ANALYSIS OF MILLET TABLEWARE

The proximate and nutrient analysis of standardised millet tableware from pearl millet and sorghum in unprocessed and processed flour revealed a significant difference. Sorghum tableware generally had higher moisture percentage compared to pearl millet tableware. Ash content of pearl millet and sorghum showed a significant difference between unprocessed and processed variants. Carbohydrate content was higher in sorghum tableware, particularly in unprocessed and roasted forms. Protein content was the highest in sorghum as compared to pearl millet and roasted tableware exhibited significant difference than unprocessed pearl millet and sorghum tableware. Fat content significantly reduced after germination and roasting in pearl millet and sorghum. Fiber content was higher in roasted forms as compared to unprocessed and germinated tableware.

Table XII

Proximate and Nutrient Analysis of Standardised Millet Tableware

S. No	Nutrient Analysis	Pearl millet			Sorghum			F value
		PMUT	PMGT	PMRT	SUT	SGT	SRT	
1	Moisture (%)	3.20 ± 0.02	3.43 ± 0.09	3.21 ± 0.05	3.57 ± 0.04	3.51 ± 0.06	3.51 ± 0.06	41.59*
2	Ash (%)	12.72 ± 0.09	12.94 ± 0.10	12.62 ± 0.04	12.25 ± 0.04	12.43 ± 0.08	12.70 ± 0.24	12.24*
3	Carbohydrate (g)	60.35 ± 0.13	60.32 ± 0.07	64.29 ± 0.08	72.35 ± 0.12	71.86 ± 0.21	72.82 ± 0.12	6093.09*
4	Protein (g)	9.78 ± 0.06	9.41 ± 0.11	9.94 ± 0.47	10.34 ± 0.13	10.14 ± 0.1	11.90 ± 0.14	218.73*
5	Fat (g)	6.20 ± 0.04	5.96 ± 0.05	5.74 ± 0.12	1.9 ± 0.07	1.61 ± 0.04	1.86 ± 0.11	2407.83*
6	Fiber (g)	11.19 ± 0.10	10.94 ± 0.17	12.24 ± 003	10.62 ± 0.07	10.38 ± 0.09	12.41 ± 0.16	295.52*
7	Vitamin C (mg)	0.32 ± 0.08	0.36 ± 0.05	0.39 ± 0.02	0.37 ± 0.05	0.38 ± 0.06	0.33 ± 0.09	0.583**
8	Iron (mg)	6.43 ± 0.06	6.50 ± 0.04	7.16 ± 0.09	3.85 ± 0.11	3.94 ± 0.08	4.25 ± 0.08	1005.08*
9	Calcium (mg)	32.34 ± 0.06	32.42 ± 0.05	32.96 ± 0.60	33.36 ± 0.16	33.54 ± 0.2	33.61 ± 0.17	12.17*

10	Phosphorus (mg)	196.9 ± 0.19	197.16 ± 0.13	199.54 ± 0.19	152.96 ± 0.08	153.28 ± 0.16	157.72 ± 0.10	75882.41*
*Significant, **Not Significant (*p<0.05*), PMUT- Unprocessed Pearl millet Tableware, PMGT – Germinated Pearl millet Tableware, PMRT – Roasted Pearl millet Tableware, SUT – Unprocessed Sorghum Tableware, SGT – Germinated Sorghum Tableware, SRT – Roasted Sorghum Tableware								

Vitamin C exhibited no significant differences among all the variations. Pearl millet tableware showed the highest iron content than sorghum tableware especially in its roasted variation. Calcium was relatively consistent across all millet tableware, with roasted variants exhibited a slightly higher content. Phosphorus content was the highest in roasted pearl millet tableware (PMRT). Roasted pearl millet tableware exhibited highest nutrient content, especially fiber, iron and phosphorous content, while sorghum tableware excelled in carbohydrate, protein and calcium content. Gwekwe, *et al*. (2024) and Rahman *et al*. (2023) recorded the same results in millet. The reduction in protein content in germinated pearl millet and sorghum tableware attributed to the proteolysis, which break down protein into free amino acids like lysine and methionine, and the redistribution of nitrogenous material to support embryonic growth. Roasted pearl millet and sorghum tableware, showed enhanced protein content due to the concentration effect from moisture loss and the inactivation of proteolytic enzymes during roasting. Sunil *et al.* (2024) found that increase in dietary fiber in millet during processing was due to changes and biosynthesis of cell wall polysaccharides and disrupt in protein-carbohydrate interactions. Kayisoglu *et al*. (2024) found that iron and calcium content increased upto two per cent after soaking and germination. Multi-millet edible bowl provided a higher content of dietary fiber and protein while delivering lower levels of calories, fat, and moisture (Jaspal *et al.,* 2024). Further, Molu *et al*. (2024b), developed edible dessert cup from finger millet that exhibited, 83 g of carbohydrate, 9 g of protein, 3 g of fat and 1 g of crude fiber which resulted in lower nutritive value than the tableware developed in the present study, except carbohydrate. Kaur & Gill (2021) found the similar results in pearl millet flour that during germination, protein, fat and fiber decreased due to enzymatic degradation and physiochemical changes.

4.2.3 SENSORY EVALUATION OF STANDARDISED MILLET TABLEWARE

The sensory evaluation was done for standardised millet tableware by 30 semi-trained panel members using 9-point hedonic scale and the sensory scores is given in Table XIII.

Table XIII

Sensory Evaluation of Standardised Millet Tableware

S. No	Millet Tableware	Shape or Appearance	Colour	Taste	Flavour	Crispiness	Overall Acceptability
Sensory Evaluation of Standardised Millet Cup							
1	**PMUC**	8.7 ± 0.48	8.2 ± 0.91	7.9 ± 0.73	8 ± 0.94	8.5 ± 1.08	8.1 ± 1.10
2	**PMGC**	8.8 ± 0.42	8.4 ± 0.91	8.1 ± 0.37	8.3 ± 0.45	8.6 ± 0.96	8.4 ± 0.09
3	**PMRC**	8.1 ± 0.99	7.7 ± 0.82	7.9 ± 1.10	7.4 ± 0.84	7.9 ± 1.10	8.2 ± 0.63
4	**SUC**	8.1 ± 0.56	8.1 ± 0.73	7.8 ± 1.12	7 ± 0.94	7.6 ± 0.96	7.3 ± 0.67
5	**SGC**	8.6 ± 0.66	8.6 ± 0.66	8.3 ± 0.80	8.1 ± 0.83	8.4 ± 0.72	8.4 ± 0.72
6	**SRC**	7.8 ± 1.54	8.5 ± 0.70	7.7 ± 1.49	7.6 ± 0.69	8.2 ± 1.31	7.9 ± 0.87
F Value		1.93**	2.07**	0.44**	3.81*	1.42**	2.41*
Sensory Evaluation of Standardised Millet Bowl							
7	**PMUB**	8.3 ± 0.83	8.1 ± 0.73	7.6 ± 0.84	8.1 ± 0.87	8 ± 0.81	7.6 ± 0.96
8	**PMGB**	8.4 ± 0.09	8.0 ± 0.35	7.8 ± 0.25	8.3 ± 0.01	7.9 ± 0.12	8.0 ± 0.14
9	**PMRB**	8.3 ± 0.67	7.7 ± 0.48	6.9 ± 0.87	7.4 ± 0.51	8 ± 0.81	7.7 ± 0.67
10	**SUB**	8 ± 0.81	7.6 ± 0.96	7.6 ± 0.84	6.7 ± 0.48	7.2 ± 0.91	7.4 ± 0.51
11	**SGB**	8.1 ± 0.72	8.1 ± 0.39	7.8 ± 0.12	6.9 ± 0.13	7.6 ± 0.42	7.9 ± 0.32
12	**SRB**	8.4 ± 0.84	8.3 ± 0.82	7.5 ± 0.84	7.4 ± 0.69	8.4 ± 0.96	7.8 ± 0.73
F Value		0.406**	0.99**	1.88**	12.65*	2.27**	0.79**
Sensory Evaluation of Standardised Millet Katori							
13	**PMUK**	8.3 ± 0.82	8.5 ± 0.52	7.3 ± 1.33	7.7 ± 0.67	8 ± 1.05	8 ± 0.94
14	**PMGK**	8.5 ± 0.53	8.2 ± 0.16	7.5 ± 0.97	7.9 ± 0.12	7.9 ± 0.64	8.2 ± 0.12
15	**PMRK**	8.8 ± 0.42	8.6 ± 0.51	7.4 ± 1.07	7.6 ± 0.96	7.7 ± 1.25	8.2 ± 0.78
16	**SUK**	8.2 ± 1.03	8.4 ± 0.69	6.9 ± 0.87	7.1 ± 0.87	7 ± 0.94	7.8 ± 0.62
17	**SGK**	8.2 ± 1.03	8.4 ± 0.69	7.2 ± 0.87	7.1 ± 0.87	7 ± 0.94	7.8 ± 0.03
18	**SRK**	8.7 ± 0.48	8.6 ± 0.69	7.9 ± 0.73	7.8 ± 0.91	7.9 ± 1.10	8 ± 0.81
F Value		1.11**	0.57**	3.85*	1.80**	1.95**	0.33**

Sensory Evaluation of Standardised Millet Spoon							
19	**PMUS**	8.6 ± 0.51	8.2 ± 0.78	8.1 ± 0.73	7.8 ± 1.13	8.3 ± 1.05	8.1 ± 0.87
20	**PMGS**	8.3 ± 0.43	8.1 ± 0.69	8.3 ± 0.14	8 ± 0.56	8.2 ± 0.97	8.0 ± 0.43
21	**PMRS**	8.3 ± 0.67	7.7 ± 0.94	6.9 ± 1.28	7.2 ± 1.22	7.4 ± 0.84	8.1 ± 0.56
22	**SUS**	8.3 ± 0.48	8.1 ± 0.56	7.7 ± 1.25	7 ± 0.66	7.6 ± 1.17	7.6 ± 0.69
23	**SGS**	8.2 ± 0.23	8.0 ± 0.54	7.9 ± 0.02	7.5 ± 0.27	7.9 ± 0.87	8.1 ± 0.72
24	**SRS**	8.8 ± 0.42	8.8 ± 0.42	8.2 ± 0.78	7.9 ± 0.56	8.2 ± 1.03	8.2 ± 0.78
F Value		1.45**	3.05*	3.19*	1.97**	1.40**	1.05**
Sensory Evaluation of Standardised Millet Plate							
25	**PMUP**	8.9 ± 0.31	8.6 ± 0.51	8.5 ± 0.52	8.7 ± 0.48	8.5 ± 0.97	8.7 ± 0.67
26	**PMGP**	8.3 ± 0.47	8.2 ± 0.24	8.3 ± 0.13	8.4 ± 0.12	8.3 ± 0.43	8.3 ± 0.43
27	**PMRP**	8.8 ± 0.63	7.8 ± 0.91	7.2 ± 1.31	7.3 ± 0.94	7.2 ± 1.81	8 ± 0.66
28	**SUP**	8.6 ± 0.51	8.1 ± 0.87	7.2 ± 0.91	7.5 ± 0.91	7.5 ± 1.08	8.1 ± 0.56
29	**SGP**	8.5 ± 0.42	8.2 ± 0.14	7.8 ± 0.87	7.6 ± 0.63	7.9 ± 0.93	8.4 ± 0.12
30	**SRP**	8.9 ± 0.31	8.6 ± 0.51	7.8 ± 1.22	8.2 ± 0.91	8.4 ± 0.84	8.5 ± 0.84
F Value		2.20**	1.68**	3.50*	5.13*	2.20*	1.39**
*Significant, **Not Significant ($p<0.05$)							

The overall acceptability of unprocessed cup (PMUC and SUC) was in the liked moderate to liked very much category, and PMUC exhibited high scores than SUC. Germinated pearl millet (PMGC) and sorghum (SGC) cup, scored the highest overall acceptability (8.4) among all the variants. PMGC exhibited the highest score for shape or appearance (8.8), and crispiness (8.6), which proved that, germination enhanced the sensory attributes through improved texture. Roasted cup (PMRC and SRC) exhibited lower scores in taste and flavour, due to the change in flavour during roasting. PMRC scored higher overall acceptability (8.2) compared to SRC (7.9), emphasizing the superior sensory attributes of pearl millet than sorghum when roasted. The germinated pearl millet and sorghum cup exhibited the highest sensory attributes when compared to its unprocessed and roasted counterparts.

Unprocessed pearl millet bowl (PMUB) showed liked very much scores in shape (8.3), colour and flavour (8.1). Germinated pearl millet bowl (PMGB) achieved the highest overall acceptability (8.0), attributed to its balanced flavour (8.3), shape (8.4), and crispiness (7.9). Roasted pearl millet bowl (PMRB) scored lower overall (7.7), with a significant drop in taste (6.9), likely due to flavour changes caused by roasting. Among sorghum variants, germinated sorghum bowl (SGB) had the highest overall acceptability (7.9), and SRB with strong performance in crispiness (8.4) and colour (8.3) that showed moderate acceptability (7.8). Unprocessed sorghum bowl (SUB) scored the lowest in flavour (6.7) and overall acceptability (7.4), indicating limitations in sensory appeal compared to pearl millet counterparts. Sensory evaluation of millet bowl showed, pearl millet bowl, especially the germinated variation, scored high acceptability than sorghum bowl.

Among pearl millet katori, the roasted variant (PMRK) exhibited the highest scores in shape and appearance (8.8) and colour (8.6), showed enhanced visual appeal due to roasting. Germinated pearl millet katori (PMGK) showed high scores in taste, flavour, crispiness and overall acceptability (8.2), indicated that germination increased the sensory attributes. Unprocessed pearl millet katori (PMUK) also scored well, with liked very much scores in colour (8.5) and overall acceptability (8.0). While, sorghum katori exhibited slightly lower sensory scores as compared to pearl millet katori. Roasted sorghum katori (SRK) showed the highest acceptability (8.0) among sorghum variants, with liked moderately scores for taste and crispiness (7.9). However, both unprocessed (SUK) and germinated sorghum katori (SGK) had lower scores in taste (6.9, 7.2) and overall acceptability (7.8). Sensory evaluation of millet katori exhibited, pearl millet katori particularly in the roasted and germinated forms scored superior scores than sorghum katori.

The sensory evaluation of standardised millet spoon highlighted that, roasted sorghum spoon (SRS) exhibited the highest scores in shape or appearance (8.8) and colour (8.8), taste (8.2) and overall acceptability (8.2). Unprocessed pearl millet spoon (PMUS) exhibited liked very much scores in taste (8.1), crispiness (8.3), and overall acceptability (8.1), and suggested that minimal processing can preserve favourable sensory qualities. Pearl millet (PMGS) and Sorghum (SGS) germinated spoon showed consistent, liked very much scores in all parameters, though slightly lower than the roasted counterparts. In contrast, roasted pearl millet spoon (PMRS) had lower taste (6.9) and crispiness (7.4) scores but exhibited good overall acceptability (8.1). Similarly, unprocessed sorghum spoon (SUS) and germinated sorghum spoon (SGS) had moderate scores, with taste and flavour. Sensory evaluation of spoon showed that, roasted sorghum spoon scored like very much in all sensory characteristics which was higher as compared to unprocessed and germinated spoon.

The sensory evaluation of standardised millet plate revealed that, unprocessed pearl millet plate (PMUP) and roasted sorghum plate (SRP) scored the highest overall acceptability (8.7 and 8.5). PMUP also exhibited the highest scores in taste and flavour (8.5

and 8.7) while, germinated pearl millet (PMGP) and sorghum plate (SGP) scored liked very much overall acceptability (8.3 and 8.4), that exhibited germination enhanced the favourable sensory attributes. Roasted pearl millet plate (PMRP) showed liked moderately scores in taste (7.2) and crispiness (7.2), and liked very much in appearance (8.8), indicating slightly reduced in colour, taste, flavour and crispiness due to roasting. Similarly, unprocessed sorghum plate (SUP) had moderate scores in taste and crispiness. Overall, unprocessed pearl millet plate (PMUP) and roasted sorghum plate (SRP) resulted in the highest sensory scores, while germinated variants showed a consistent liked very much scores, emphasizing the importance of processing in optimizing millet tableware.

Sensory evaluation of the millet tableware exhibited different scores according to the shape (cup, bowl, katori, spoon and plate) and process (unprocessed, germinated and roasted). All the tableware in unprocessed, germinated and roasted forms scored liked moderately to liked very much category. Specifically, spoon in all variants scored superior sensory attributes as compared to other tableware. Unprocessed and germinated variants scored more as compared to roasted variants. The observed result is similar with the finding of, Putri *et al.* (2022), experimented on consumer acceptability of sorghum-based ice cream cones among 100 consumers and found 70 per cent of sorghum flour with 30 per cent tapioca flour to be highly acceptable. Similarly, Mandal & Antarkar (2024) found that, pearl millet and sorghum wafer cones scores indicate liked very much to liked extremely in 5-point hedonic scale and malting of grains further enhanced the sensory attributes. Molu *et al.* (2024b) stated that, the edible dessert cup made from finger millet, maize and guar gum scored good organoleptic qualities in colour, flavour and taste while appearance and texture scored less due to the coarse nature of finger millet flour used. Further, edible bowl made up of wheat flour, semolina and citrus peel was highly acceptable (Stuti & Virginia, 2022).

4.2.4 FUNCTIONAL PROPERTIES OF STANDARDISED MILLET TABLEWARE

Fourier Transform Infrared Spectroscopy (FTIR) and Thermo Gravimetric Analysis (TGA) were done for standardised millet tableware to determine the presence of functional compounds and to observe its thermal degradation.

4.2.4.1 FTIR OF STANDARDISED MILLET TABLEWARE

i. FTIR of Standardised Pearl millet Tableware

The FTIR spectrum of tableware from unprocessed (PMUT), germinated (PMGT) and roasted (PMRT) pearl millet tableware exhibited distinct characteristics and the graph is shown in Figure - 9.

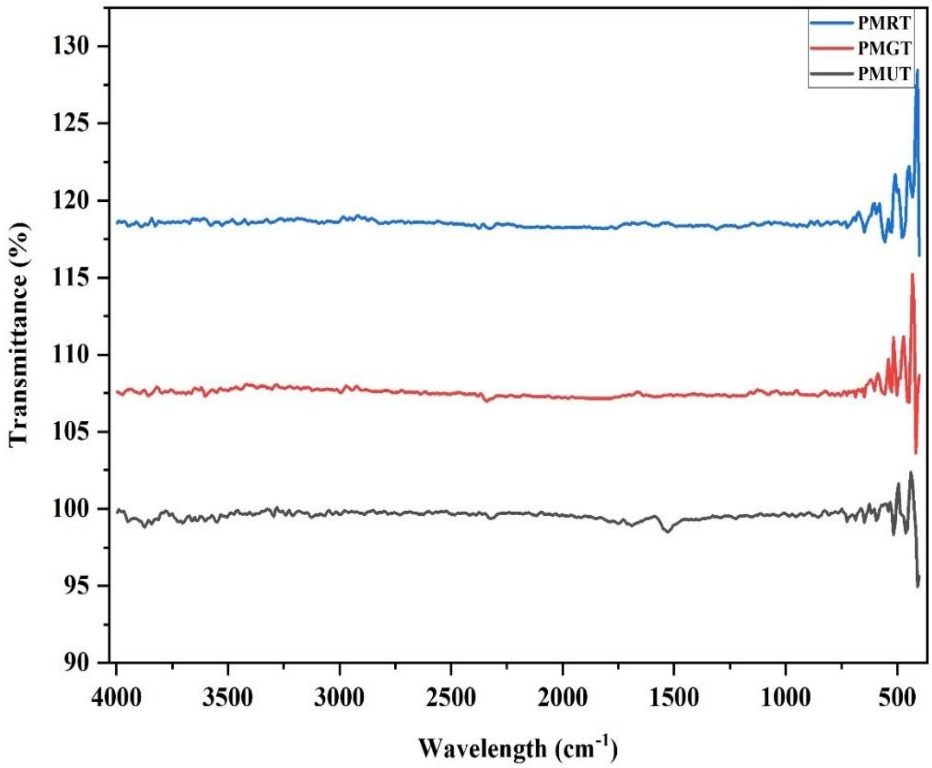


Figure - 9

FTIR of Standardised Pearl millet Tableware

The unprocessed and germinated pearl millet (PMUT, PMGT) tableware showed a sharp peak at 3603 cm^{-1} and a weaker peak at 3857 cm^{-1}, corresponding to O-H stretching vibrations, showed the presence of water and hydroxyl groups. However, the peaks were less prominent compared to PMRT, reflected a reduction in moisture content likely due to roasting and baking. PMGT exhibited prominent peaks in the range of 648 cm^{-1} to 447 cm^{-1}, which showed that, the rearrangement of polysaccharides and lipids, whereas PMRT exhibited similar peaks with slightly less intensity. The sharp peaks highlighted an intermediate state of molecular ordering compared to the more pronounced changes observed in the unprocessed tableware (PMUT). Additionally, the absence of strong peaks around 1689 cm^{-1} and 1527 cm^{-1} in PMUT and PMRT, showed a lesser degree of structural changes in protein components during processing. The FTIR analysis of PMUT, PMRT, and PMGT highlighted a progressive change in molecular structure from unprocessed to roasted and germinated forms. PMUT retained its original moisture and hydroxyl properties, but PMRT had significant crystallinity and less moisture, and PMGT had mild structural alterations. The peaks between 1200 cm^{-1} to 800 cm^{-1} was due to O-H and C-H bond which was present in PMUT, PMGT and PMRT. Less intensive peaks were found between 700 – 800 cm^{-1} which confirmed the presence of phenols or flavonoids in PMGT and PMRT which was also confirmed by the quantitative study in Phase - I. The result of present study is supported by the findings of, Kaur & Gill (2021) stated that, germination showed decreased peaks due to partial depolymerization of amides. Prasad & Sahu (2023) found, similar peaks in the region of 700 – 1200 cm^{-1} in soaked and germinated pearl millet. Sharma & Sharma (2022) also found that the peaks between 750 – 880 cm^{-1} was due to the presence of aromatic rings and phenolic compounds in soaked and germinated pearl millet.

ii. FTIR of Standardised Sorghum Tableware

The FTIR spectra of sorghum unprocessed, germinated, and roasted (SUT, SGT, and SRT) tableware showed various distinctive peaks due the presence of chemical compositions, as shown in Figure - 10.

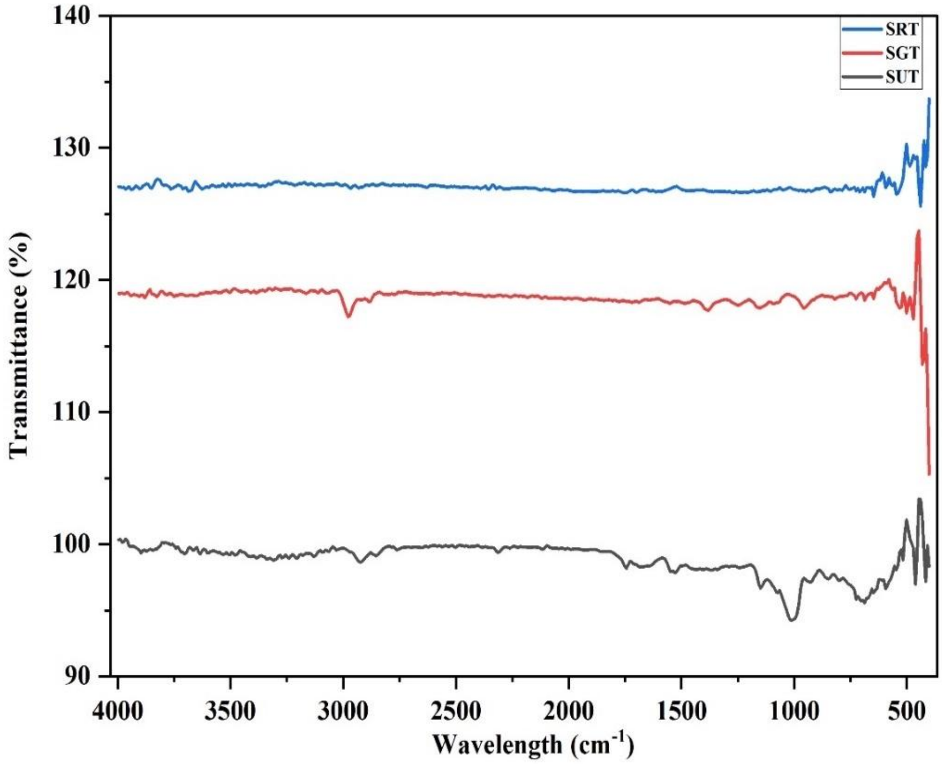


Figure – 10

FTIR of Standardised Sorghum Tableware

The unprocessed sorghum tableware (SUT) spectrum exhibited the presence of significant peaks at 3703 cm^{-1} (indicative of O–H stretching from hydroxyl groups), 2924 cm^{-1} (C–H stretching of aliphatic compounds), and 1743 cm^{-1} (C=O stretching, showed the presence of esters or carboxylic acids). The peaks at 1527 cm^{-1} exhibited N–H bending, and the peaks around 1149 cm^{-1} - 1010 cm^{-1} exhibited C–O stretching, due to the presence of carbohydrates or esters, while the region below 800 cm^{-1} reflected C–H bending or other skeletal vibrations. The SRT spectrum showed sharp peaks around 648, 594, 547, and 439 cm^{-1} due to the presence of organic or mineral components. The peaks at SGT exhibited peaks at, 2978 cm^{-1} correspond to C–H stretching, indicated the presence of aliphatic hydrocarbons. A weak O–H stretching peak exhibited near 3826 cm^{-1} due to residual hydroxyl groups and a sharp peak at 1381 cm^{-1} showed C–H bending, due to the presence of methyl or methylene groups.

Peaks at 1149 cm^{-1} and 956 cm^{-1} indicate C–O stretching, commonly linked to esters, ethers, or carbohydrates. The broader fingerprint region below 800 cm^{-1}, with peaks at 725, 686, and 532 cm^{-1}, due to inorganic skeletal vibrations. SUT had a greater abundance of organic functional groups, such as hydroxyls, carbonyls, and amides and SGT that emphasised on inorganic compounds and less organic compounds whereas SRT primarily had inorganic compounds. The result of the present study is similar to the findings of Lin *et al.* (2021), who identified similar peaks in sorghum flour. Kaur & Gill (2021) observed the changes in amide 1 and carbohydrate region which was due to partial depolymerization of protein and polysaccharide molecules during germination. Shukla *et al*. (2024) observed similar peaks around the 1700 cm^{-1} region due to C=O peaks in popped finger millet. Sharanagat *et al*. (2024) and Batariuc *et al*. (2021) found similar peaks in dry and microwave roasted sorghum.

4.2.4.2 TGA OF STANDARDISED MILLET TABLEWARE

i. TGA of Standardised Pearl millet Tableware

The thermo-gravimetric analysis (TGA), of unprocessed, germinated and roasted pearl millet tableware was done to analyse the thermal stability, composition, and degradation behaviour over 20ºC to 1000ºC and the peaks were plotted in Figure - 11.

Unprocessed, germinated and roasted pearl millet tableware weighing 11.30 mg, 6.37 mg and 7.87 mg were taken to analyse thermal degradation. The first peak (20°C–200°C), attributed to the loss of moisture and volatile organic compound, PMUT, PMGT and PMRT exhibited 5.1 per cent, 6.4 per cent and 4.9 per cent of weight loss. The second peak (300°C–680°C), showed a 68.1, 49.1 and 67.9 percentage of weight loss in PMUT, PMGT and PMRT respectively, which indicated the decomposition of organic (cellulose, hemicellulose, and lignin) compounds. Upto 3 percentage of thermal degradation was found in the third peak (650°C - 950°C) suggested the minimal decomposition of inorganic compounds. The total weight loss (20°C–980°C) ranged from 77.6 per cent (PMUT), 88.8 per cent (PMGT) and 123.7 per cent (PMRT) represented a significant thermal degradation in germinated and roasted pearl millet tableware as compared with unprocessed pearl millet tableware. The finding of the present study is supported by Vidhyalakshmi & Meera (2023), Mirzababaee *et al*. (2022), and Yen *et al*. (2021) reported a decreased gelatinization enthalpy in roasted or thermally treated pearl millet as compared to its untreated form at a temperature below 100°C.

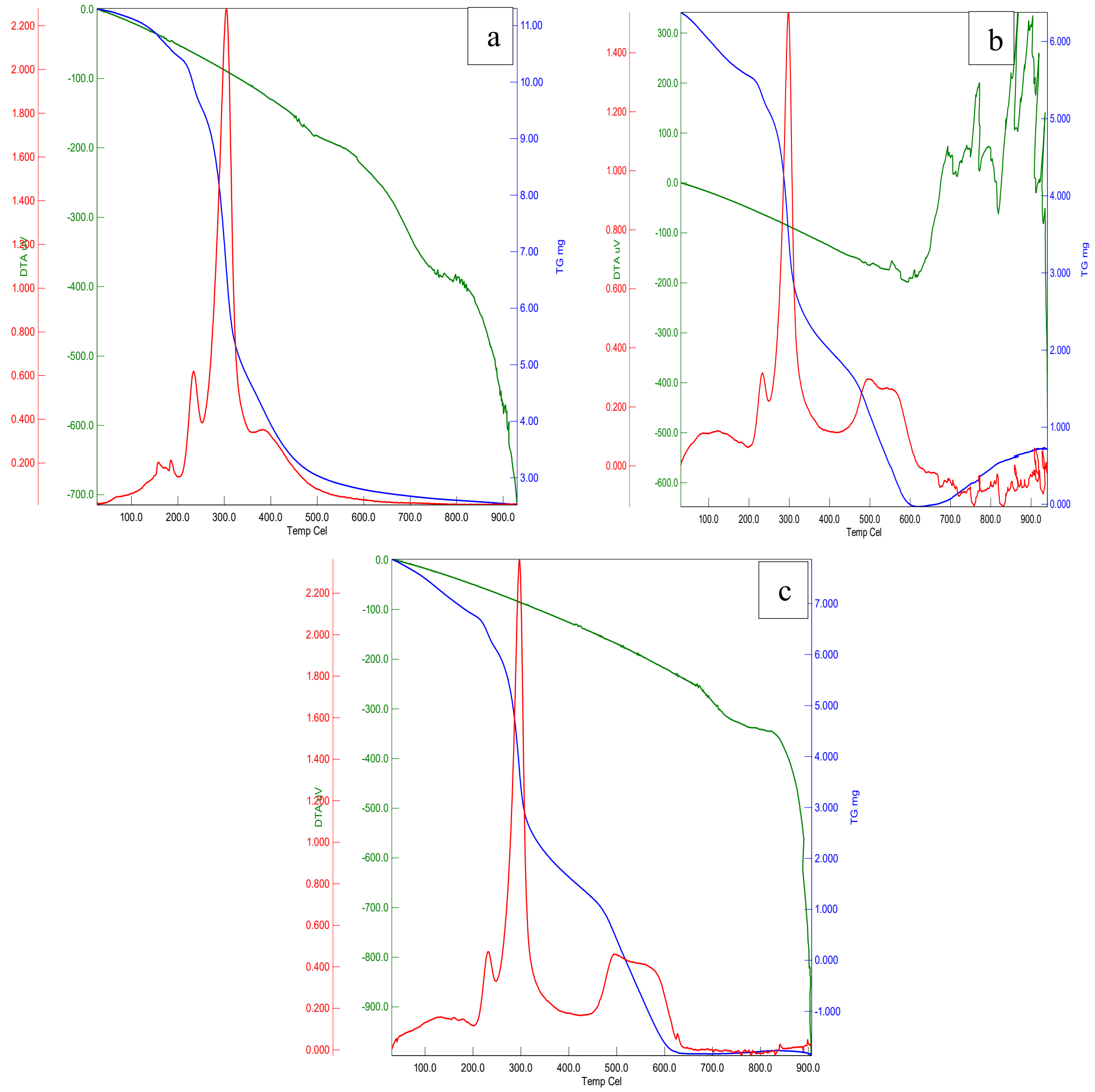


Figure – 11

TGA of Pearl millet Tableware, a. Unprocessed Pearl millet Tableware, b. Germinated Pearl millet Tableware, c. Roasted Pearl millet Tableware

ii. TGA of Standardised Sorghum Tableware

Thermal degradation of unprocessed, germinated and roasted sorghum tableware was found between 20ºC to 1000ºC is given in Figure – 12.

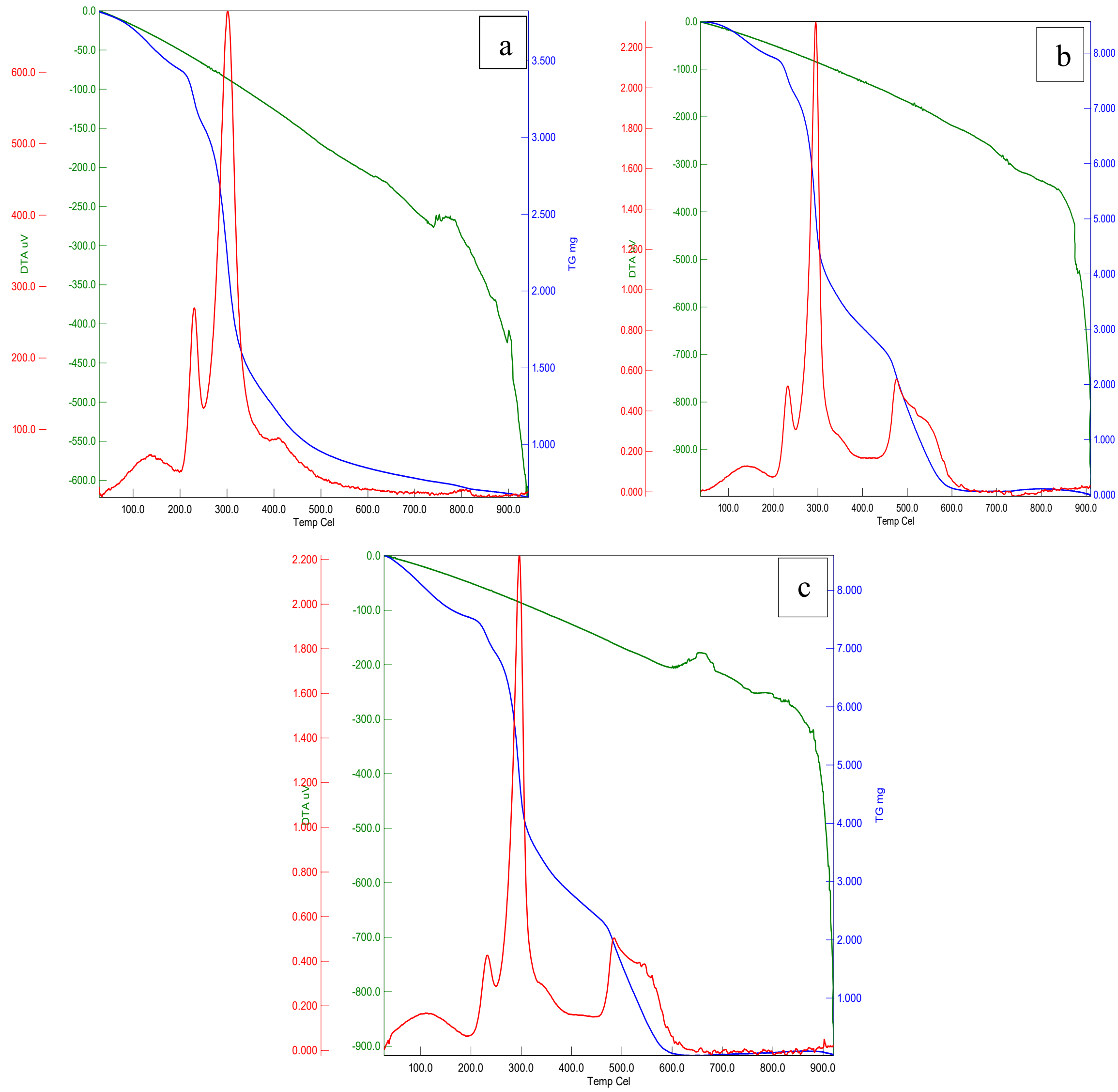


Figure – 12

TGA of Sorghum Tableware, a. Unprocessed Sorghum Tableware, b. Sorghum Germinated Tableware, c. Roasted Sorghum Tableware

The thermal decomposition, weight loss and phase transition were determined by 3.82 mg, 8.6 mg, and 8.57 mg, of unprocessed (SUT), germinated (SGT) and roasted (SRT) sorghum tableware. Between 20°C to 100°C, 3.82 per cent, 8.6 per cent and 8.57 per cent of weight loss in SUT, SGT, and SRT was indicated the elimination of bound water. The second peak, which occurred between 100°C and 280°C, showed 40 per cent, 57.6 per cent, and 52.4 per cent mass loss in SUT, SGT, and SRT due to polysaccharide degradation, particularly starch and cellulose. The third peak was observed between, 300°C to 680°C, and exhibited a mass thermal degradation of 33 per cent, 35.2 per cent, and 41 per cent in SUT, SGT, and SRT indicating the degradation of lignin and protein. Minimal loss between

680°C to 900°C, showed the decomposition of other organic compounds ranging from 2 to 5 per cent.

A total thermal loss of 82.8 per cent in SUT, 99.8 per cent in SGT, and 100.3 per cent in SRT was observed. SGT and SRT exhibited a total degradation whereas SUT exhibited 17.2 per cent of residues. The study is on par with the findings of Singh *et al*. (2024) who stated that, germination of sorghum lowered gelatinization temperature due to alteration of polysaccharides. Batariuc *et al*. (2021) found that, dry roasted sorghum showed an impact on kernel hardness and softened the endosperm. The initial step involved moisture dehydration from 25 to 200°C, and protein, carbohydrate, and lipid breakdown at 200 - 550°C due to depolymerization, decarboxylation, and cracking reactions and other organic components degraded at 550 - 800°C (Yen *et al*., 2021). Roasted sorghum exhibited destruction of crystalline structure, starch gelatinization, amylose-lipid bonds in increasing temperature from 30 to 310ºC (Sharanagat *et al*., 2024).

4.2.4.4 WATER ABSORPTION RATE OF STANDARDISED MILLET TABLEWARE

i. Water Absorption Rate of Standardised Millet Tableware at Ambient Temperature

The table XIV presents the water absorption rate (%) of pearl millet and sorghum tableware at 20, 30 and 40 minutes at 32ºC which was the ambient food serving temperature.

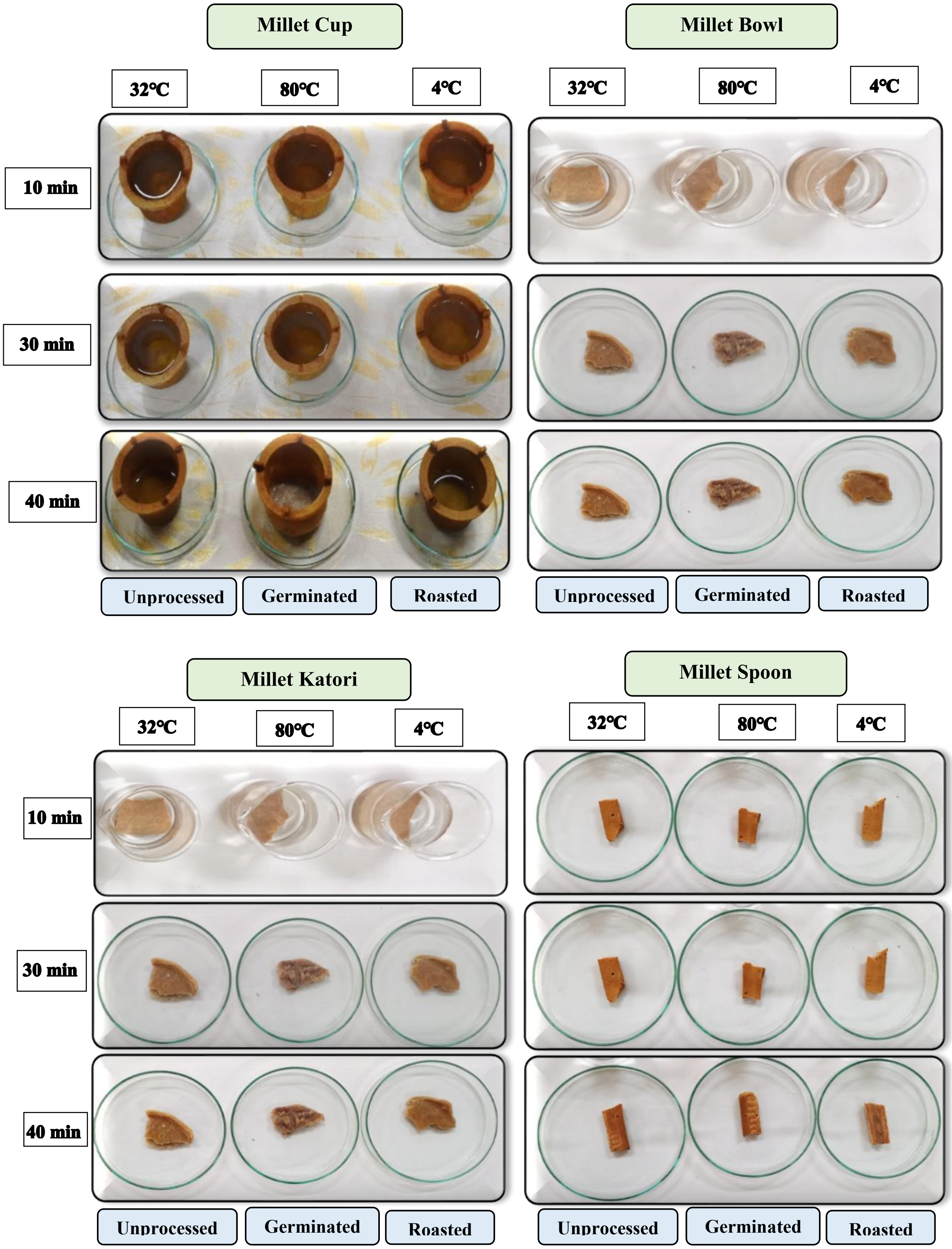
Table XIV

Water Absorption Rate at Ambient Temperature (32ºC)

S. No	Water Absorption Rate (%)	Pearl millet			Sorghum		
Millet Cup		PMUC	PMGC	PMRC	SUC	SGC	SRC
1	20 min	7.86	10.28	9.40	6.60	5.85	3.31
2	30 min	12.79	5.93	8.59	6.63	8.93	4.27
3	40 min	14.97	14.8	10.83	9.54	5.42	4.61
Millet Bowl		PMUB	PMGB	PMRB	SUB	SGB	SRB
1	20 min	10.5	14.52	5.17	7.54	13.46	7.20
2	30 min	7.93	7.57	4.91	12.28	13.55	9.25
3	40 min	7.35	9.85	7.81	10.93	13.43	8.47
Millet Katori		PMUK	PMGK	PMRK	SUK	SGK	SRK
1	20 min	8.62	9.61	7.27	8.92	12.28	11.76
2	30 min	9.52	10.52	8.47	8.19	7.81	7.01
3	40 min	7.24	12.69	7.81	9.09	11.59	8.19

Millet Spoon		PMUS	PMGS	PMRS	SUS	SGS	SRS
1	20 min	17.39	21.05	16.01	14.80	18.18	12.5
2	30 min	18.51	8.69	17.24	12.90	16.12	14.8
3	40 min	15.62	14.70	16.0	14.28	19.35	12.90
Millet Plate		**PMUP**	**PMGP**	**PMRP**	**SUP**	**SGP**	**SRP**
1	20 min	7.14	9.80	5.26	6.77	9.25	6.89
2	30 min	8.33	8.92	6.25	6.34	8.47	8.06
3	40 min	7.69	13.11	7.81	9.46	7.81	7.46

The highest water absorption rate among millet cup at ambient temperature was measured in PMGC and the lowest was measured in SRC. Germinated cup showed the highest water absorption rate, followed by unprocessed and roasted variants. Among bowls, the highest water absorption rate was found in SGB and the lowest was noted in PMRB which was within 20 minutes. Among millet katori, PMGK and SGK absorbed more water as compared to its unprocessed and roasted variants. Millet spoon consistently exhibited the highest water absorption, particularly in PMUS (17.39–18.51%) and PMGS (8.69–21.05%), indicating greater hydrophilicity. Millet plate showed notably the highest water absorption rate in PMGB (9.80% at 20 minutes) bowl. The water absorption rate of millet tableware which exposed at 32ºC for 40 minutes showed that sorghum tableware absorbed less water than pearl millet tableware and spoon had the highest absorption rate. The millet tableware showed an increased water absorption rate at the initial stage (within 20 minutes), followed by prolonged exposure (20 minutes to 40 minutes). The result of water absorption rate is supported by the findings of Rajendran *et al*. (2020) who proved that, at a lower temperature, water absorption was higher at initial phase followed by a slower rate in later stages. It was due to high mass transfer during the initial period, which was influenced by moisture, protein, carbohydrate, and fat content in later stages.


Millet Cup
32°C
80°C
4°C
10 min
30 min
40 min
Unprocessed
Germinated
Roasted
Millet Bowl
32°C
80°C
4°C
Unprocessed
Germinated
Roasted
Millet Katori
32°C
80°C
4°C
10 min
30 min
40 min
Unprocessed
Germinated
Roasted
Millet Spoon
32°C
80°C
4°C
Unprocessed
Germinated
Roasted

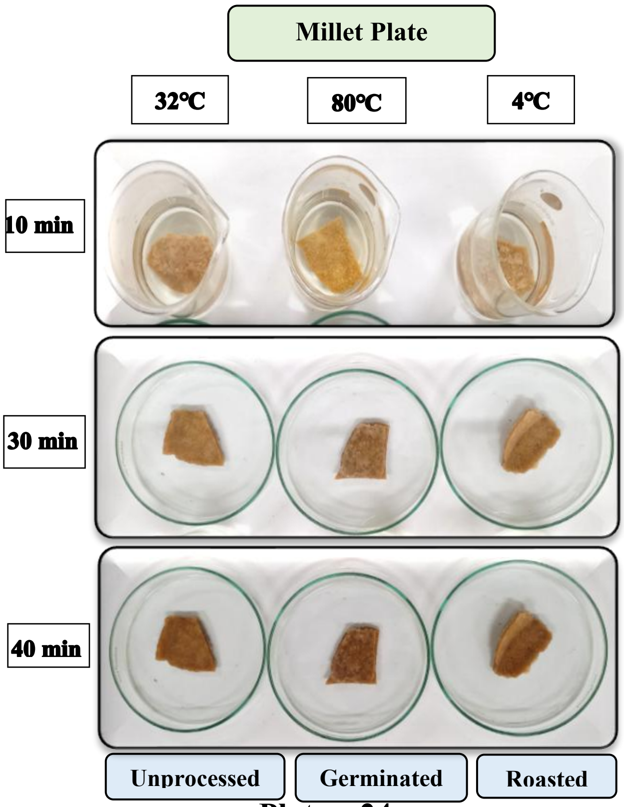


Plate – 24

Water Absorption Rate of Millet Tableware

ii. Water Absorption Rate of Standardised Millet Tableware at Hot Temperature

The Table XV, illustrates the water absorption rates (%) of standardised millet-based tableware made from pearl millet and sorghum was exposed at 80°C, and measured at the duration of 20, 30 and 40 minutes.

Table XV

Water Absorption Rate at Hot Temperature (80^{o}C)

S. No	Water Absorption Rate (%)	Pearl millet			Sorghum		
Millet Cup		PMUC	PMGC	PMRC	SUC	SGC	SRC
1	20 min	10.74	14.12	7.33	7.83	9.52	6.52
2	30 min	25.86	33.56	24.11	19.56	25.85	17.65
3	40 min	37.45	42.18	35.87	27.34	39.41	25.91
Millet Bowl		PMUB	PMGB	PMRB	SUB	SGB	SRB
1	20 min	11.25	17.76	10.12	10.43	15.21	9.87
2	30 min	19.96	28.22	17.25	18.86	22.58	16.43
3	40 min	26.72	38.24	24.58	25.14	32.14	22.78

Millet Katori		PMUK	PMGK	PMRK	SUK	SGK	SRK
1	20 min	13.51	19.52	11.86	10.24	18.25	8.25
2	30 min	23.02	31.82	22.68	19.73	28.42	15.24
3	40 min	31.95	43.42	34.51	35.41	36.45	25.87
Millet Spoon		**PMUS**	**PMGS**	**PMRS**	**SUS**	**SGS**	**SRS**
1	20 min	24.64	35.14	21.02	22.54	31.34	17.18
2	30 min	32.15	41.27	28.15	33.28	42.57	29.76
3	40 min	40.96	56.73	37.58	36.75	54.35	34.12
Millet Plate		**PMUP**	**PMGP**	**PMRP**	**SUP**	**SGP**	**SRP**
1	20 min	10.47	15.58	9.73	12.43	19.52	10.07
2	30 min	18.52	24.73	16.29	19.14	27.14	17.81
3	40 min	24.48	37.84	27.45	27.56	39.47	29.14

Water absorption rate of millet tableware consistently increased when exposed at 80ºC for a prolonged period (40 minutes). Millet spoon showed the highest rate, particularly for PMGS (35.14–56.73%) and SGS (31.34–54.35%). Millet katori also absorbed significant amount of water, with PMGK and SGK exhibited 43.42 per cent and 36.45 per cent of water at 40 minutes. Millet bowl exhibited moderate absorption, peaking at 38.24 per cent for PMGB and 32.14 per cent for SGB at 40 minutes. Millet cup and plate exhibited comparatively lower rates, as PMGP and SUP absorbed more water when compared to its pearl millet and sorghum counterparts, respectively. Sorghum tableware showed lower water absorption than pearl millet tableware, which withstood for prolonged duration, exhibited its hydrophilic nature. The result of the present study is supported by the findings of Rajendran *et al*. (2020), who found that, at high temperature, water absorption increased with higher wheat and pearl millet flour composition due to the temperature- and concentration-dependent behaviour of starch in millet flour. As temperature rise, starch granules absorb more water and release amylose and amylopectin through solubilization. The increase in millet flour reduced water absorption, due to the presence of large polygonal starch granules and higher gelatinization temperature (75.8°C–84.9°C).

iii. Water Absorption Rate of Standardised Millet Tableware at Cold Temperature

The Table XVI, presents the water absorption rates (%) of standardised millet-based tableware from pearl millet and sorghum tableware at a cold temperature of 4°C, for 40 minutes.

Table XVI

Water Absorption Rate at Cold Temperature (4°C)

S. No	Water Absorption Rate (%)	Pearl millet			Sorghum		
Millet Cup		**PMUC**	**PMGC**	**PMRC**	**SUC**	**SGC**	**SRC**
1	20 min	0.82	1.24	0.79	0.74	1.01	0.72
2	30 min	1.72	2.09	1.28	1.21	1.67	1.08
3	40 min	2.45	2.93	1.98	1.82	2.15	1.75
Millet Bowl		**PMUB**	**PMGB**	**PMRB**	**SUB**	**SGB**	**SRB**
1	20 min	9.58	9.54	7.58	8.54	11.54	7.84
2	30 min	14.52	17.85	12.54	15.21	19.01	14.92
3	40 min	22.96	28.78	20.84	20.75	29.84	21.84
Millet Katori		**PMUK**	**PMGK**	**PMRK**	**SUK**	**SGK**	**SRK**
1	20 min	7.52	8.15	6.52	8.02	10.24	8.42
2	30 min	13.85	15.84	14.15	14.84	18.51	13.72
3	40 min	21.42	24.12	20.98	19.94	27.45	20.53
Millet Spoon		**PMUS**	**PMGS**	**PMRS**	**SUS**	**SGS**	**SRS**
1	20 min	6.52	8.63	6.24	5.37	7.56	5.72
2	30 min	8.96	10.85	8.56	9.62	10.25	7.12
3	40 min	11.54	14.54	10.98	12.5	12.58	9.25
Millet Plate		**PMUP**	**PMGP**	**PMRP**	**SUP**	**SGP**	**SRP**
1	20 min	10.12	13.81	9.15	7.27	14.62	8.53
2	30 min	18.87	21.28	15.82	16.72	21.35	13.67
3	40 min	26.15	31.53	22.64	24.57	30.79	22.73

Millet bowl and millet plate showed the highest water absorption, particularly for PMGB (28.78%) and PMGP (31.53%) when exposed upto 40 minutes. Millet katori also demonstrated significant water absorption, with 24.12 per cent in PMGK and 27.45 per cent in SGK after 40 minutes. In contrast, millet cup and millet spoon displayed lower absorption rates, with PMGS (14.54%) and PMGC (2.93%) reaching its highest levels at 40 minutes.

Exposure of millet tableware at cold temperature showed that pearl millet tableware generally absorbed more water than sorghum variants, especially in the millet bowl and millet plate. The result of the present study is supported by the findings of Rajendran *et al*. (2020) who stated that, the water absorption capacity of edible cutlery was increased with higher concentrations of pearl millet due to the presence of the highest proportion of starch granules (amorphous) that enhanced water absorption. Thagunna *et al*. (2023) found that wheat flour and rice flour formed gluten networks and starch-water bonds that retained moisture for a longer duration.

Water absorption rate at ambient, hot and cold temperatures exhibited that, germinated cup, bowl, katori, spoon and plate absorbed more water followed by its unprocessed and roasted tableware. Hence, the result showed that, the unprocessed and roasted pearl millet and sorghum tableware was suitable for serving for more than 30 minutes at all the three selected temperatures which was also confirmed by exposure test.

4.2.5 TEXTURE ANALYSIS OF STANDARDISED MILLET TABLEWARE

Textural Analysis like hardness, break force, elastic force and drop test of the standardised cup, bowl, katori, spoon and plate from unprocessed, germinated and roasted pearl millet and sorghum was carried out.

4.2.5.1 TEXTURE ANALYSIS OF STANDARDISED MILLET TABLEWARE

The texture analysis of the standardised millet tableware was measured in triplicates and discussed in Table XVII. Tableware including cup, bowl, katori, spoon and plate without any cracks or deformities were selected to measure the hardness, break force and elastic force.

The hardness and break force, of the pearl millet cup showed that, PMGC exhibited the lowest value (31.64 ± 3.16 n), indicating a soft texture, while the PMUC showed the highest hardness (44.25 ± 1.29 N), followed by its roasted cup. Among sorghum cup, SGC had the lowest hardness (16.33 ± 0.04 N), whereas the SRC and SUC displayed comparable higher hardness force. Elastic force exhibited significant differences, where PMGC showed the highest elasticity (63.93 ± 5.49 N/mm²), while unprocessed and roasted pearl millet variants (PMUC and PMRC) showed minimal elasticity (0.07 ± 0.04 and 0.06 ± 0.02 N/mm²). Similarly, SGC demonstrated the lowest elasticity as compared with SUC and SRC, which displayed moderate and higher elasticity, respectively. The F-value ($p<0.05$) was statistically significant between processed tableware (germinated and roasted) and unprocessed tableware that showed an influence on texture attributes of millet cup, impacting the hardness and elasticity. Roasted cup had more adhesive force that bind the ingredients together to provide a structure for a prolonged period. The finding is supported by the research of, Pulungan & Santoso (2020), who found the fracturability between 0.25 – 0.60 N in the developed sweet potato edible cup depends upon the flour proportion, and the findings are lower than the values observed in the present study. Further, Molu *et al*. (2024b) developed edible dessert cup from finger millet exhibited a hardness force of 45 N to 68 N which is higher than result of the present study.

Among pearl millet bowl, the PMUB exhibited the highest hardness (32.68 ± 7.43 N), while the PMRB had the lowest (21.71 ± 2.76 N) hardness force. Among the sorghum bowl, SRB exhibited the highest hardness (50.94 ± 6.92 N), which was significantly higher than SUB (44.52 ± 7.31 N) and SGB (38.27 ± 5.84 N) bowl. Elastic force of bowl showed that, SRB exhibited the highest value (373.16 ± 8.17 N/mm²), followed by SUB and PMUB. The lowest elastic force was found in germinated variants, PMGB (57.09 ± 5.41 N/mm²) and SGB (67.03 ± 7.72 N/mm²). The results indicated that pearl millet and sorghum bowl and its unprocessed and processed forms significantly influenced the texture properties of the millet bowl ($p < 0.05$). The results were supported by the findings of Sharanagat *et al*. (2024) who stated that the hardness of raw sorghum baked products increased from 13.34 N - 21.09 N to 19.20 N - 50.31 N due to starch integrity loss and a weakened gluten–starch network. Similarly, Nehra *et al*. (2024) found that the texture properties of biobased edible bowl increased with increasing concentration of spent coffee grain bowl from 5 to 19 kgf (kilogram force).

PMRK exhibited the highest hardness (68.14 ± 14.98 N) and elastic force (112.2 ± 5.56 N/mm²), which indicated superior structural strength compared to the unprocessed (PMUK) and germinated (PMGK) variations. SRK (49.32 ± 1.04 N) exhibited the highest hardness force followed by SUK (47.84 ± 0.3 N) and SGK (29.14 ± 2.72 N). The elastic force of PMRK and SRK were higher followed by its germinated and unprocessed variants. PMGK and SUK demonstrated the least strength in both parameters (hardness and elastic force). The result suggested that roasting millets enhanced the textural analysis of pearl millet katori, while germination reduced the textural property.

Table XVII

Texture Analysis of Millet Tableware

S.No	Variations	Cup (C)		Bowl (B)		Katori (K)		Spoon (S)		Plate (P)	
		Hardness and Break force (N)	Elastic force (N/mm^2)	Hardness and Break force (N)	Elastic force (N/mm^2)	Hardness and Break force (N)	Elastic force (N/mm^2)	Hardness and Break force (N)	Elastic force (N/mm^2)	Hardness and Break force (N)	Elastic force (N/mm^2)
1	**PMU**	44.25 ± 1.29	0.07 ± 0.04	32.68 ± 7.43	153.21 ± 5.66	62.47 ± 2.69	40.87 ± 2.49	31.48 ± 2.79	77.87 ± 5.91	43.15 ± 2.77	145.47 ± 4.31
2	**PMG**	31.64 ± 3.16	63.93 ± 5.49	25.31 ± 3.28	57.09 ± 5.41	42.45 ± 3.48	28.88 ± 3.16	38.47 ± 5.44	58.71 ± 5.87	39.16 ± 3.30	99.20 ± 2.92
3	**PMR**	40.15 ± 2.26	0.06 ± 0.02	21.71 ± 2.76	103.86 ± 7.54	68.14 ± 14.98	112.2 ± 5.56	35.44 ± 2.21\	94.68 ± 4.18	49.35 ± 3.85	95.58 ± 3.35
4	**SU**	41.39 ± 0.38	54.66 ± 2.08	44.52 ± 7.31	158.7 ± 2.38	47.84 ± 0.3	55.58 ± 0.82	31.006 ± 1.7	113.78 ± 5.13	46.5 ± 3.60	144.45 ± 1.11
5	**SG**	16.33 ± 0.04	4.07 ± 0.05	38.27 ± 5.84	67.03 ± 7.72	29.14 ± 2.72	40.45 ± 2.51	18.88 ± 3.42	42 ± 3.45	32.07 ± 3.80	83.51 ± 4.43
6	**SR**	40.17 ± 0.23	13.67 ± 1.16	50.94 ± 6.92	373.16 ± 8.17	49.32 ± 1.04	70.47 ± 2.15	32.94 ± 6.73	97.76 ± 0.84	51.57 ± 0.57	278.06 ± 1.91
F Value		**98.78***	**98.78***	**1715.76***	**970.01***	**114.59***	**278.42***	**14.25***	**101.98***	**15.14***	**1483.80***

*Significant, **Not Significant (*$p<0.05$*), PMU – Unprocessed Pearl millet, PMG – Germinated Pearl millet, PMR – Roasted Pearl millet, SU-Unprocessed Sorghum, SG-Germinated Sorghum, SR-Roasted Sorghum

Among millet spoon, the highest hardness force was exhibited in PMGS (38.47 ± 5.44 N) and SRS (32.94 ± 6.73) than PMUS and SUS. PMUS and SGS showed the least hardness and elastic force. The highest elastic force was found in PMRS (94.68 ± 4.18 N/mm^2) and SUS (113.78 ± 5.13), highlighted its structural resilience. The roasted pearl millet and germinated sorghum spoon exhibited the lowest hardness but moderate elastic force. The findings indicated that germination improved hardness, whereas roasting significantly improved elasticity in pearl millet spoon. Previous study by Okonkwo *et al*. (2020) found that, edible flour formulated with crab flour exhibited a 10 kgf hardness force which was highest than the result of the present study. Siddiqui *et al*. (2023) found that mosambi peel and sago powder edible spoon exhibited acceptable textural properties and the highest hardness force reduce the overall consumer acceptability.

Pearl millet and sorghum plate exhibited the similar pattern. The highest hardness force was found in PMRP (49.35 ± 3.85 N) and SRP (51.57 ± 0.57 N) and it demonstrated the highest hardness and elastic force, followed by the unprocessed variants (PMUP and SUP). Germinated plate (PMGP and SGP) showed the least hardness and elastic force. The results suggest that roasting improved hardness and elastic force and germinated millet plate exhibited a least textural property.

Texture analysis of millet tableware showed that roasted millet tableware exhibited the highest hardness, break force and elastic force, followed by unprocessed millet tableware. Germinated pearl millet and sorghum tableware exhibited the least textural properties. The result of the present study is supported by the findings of Andrejko & Blicharz-Kania (2024), who confirmed that baked cereal products with lower fat content were harder and the presence of dietary fibre, including cellulose and lignin, enhanced the rigidity and pressure resistance of tableware. Ramakrishnan *et al*. (2023) stated that non-thermal reactions of millet, including fermentation, exhibited an alteration in starch granules with high water and low oil absorption capacities, which provided a uniform smooth texture and strong setback viscosity.

4.2.5.2 DROP TEST OF STANDARDISED MILLET TABLEWARE

The drop test of standardised millet tableware was measured by dropping it from 10 cm to 150 cm on a smooth surface that paved way to measure the free fall or accidental fall. Cup, bowl, katori, spoon and plate showed no cracks till 70 cm, 90 cm, 70 cm, 30 cm and 80 cm respectively and the observations are discussed and tabulated below.

i. Drop Test of Standardised Millet Cup

Drop resistance of the cup was assessed by dropping the standardised millet cup from 70 cm to 140 cm on a smooth surface and the obtained result is tabulated in Table XVIII.

Table XVIII

Drop Test of Standardised Millet Cup

S. No	Drop test (cm)	Pearl millet			Sorghum		
		PMUC	PMGC	PMRC	SUC	SGC	SRC
1	70	No cracks	No cracks	No cracks	No cracks	No cracks	No cracks
2	80	No cracks	First crack	No cracks	First crack	First crack	No cracks
3	90	First crack	Corners cracked	No cracks	Cracked	Corners cracked	No cracks
4	100	Corners cracked	Broken	First crack at edge	Corners cracked	Broken	No cracks
5	110	Broken	Broken	Corners cracked	Broken	Broken	First crack
6	130	Broken	Broken	Broken	Broken	Broken	Corners cracked
7	140	Broken	Broken	Broken	Broken	Broken	Broken

All cup were intact, with no evident cracks till 70 cm. At 80 cm, germinated pearl millet (PMGC) and sorghum (SGC) cup began to crack, although its unprocessed and roasted cup remained intact. At 90 cm, PMUC, SUC exhibited the first crack, and its germinated counterpart (PMGC, SGC) found to be cracked at corner. The roasted sorghum cup (SRC) remined intact upto 100 cm and showed its initial crack at 110 cm. By 110 cm to 130 cm, all cup was broken, except SRC. Roasted sorghum cup had the highest drop resistance, but germinated pearl millet and sorghum cup had the lowest impact resistance.

ii. Drop Test of Standardised Millet bowl

The drop test of standardised millet bowl from pearl millet and sorghum was dropped from 90 cm to 160 cm on the smooth surface and the results are given in Table XIX.

The drop test of millet bowl showed, varying resilience across the pearl millet and sorghum variants. PMUB showed no crack up to 120 cm, edges cracked at 130 cm, and bottom cracked at 140 cm, and broke completely at 150 cm. Similarly, PMGB exhibited least drop resistance showed the first crack at 100 cm and completely broken at 130 cm.

PMRB was moderately resilient, with crack appeared at 130 cm and broke entirely at 160 cm. Among the sorghum bowl, SUB was highly durable, showed no damage up to 130 cm, with corners cracked at 140 cm and broken fully at 150 cm. SGB started to crack at 120 cm and completely broken at 140 cm. SRB exhibited as the most durable bowl that showed corners cracked at 150 cm and completely broken at 160 cm.

Table XIX

Drop Test of Standardised Millet Bowl

S. No	Drop test (cm)	Pearl millet			Sorghum		
		PMUB	PMGB	PMRB	SUB	SGB	SRB
1	90	No cracks	No cracks	No cracks	No cracks	No cracks	No cracks
2	100	No cracks	First crack	No cracks	No cracks	No cracks	No cracks
3	120	No cracks	Edges cracked	No cracks	No cracks	First crack	No cracks
4	130	Edges cracked	Broken	First crack	First crack	Corners cracked	No cracks
5	140	Cracked at bottom	Broken	Corners cracked	Corners cracked	Broken	First crack
6	150	broken	Broken	Cracked at bottom	Broken	Broken	Corners cracked
7	160	Broken	Broken	Broken	Broken	Broken	Broken

iii. Drop Test of Standardised Millet Katori

Table XX explains the drop test of unprocessed, germinated and roasted pearl millet and sorghum from a height of 70 cm to 130 cm.

The drop test for millet katori highlighted that, PMUK resisted damage up to 90 cm, edge cracked at 100 cm and bottom cracked at 110 cm, and entirely broken at 120 cm. PMGK was less durable, showed first crack at 80 cm and broken completely by 100 cm. Whereas, PMRK exhibited better drop resistance as compared to PMUK and PMGK which exhibited corners and bottom cracked at 110 cm and 120 cm respectively, and fully broken at 130 cm. Sorghum katori exhibited that, SUK demonstrated high resilience, with no damage up to 100 cm, corner cracked at 110 cm, and broken completely at 120 cm. SGK started to crack at 90 cm and broken entirely at 110 cm, while SRK showed better durability, with corner’s cracked at 120 cm and completely broken at 130 cm. PMRK and SRK showed better drop resistance as compared to its unprocessed and germinated counterparts that showed first crack after dropped from 100 cm and 110 cm whereas, completely broken at a height of 130 cm.

Table XX

Drop Test of Standardised Millet Katori

S. No	Drop test (cm)	Pearl millet			Sorghum		
		PMUK	PMGK	PMRK	SUK	SGK	SRK
1	70	No cracks	No cracks	No cracks	No cracks	No cracks	No cracks
2	80	No cracks	First crack	No cracks	No cracks	No cracks	No cracks
3	90	No cracks	Edges cracked	No cracks	No cracks	First crack	No cracks
4	100	Edges cracked	Broken	First crack	First crack	Corners cracked	No cracks
5	110	Cracked at bottom	Broken	Corners cracked	Corners cracked	Broken	First crack
6	120	broken	Broken	Cracked at bottom	Broken	Broken	Corners cracked
7	130	Broken	Broken	Broken	Broken	Broken	Broken

iv. Drop Test of Standardised Millet Spoon

Standardised millet spoon without any cracks or deformities was taken to analyse the drop test from 30 cm to 80 cm and the results were provided in Table XXI.

Table XXI

Drop Test of Standardised Millet Spoon

S. No	Drop test (cm)	Pearl millet			Sorghum		
		PMUS	PMGS	PMRS	SUS	SGS	SRS
1	30	No cracks	No cracks	No cracks	No cracks	No cracks	No cracks
2	40	No cracks	First crack	No cracks	No cracks	Hand cracked	No cracks
3	50	First crack	Broken	First crack	No cracks	Edges broken	No cracks
4	60	Hand cracked	Broken	Edges cracked	First crack	Broken	Edges broken
5	70	Broken	Broken	Hand cracked	Hand cracked	Broken	Broken
6	80	Broken	Broken	Broken	Broken	Broken	Broken

Millet spoon exhibited the lowest drop resistance among the standardised millet tableware (cup, bowl and katori). PMUS, withstood up to 40 cm without any cracks, showed that hand portion spoon was cracked at 60 cm, and broken completely at 70 cm. PMGS exhibited the least durability that broken entirely at 50 cm. PMRS showed similar results like PMUS, which started to crack at 50 cm and broken completely by 80 cm. Among sorghum spoon, SUS exhibited moderate resilience, broken entirely at 80 cm and SGS showed hand, edge and completely broken at 40 cm, 50 cm and 60 cm respectively, while SRS was slightly more durable, that withstood with a fallen resistance upto 50 cm and entirely broken at 70 cm. Roasted pearl millet and sorghum spoon showed higher drop resistance (at 50 cm) when compared to its unprocessed and roasted variants.

v. Drop Test of Standardised Millet Plate

The drop test of standardised millet plate revealed the distinct durability trends when dropped from 80 cm to 140 cm on the smooth surface and the results were tabulated in Table XXII.

Table XXII

Drop Test of Standardised Millet Plate

S. No	Drop test (cm)	pearl millet			Sorghum		
		PMUP	PMGP	PMRP	SUP	SGP	SRP
1	80	No cracks	No cracks	No cracks	No cracks	No cracks	No cracks
2	90	No cracks	First crack	No cracks	No cracks	No cracks	No cracks
3	100	No cracks	Edges cracked	No cracks	No cracks	First crack	No cracks
4	110	Edges cracked	Broken	First crack	First crack	Corners cracked	No cracks
5	120	Cracked at the bottom	Broken	Corners cracked	Corners cracked	Broken	First crack
6	130	Broken	Broken	Cracked at the bottom	Broken	Broken	Corners cracked
7	140	Broken	Broken	Broken	Broken	Broken	Broken

Pearl millet plate exhibited that PMUP had no damage when dropped from 100 cm, with edge cracked at 110 cm, bottom cracks at 120 cm, and entirely at 130 cm. PMGP cracked earlier, which showed its first crack at 90 cm, edges cracked at 100 cm and completely broken at 110 cm. PMRP exhibited similar results to PMUP, which started to crack at 110 cm and was completely broken at 140 cm. For the sorghum plate, SUP was highly durable, with no cracks upto 100 cm, corners cracked at 120 cm, and entirely broken at 130 cm. SGP exhibited its first crack at 100 cm and broken fully at 110 cm whereas, SRP showed better results when compared to its counterparts as it withstood without any cracks upto 110 cm and corners cracket at 130 cm that broken completely at 140 cm. Roasted pearl millet and sorghum plate demonstrated the highest drop resistance followed by its unprocessed and germinated plate.

Sorghum tableware consistently exhibited the highest drop resistance as compared to pearl millet variants, particularly in its roasted forms. Among pearl millet tableware, roasted tableware exhibited the highest resistance than its germinated and unprocessed variants. The result suggested that roasted pearl millet and sorghum tableware was suited for applications requiring greater structural integrity, followed by unprocessed and germinated variants. The hardness force of roasted pearl millet and sorghum tableware was higher, which had a positive impact on exposure and water absorption rate (showed lower water absorption as compared to its unprocessed and germinated variants).

SELECTION OF MILLET TABLEWARE FOR FLOWER POWDER ENRICHMENT

Nutrient analysis, optical property, sensory evaluation, functional and textural properties of the standardised millet tableware from pearl millet and sorghum in unprocessed, germinated and roasted forms were evaluated. Nutrient analysis of millet tableware showed that pearl millet tableware, particularly germinated and roasted variations exhibited superior nutrient content than sorghum tableware in terms of protein, iron, and phosphorus content. The impact of processing on nutritional content showed that germination improved vitamin and mineral content, whereas roasted increased the fiber and iron content. Optical property resulted that, roasted tableware showed more darker and redder shade, whereas germinated variation showed the least lightness and redder shade as compared to unprocessed tableware. Sensory evaluation of the pearl millet and sorghum tableware showed good overall acceptability scores (liked very much category), especially in germinated variations as followed by its roasted and unprocessed tableware.

FTIR analysis showed that unprocessed tableware exhibited more organic functional groups, such as hydroxyls, carbonyls, and amides, while germinated and roasted tableware exhibited strong peaks at the inorganic compound region and weak peaks at the organic compound region. Thermal properties showed that unprocessed tableware had the highest residue when compared to its germinated and roasted counterparts, which confirmed the presence of more inorganic compounds, and germination and roasting underwent high thermal degradation with minimal residue as compared to its unprocessed variants.

Water absorption test showed that unprocessed and roasted pearl millet and sorghum tableware could hold water at ambient, hot, and cold temperatures for a longer duration without any structural changes (upto 30 minutes) than its germinated tableware, which started to absorbed water and became soggy at the initial stage (within 20 minutes). Textural analysis was an important factor in determining the quality of tableware to be utilized in the food serving sector. Germinated pearl millet and sorghum tableware, including cup, bowl, katori, spoon and plate, exhibited less hardness, break force, elastic force, and drop test as compared to roasted and unprocessed varieties. Hence, the textural properties showed that unprocessed and roasted pearl millet and sorghum tableware exhibited better results as compared to its germinated variants.

From the results obtained in Phase - II, the unprocessed and roasted pearl millet and sorghum cup, bowl, katori, spoon, and plate were selected for further enrichment. Conversely, the germinated pearl millet and sorghum were not included in the subsequent flower powder enrichment and characterisation as it exhibited the least functional and textural properties. Table XXIII shows the finalized standardised proportion developed and optimized for pearl millet and sorghum cup, bowl, katori, spoon, and plate in unprocessed and roasted forms, for further flower powder enrichment and characterisation.

Table XXIII

Selection of Tableware for further Characterisation

S. No.	Millet	Process	Standardised Proportion	Cup (C)	Bowl (B)	Katori (K)	Spoon (S)	Plate (P)
1	**Pearl millet**	**Unprocessed (PMU)**	Millet Flour (g)	10	16	13	5	34
			Binder (g)	9	10	10	4	20
			Total (g)	**19**	**26**	**23**	**9**	**54**
			Water (ml)	12	18	15	7	40
		Roasted (PMR)	Millet Flour (g)	10	16	13	5	34
			Binder (g)	9	10	10	4	20
			Total (g)	**19**	**26**	**23**	**9**	**54**
			Water (ml)	17	20	18	8	45

2	**Sorghum**	**Unprocessed (SU)**	Millet Flour (g)	10	16	13	5	34
			Binder (g)	9	10	10	4	20
			Total (g)	**19**	**26**	**23**	**9**	**54**
			Water (ml)	14	20	17	6	43
		Roasted (SR)	Millet Flour (g)	10	16	13	5	34
			Binder (g)	9	10	10	4	20
			Total (g)	**19**	**26**	**23**	**9**	**54**
			Water (ml)	16	22	19	8	45

PHASE - III

4.3 PROPERTY ANALYSIS OF NATIVE EDIBLE FLOWER

500 g of hibiscus, moringa, rose and agathi fresh flowers were shade dried and yielded 103 g, 100 g, 96 g and 120 g of powder, respectively. The powder was stored in an airtight container at 4^0C to prolong its shelf life and its characterisation is discussed below.

4.3.1 PROXIMATE AND NUTRIENT ANALYSIS OF SELECTED EDIBLE FLOWER POWDER

The proximate and nutrient analysis of selected edible flower powder like hibiscus (HFP), moringa (MFP), rose (RFP), and agathi (AFP) powder was analysed and given in Table XXIV.

Table XXIV

Proximate and Nutrient Analysis of Selected Edible Flower Powder

S. No	Nutrient Analysis	HFP	MFP	RFP	AFP	F Value
1	Moisture (%)	8.18 ± 0.42	8.9 ± 0.19	7.49 ± 0.15	7.74 ± 0.08	70.34*
2	Ash (%)	8.98 ± 0.11	9.12 ± 0.13	9.24 ± 0.11	9.77 ± 0.09	27.42*
3	Carbohydrate (g)	12.58 ± 0.16	7.48 ± 0.12	15.08 ± 0.09	9.41 ± 0.07	2509.95*
4	Protein (g)	1.23 ± 0.02	5.85 ± 0.09	3.25 ± 0.12	4.33 ± 0.02	1780.95*
5	Fat (g)	4.21 ± 0.05	3.91 ± 0.04	2.49 ± 0.05	2.38 ± 0.11	535.012*
6	Fiber (g)	1.48 ± 0.03	7.76 ± 0.04	8.92 ± 0.05	7.95 ± 0.06	15737.37*
7	Vitamin C (mg)	7.93 ± 0.01	108.66±5.68	94.52 ± 0.45	21.63 ± 0.04	950.24*
8	Iron (mg)	0.98 ± 0.03	3.85 ± 0.05	1.32 ± 0.10	2.6 ± 0.55	1072.44*
9	Calcium (mg)	3.76 ± 0.06	82.7 ± 0.24	8.19 ± 0.04	72.17 ± 0.04	298186.74*

*-Significant, ** Not Significant ($p<0.05$), AFP – Agathi flower powder, HFP – Hibiscus flower powder, MFP – Moringa flower powder, RFP – Rose flower powder

The moisture content was highest in MFP (8.9%) and lowest in RFP (7.49%), while ash content ranged from 8.98 per cent in HFP to 9.77 per cent in AFP. Carbohydrate content was highest in RFP (15.08 g) and lowest in MFP (7.48 g). Protein content was highest in MFP (5.85 g) and was lowest in HFP (1.23 g). Fat content was highest in HFP (4.21 g) and lowest in AFP (2.38 g), whereas fiber content was highest in RFP (8.92 g) and lowest in HFP (1.48 g). Vitamin C was abundant in MFP (108.66 mg), with the lowest in HFP (7.93 mg). Iron was highest in MFP (3.85 mg) and lowest in HFP (0.98 mg), while calcium content was significantly higher in MFP (82.7 mg) compared to HFP (3.76 mg). The F-values of the nutritive value were statistically significant ($p < 0.05$) among all flowers. Similar result is observed in the previous study by Samkaria & Kumari (2025) and Hait & Kashyap (2024) found that edible flowers showed the presence of protein, vitamins, carbohydrate and fat.

4.3.2 PHYTOCHEMICAL SCREENING OF SELECTED EDIBLE FLOWER POWDER

The phytochemical screening of the selected edible flower powder revealed notable variations in its profile as shown in Table XXV.

Table XXV

Phytochemical Screening of Selected Edible Flower Powder

S. No	Phytochemical Screening	HFP	MFP	RFP	AFP
1	Alkaloids	- + + +	- + + +	+ + + +	- - + +
2	Amino acids	+ + + +	+ + + +	+ + + +	+ + + +
3	Anthocyanins	+ + + +	- + + +	- + + +	- - + +
4	Carbohydrate	+ + + +	+ + + +	+ + + +	+ + + +
5	Flavonoids	+ + + +	- + + +	+ + + +	- + + +
6	Glycosides	- + - +	+ + + +	- + + +	- + + +
7	Phenol	+ + + +	+ + + +	+ + + +	- + + +
8	Phytic acid	+ + + +	- + + +	+ + + +	- - + +
9	Saponin	- + + +	- + + +	+ + + +	- + + +
10	Tannin	+ + + +	+ + + +	+ + + +	- - + +
11	Terpenoids	+ - + +	- + + +	- + + +	- - + +
* '+' denotes presence, '-' denotes absence, in the order of aqueous, ethanol, chloroform, and acetone					

Hibiscus flower powder (HFP) demonstrated the presence of many phytochemicals, including amino acid, anthocyanin, carbohydrate, flavonoids and tannins. Moringa flower powder (MFP) exhibited a rich presence of amino acids, carbohydrates, phenols, glycosides, and tannins across all tested solvents and phytic acid, alkaloids, flavonoids, saponin, anthocyanins and terpenoids were absent in aqueous extract. Rose flower powder (RFP) was similarly rich, showing strong presence of alkaloids, amino acids, flavonoids, carbohydrates, phenols, phytic acid, saponin, and tannin, although slightly less consistent than HFP. Agathi flower powder (AFP), exhibited good levels of amino acids, carbohydrates and exhibited a weaker presence of alkaloids, anthocyanins, terpenoids, phytic acid and tannin in aqueous and ethanol solvents. The results highlighted that HFP and RFP showed the highest presence of phytochemical content, followed by MFP and AFP. The finding of the present study is on par with, Sehgal *et al*. (2021) who found that, ethanol extract of moringa flower exhibited medium phytochemical constituents and hibiscus flower showed strong phytochemical constituents.

4.3.3 ANTIOXIDANT ACTIVITY OF SELECTED EDIBLE FLOWER POWDER

The antioxidant activity of selected edible flower powder was assessed based on its percentage of inhibition at varying concentrations (10–750 µg/ml), and the results are given in Figure – 13.

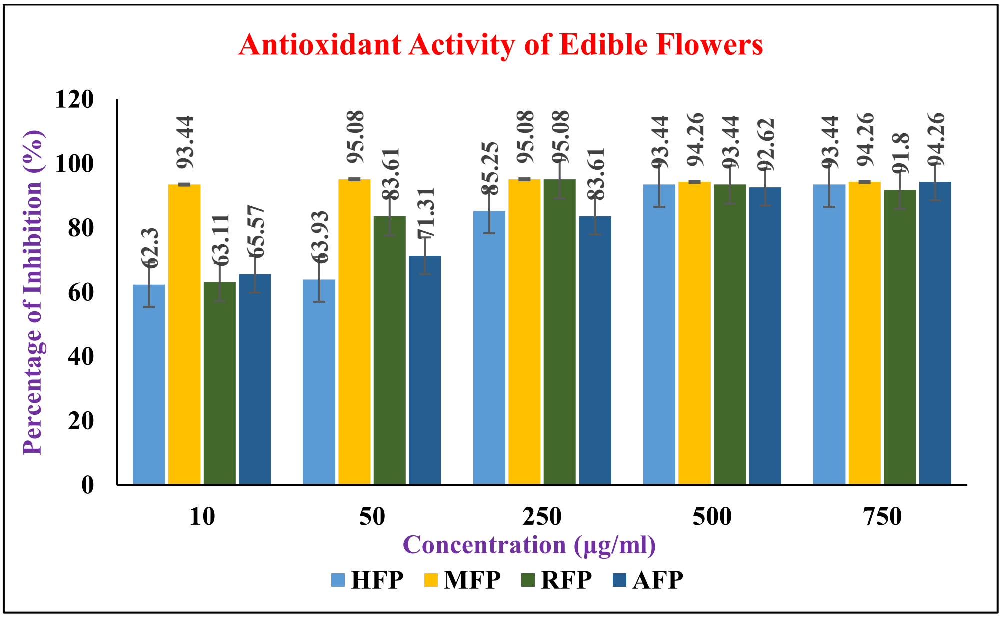


Figure – 13
Antioxidant Activity of Selected Edible Flower Powder

MFP exhibited the highest inhibition across most concentrations, peaking at 95.08 per cent from 50 µg/ml onwards, indicated a strong and consistent antioxidant activity. RFP showed high inhibition at 250 µg/ml (95.08%) but showed variability at other concentrations. HFP and AFP demonstrated moderate antioxidant activities, with maximum inhibitions of 92.62 per cent and 94.26 per cent, respectively, at higher concentrations| (500–750 µg/ml). The IC_{50} values highlighted that RFP showed strong (46.69 µl/ml) antioxidant activity, followed by HFP (54.92 µl/ml), AFP (78.09 µl/ml), which possessed moderate activity, and MFP (139.88 µl/ml) showed weak activity. Regression analysis showed varying degrees of correlation (R^2), with AFP being exhibited the strongest correlation (0.8263) between concentration and inhibition percentage. The finding demonstrated that strong antioxidant activity was found in hibiscus flower powder (HFP) and rose flower powder (RFP), which was taken for further enrichment in standardised millet tableware. The observations of the present study align with the findings of Samkaria & Kumari (2025) and Hegde *et al*. (2022) found that, sesbania, rose and moringa showed strong antioxidant activity.

4.3.4 OPTICAL PROPERTY OF SELECTED EDIBLE FLOWER POWDER

The optical property of edible flower powder revealed significant variations in lightness (L*), redness/greenness (a*), and yellowness/blueness (b*) and total colour difference (ΔE) were analysed and the results of the optical property of selected edible flower powder is given in Table XXVI.

Table XXVI

Optical Property of Selected Edible Flower Powder

S.No	Parameter	HFP	MFP	RFP	AFP	F Value
1	L*	14.3 ± 0.20	37.35 ± 0.32	35.66 ± 1.11	48.56 ± 1.12	927.986*
2	a*	20.16 ± 1.01	6.43 ± 0.08	19.37 ± 0.41	9.6 ± 0.61	362.14*
3	b*	3.80 ± 0.36	15.28 ± 0.14	2.35 ± 0.15	7.72 ± 0.42	1126.01*
4	ΔE	1.44 ± 0.68	0.49 ± 0.16	1.62 ± 0.61	1.78 ± 0.81	2.57**

*-Significant, ** Not Significant (*$p<0.05$*), L* Lightness (0 black to 100 White); a* (+60 red to -60 green); b* (+60 yellow to -60 blue)

Agathi flower powder (AFP) exhibited the highest lightness (L* = 48.56), indicating a lighter appearance, while Hibiscus flower powder (HFP) had the lowest lightness (L* = 14.3). In terms of redness (a*), HFP (20.16) and Rose flower powder (RFP, 19.37) displayed the most intense red tones, while Moringa flower powder (MFP) had the least redness (a* = 6.43). Yellowness (b*) was most pronounced in MFP (15.28) and minimal in RFP (2.35). The ΔE values, which indicated the overall colour differences, ranged from 0.49 in MFP to

1.78 in AFP, showed the least overall colour variation. The F-values confirmed a significant difference ($p < 0.05$) for L*, a*, and b* parameters and emphasized the distinct optical characteristics of selected edible flower powder. The result of the present study is confirmed by the findings of Pires *et al*. (2021) found that the colour properties of edible flowers were due to the presence of anthocyanins, carotenoids and phenolic compounds.

FINALIZING SELECTED EDIBLE FLOWER FOR ENRICHMENT IN MILLET TABLEWARE

A comprehensive analysis of the selected edible flower powder revealed its distinct nutritional and functional profiles. Hibiscus and rose flower powder exhibited strong antioxidant activity and vibrant red hue, which enhances the aesthetic appeal of millet-based tableware. Microbial load analysis for 120 days showed that RFP and HFP maintained consistently lower microbial load as compared to MFP, proving its microbial stability.

Based on the nutrient content, phytochemical profile, antioxidant activity, optical property, and microbial stability, hibiscus and rose flower powder have emerged as the most suitable source to enhance functional properties and sensory acceptability of the unprocessed and roasted pearl millet and sorghum tableware, including cup, bowl, katori, spoon and plate.

PHASE - IV

4.4 CHARACTERISATION OF STANDARDISED FLOWER-ENRICHED MILLET TABLEWARE

4.4.1 PROXIMATE AND NUTRIENT ANALYSIS OF FLOWER-ENRICHED MILLET TABLEWARE

100 g of tableware consists of approximately five cups, four bowls and katori, ten spoons and two plates respectively.

i. Proximate and Nutrient Analysis of Flower-Enriched Pearl millet Tableware

The nutrient analysis of the standardised flower-enriched pearl millet tableware is provided in Table XXVII.

Table XXVII

Proximate and Nutrient Analysis of Flower-Enriched Pearl millet Tableware

S. No	Nutrient Analysis	Unprocessed Pearl millet			Roasted Pearl millet			F value
		PMUT	PMUHT	PMURT	PMRT	PMRHT	PMRRT	
1	Moisture (%)	3.20 ± 0.02	3.81 ± 0.06	3.87 ± 0.03	3.91 ± 0.05	3.43 ± 0.10	3.83 ± 0.08	59.61*

2	Ash (%)	12.72 ± 0.09	12.46 ± 0.17	12.68 ± 0.15	12.62 ± 0.04	12.77 ± 0.14	12.68 ± 0.2	1.75**
3	Carbohydrate (g)	60.35 ± 0.13	64.55 ± 0.14	65.65 ± 0.19	64.29 ± 0.08	66.38 ± 0.08	66.23 ± 0.09	937.63*
4	Protein (g)	9.78 ± 0.06	9.81 ± 0.07	9.74 ± 0.11	12.94 ± 0.47	12.99 ± 0.08	12.98 ± 0.24	962.76*
5	Fat (g)	6.20 ± 0.04	7.76 ± 0.07	8.56 ± 3.40	5.74 ± 0.12	6.19 ± 0.15	6.44 ± 0.09	3.19*
6	Fiber (g)	11.19 ± 0.10	12.42 ± 0.07	12.16 ± 0.07	12.24 ± 003	12.86 ± 0.19	12.44 ± 0.11	90.18*
7	Vitamin C (mg)	0.32 ± 0.08	0.29 ± 0.08	0.36 ± 0.06	0.39 ± 0.02	0.29 ± 0.05	0.29 ± 0.05	0.97**
8	Iron (mg)	6.43 ± 0.06	7.38 ± 0.07	7.43 ± 0.06	7.16 ± 0.09	7.46 ± 0.21	7.17 ± 0.56	6.85*
9	Calcium (mg)	32.34 ± 0.06	33.42 ± 0.13	34.44 ± 0.09	32.96 ± 0.60	33.44 ± 0.15	33.6 ± 0.12	9.28*
10	Phosphorus (mg)	196.9 ± 0.19	202.26 ± 0.06	205 ± 1.09	199.54 ± 0.19	206.26 ± 0.21	204.44 ± 0.20	177.06*

*Significant, **Not Significant (*p<0.05*), PMUT- Unprocessed Pearl millet Tableware, PMUHT - Unprocessed Pearl millet Hibiscus-enriched Tableware, PMURT - Unprocessed Pearl millet Rose-enriched Tableware, PMRT - Roasted Pearl millet Tableware, PMRHT - Roasted Pearl millet Hibiscus-enriched Tableware, PMRRT - Roasted Pearl millet Rose-enriched Tableware

The nutrient analysis of flower-enriched pearl millet tableware revealed distinct variations. Moisture content ranged from 3.20 per cent to 3.91 per cent, and roasted variants exhibited higher moisture content (3.43 to 3.91 %). Ash content was consistent (12.46 – 12.77%), which showed minimal variation. Carbohydrate content was significantly higher in roasted tableware (64.29–66.38 g) compared to unprocessed variants (60.35–65.65 g), which indicated the impact of roasting and flower powder enrichment. Protein content showed a significant difference between roasted and flower powder enrichment as compared to PMUT. Fat content was highest in PMURT (8.56 g) and the least content was observed in PMRT (5.74 g). Fiber content was increased in flower-enriched tableware, particularly in hibiscus-enriched (12.42–12.86 g) variant. Vitamin C content was exhibited similar results (0.29–0.39 mg) in all variants. Iron content (6.43–7.46 mg) and calcium content (32.34–

34.44 mg) were improved in roasted pearl millet with flower-enriched variants. Phosphorus content consistently increased with roasting and flower enrichment, and the highest content was observed in PMRHT (206.26 mg). The result of nutrient analysis of flower-enriched pearl millet tableware highlighted that the roasting of pearl millet and flower-enrichment showed significant differences in carbohydrates, protein, and fiber content as compared with its unprocessed counterpart. The nutrient content of the present study is similar with the findings of Meshram *et al*. (2025), who developed edible cups from kodo millet by incorporating guar gum and hibiscus flower extract.

ii. Proximate and Nutrient Analysis of Flower-Enriched Sorghum Tableware

Table XXVIII summarizes the proximate and nutrient analysis of the flower-enriched sorghum (unprocessed and roasted) tableware.

Table – XXVIII

Proximate and Nutrient Analysis of Flower-Enriched Sorghum Tableware

S. No	Nutrient Analysis	Sorghum Unprocessed			Roasted Sorghum			F value
		SUT	SUHT	SURT	SRT	SRHT	SRRT	
1	Moisture (%)	3.57 ± 0.04	3.40 ± 0.07	3.66 ± 0.04	3.51 ± 0.06	4.10 ± 0.08	3.62 ± 0.04	46.82*
2	Ash (%)	6.12 ± 0.02	6.13 ± 0.02	6.19 ± 0.05	6.41 ± 0.07	6.13 ± 0.05	6.28 ± 0.02	19.49*
3	Carbohydrate (g)	72.35 ± 0.12	78.13 ± 0.03	76.34 ± 0.11	72.64 ± 0.24	77.36 ± 0.80	77.72 ± 0.20	864.91*
4	Protein (g)	10.34 ± 0.13	10.25 ± 0.08	11.12 ± 0.08	11.90 ± 0.14	12.19 ± 0.13	12.14 ± 0.09	179.87*
5	Fat (g)	1.9 ± 0.07	1.84 ± 0.12	2.15 ± 0.11	1.86 ± 0.11	2.14 ± 0.11	2.42 ± 0.04	15.82*
6	Fiber (g)	10.62 ± 0.07	13.30 ± 0.16	13.42 ± 0.14	13.41 ± 0.16	13.64 ± 0.08	13.7 ± 0.14	239.46*
7	Vitamin C (mg)	0.37 ± 0.05	0.27 ± 0.07	0.28 ± 0.08	0.33 ± 0.09	0.27 ± 0.06	0.29 ± 0.04	0.99**
8	Iron (mg)	3.85 ± 0.11	4.8 ± 0.08	4.71 ± 0.16	4.25 ± 0.08	5.05 ± 0.08	5.50 ± 0.80	93.59*

9	Calcium (mg)	33.36 ± 0.16	34.36 ± 0.11	33.95 ± 0.10	33.61 ± 0.17	33.74 ± 0.08	33.96 ± 0.03	24.91*
10	Phosphorus (mg)	152.96 ± 0.08	157.43 ± 0.15	158.18 ± 0.14	157.72 ± 0.10	158.24 ± 0.19	158.52 ± 0.11	717.67*
*Significant, **Not Significant (*p<0.05*), SUT-Unprocessed Sorghum Tableware. SUHT-Unprocessed Sorghum Hibiscus-enriched Tableware, SURT-Unprocessed Sorghum Rose-enriched Tableware, SRT-Roasted Sorghum Tableware, SRHT-Roasted Sorghum Hibiscus-enriched Tableware, SRRT-Roasted Sorghum Rose-enriched Tableware								

Moisture content varied slightly, ranging from 3.40 per cent to 4.10 per cent, and SRHT showed the highest content (4.10 ± 0.08). Ash content was between 6.12 per cent to 6.41 per cent, which showed increased content in roasted variants. Carbohydrate content was significantly higher in flower-enriched and unprocessed tableware hence, the highest content was observed in SUHT (78.13 g) followed by SRRT (77.72 g). Protein content improved in roasted and flower enriched tableware and SRHT (12.19 ± 0.13) showed the highest content whereas least protein content was found in SUHT (10.25 ± 0.08). Rose powder incorporated variants (SURT and SRRT) exhibited highest fat and fiber content. Vitamin C was between 0.27–0.37 mg, that showed minimal variation. Iron content increased significantly in roasted sorghum with flower enriched variant and SRRT exhibited the highest (5.50 mg) content. Calcium content showed significant difference among unprocessed and roasted sorghum tableware enriched with flower powder (33.36–34.36 mg), exhibited an impact of roasting and flower powder enrichment. Phosphorus content was consistently high in flower-enriched sorghum tableware (SRHT, SURT, SRRT, 158 mg). Roasting and flower enrichment in sorghum tableware enhanced the nutritional profile, particularly carbohydrates, protein, fiber, and iron as compared to its unprocessed counterparts which was also suitable in food serving with nutritional benefits. The result of nutrient analysis of the present study is supported by the findings of, Latha Ravi & Meena (2024), Rashwan *et al*. (2021) and Tamilselvan & Kushwaha (2020) have found that sorghum as a rich of nutrients and roasting increased iron, calcium and protein while it decreased fat and dietary fiber due to the chemical compound changes. Increased protein, far or carbohydrate was found in biscuits incorporated with rose calyx powder (Hernandez-Nava *et al*., 2023).

4.4.2 ANTIOXIDANT ACTIVITY OF FLOWER-ENRICHED MILLET TABLEWARE

i. Antioxidant Activity of Flower-Enriched Pearl millet Tableware

The antioxidant activity of the hibiscus and rose enriched pearl millet tableware was done in different concentrations from 10 µl/ml to 750 µl/ml and is given in Figure - 14. Hibiscus-enriched pearl millet tableware (PMUHT), exhibited higher inhibition percentage, particularly at lower concentration (71.68% at 10 µg/ml and 93.51% at 250 µg/ml). Rose enrichment (PMURT, PMRRT) enhanced the antioxidant activity with inhibition percentage at 94.54 per cent at 500 µg/ml for unprocessed pearl millet tableware whereas 94.26 per cent at 500 µg/ml in roasted pearl millet tableware. The IC_{50} value revealed that hibiscus enriched pearl millet (46.81 µg/ml for unprocessed and 89.93 µg/ml for roasted) tableware exhibited strong and moderate antioxidant activity as compared to its unprocessed tableware (PMUT, 88.34 µg/ml) and roasted pearl millet tableware (PMRT, 144.76 µg/ml). Similarly, rose-enriched pearl millet tableware exhibited moderate antioxidant activity (PMURT, 76.55 µg/ml and PMRRT, 95.98 µg/ml) Hibiscus flower enriched pearl millet tableware showed strong antioxidant activity followed by rose flower enriched tableware and its unprocessed and roasted counterparts. Similar study by Meshram *et al.* (2025), exhibited that incorporation of hibiscus flower extract upto six per cent in kodo millet cup had significantly increased the antioxidant activity.

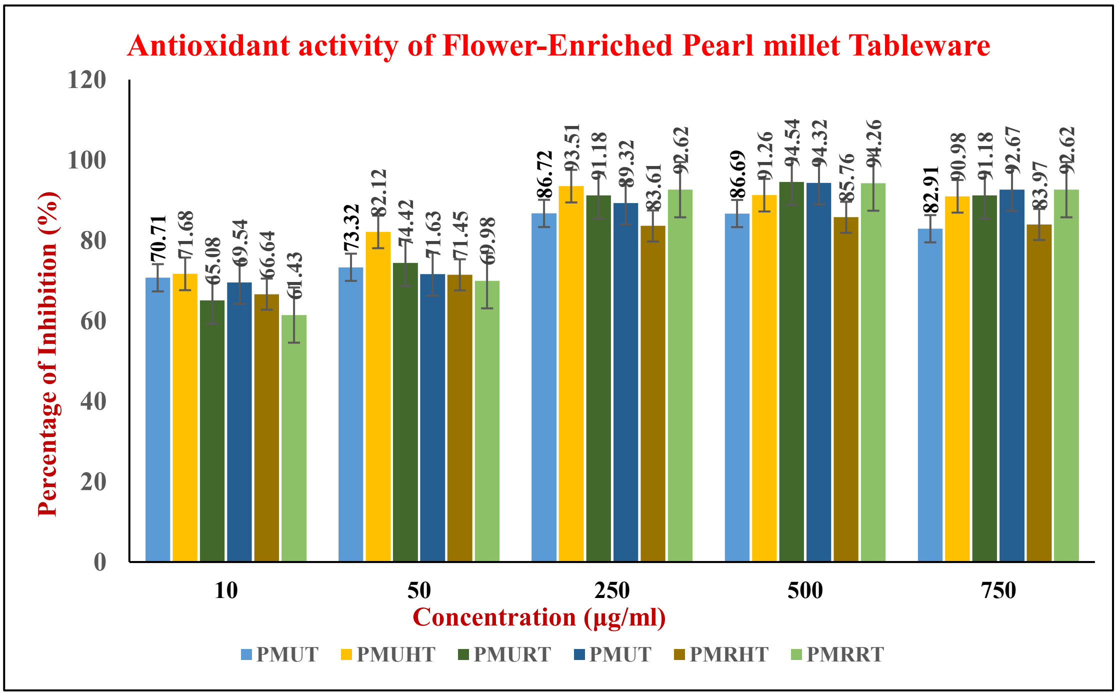


Figure – 14

Antioxidant Activity of Flower-Enriched Pearl millet Tableware

ii. Antioxidant Activity of Flower-Enriched Sorghum Tableware

The antioxidant activity of flower-enriched sorghum tableware was done at different concentrations and the percentage of inhibition is given in Figure - 15. Rose-enriched unprocessed tableware (SURT) stood with the highest inhibition percentages across all the taken concentrations (94.79% at 250 µg/ml), achieving the lowest IC_{50} value of 39.87 µg/ml. Unprocessed hibiscus-enriched sorghum tableware (SUHT) also exhibited strong antioxidant activity with a IC_{50} value of 47.74 µg/ml which was highest than SUT (51.91µg/ml)/ Roasted sorghum tableware (SRT) exhibited highest inhibition rate at higher concentration and the IC_{50} value was 72.99 µg/ml which showed moderate activity. SRHT and SRRT showed an IC_{50} value of 54.99 µg/ml (moderate) and 46.76 µg/ml (strong) respectively. In flower enriched sorghum tableware, both hibiscus and rose enriched variants showed strong antioxidant activity as compared to its unprocessed and roasted sorghum variants which showed moderate activity. The finding of the present study is parallel with the results of roasted sorghum showed a increased total phenolic content and possessed strong antioxidant activity (Xiong *et al*., 2019). Vasic *et al.* (2023), who stated that tisanes made by incorporating rose and hibiscus powder exhibited highest antioxidant activity. Biscuit enhanced with rose and hibiscus flower powder has exhibited strong antioxidant activity that reduced the ailments caused by free-radicals (Akram *et al*., 2020).

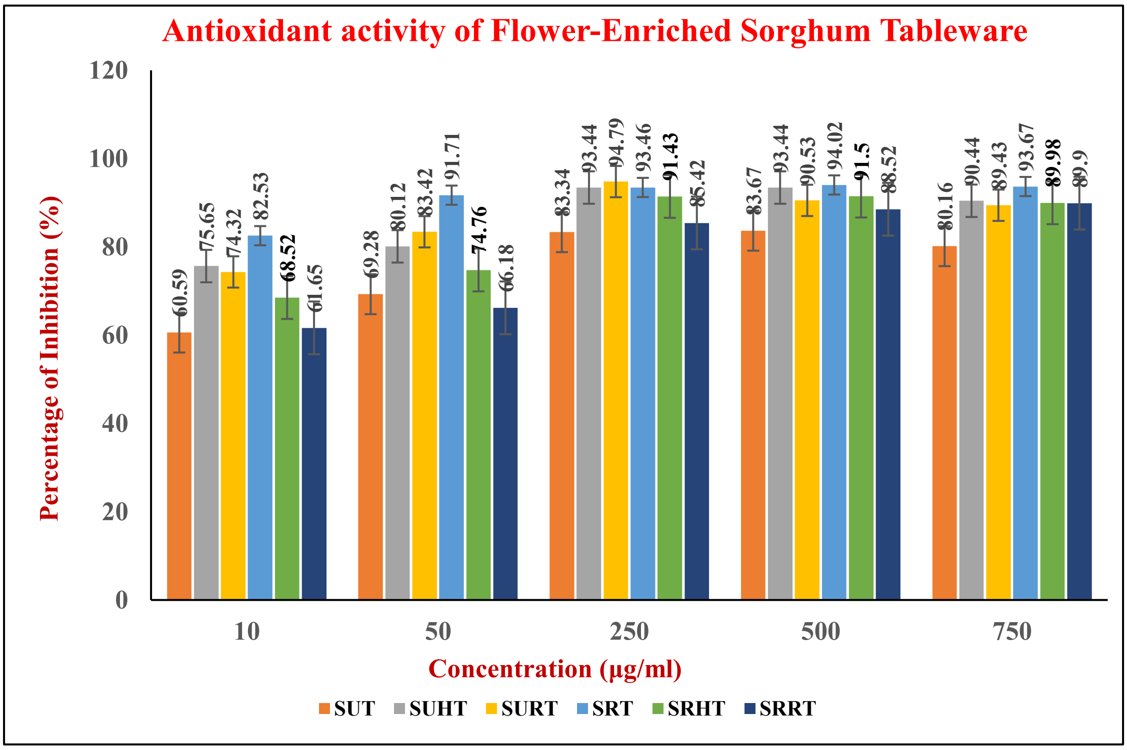


Figure – 15

Antioxidant Activity of Flower-Enriched Sorghum Tableware

Both pearl millet and sorghum tableware demonstrated strong antioxidant activity after flower powder enrichment and the strongest antioxidant activity was found in sorghum with rose flower powder enriched tableware at lower concentration. Rose powder enriched tableware exhibited strong antioxidant activity than hibiscus enriched tableware in sorghum, whereas hibiscus enriched tableware dominated in pearl millet variants. The present study found that flower-enriched pearl millet and sorghum tableware exhibited strong to moderate IC_{50} value, that emphasized the antioxidant property of flower enrichment in tableware.

4.4.3 OPTICAL PROPERTY OF FLOWER-ENRICHED MILLET TABLEWARE

The optical property of pearl millet and sorghum tableware was compared with hibiscus and rose enriched tableware and the results were discussed below,

i. Optical Property of Flower-Enriched Pearl millet Tableware

The optical property, L*, a*, b* and ΔE of flower-enriched pearl millet tableware was measured and discussed in Table XXIX. L* indicates lightness, a* and b* denotes red to green and yellow to blue hue and ΔE measures the total colour difference.

Table XXIX

Optical Property of Flower-Enriched Pearl millet Tableware

S. No	Parameters	Unprocessed Pearl millet			Roasted Pearl millet			F value
		PMUT	PMUHT	PMURT	PMRT	PMRHT	PMRRT	
1	L*	16.26 ± 0.39	12.35 ± 0.83	13.2 ± 0.62	14.15 ± 0.75	16.35 ± 0.59	12.9 ± 0.68	20.41*
2	a*	0.75 ± 0.10	1.29 ± 0.22	1.62 ± 0.56	0.65 ± 0.23	0.39 ± 0.10	1.57 ± 0.4	7.98*
3	b*	3.12 ± 0.40	5.13 ± 0.44	5.58 ± 0.04	3.14 ± 0.51	6.32 ± 0.64	5.41 ± 0.63	45.62*
4	ΔE	7.55 ± 0.46	5.28 ± 0.65	6.35 ± 0.46	7.11 ± 0.64	10.3 ± 0.75	5.63 ± 0.39	29.54*

*Significant, **Not Significant (*p<0.05*), L* Lightness (0 black to 100 White); a* (+60 red to -60 green); b* (+60 yellow to -60 blue)

The L* value ranged from 12.35 (PMUHT) to 16.35 (PMRHT), that showed the variations in brightness which was influenced by roasting and flower enrichment. The roasted tableware with flower enrichment exhibited higher lightness compared to its unprocessed counterparts, due to the Maillard reaction and pigment retention from flower powder. The a* value, indicated the redder hue with a maximum of 1.62 in PMURT and a minimum of 0.39 in PMRHT due to the presence of flower pigments, especially anthocyanins in hibiscus and flavonoids in roses, which influenced the redness hue. The highest redness was observed in rose enriched variants followed by hibiscus enriched pearl millet tableware. The b* values ranged from 3.12 (PMUT) to 6.32 (PMRHT), with roasted and hibiscus-enriched tableware exhibited enhanced yellow hues. The increased b* values in roasted variants could be attributed to caramelization and the natural yellow pigment enhanced from hibiscus and rose powder. PMRHT showed the highest colour difference (ΔE, 10.3), due to the impact of roasting and flower enrichment. The significant F values for all parameters (*p<0.05*) showed a statistically significant impact of roasting and flower enrichment on the optical property of pearl millet tableware. The results were supported by the findings of Meshram *et al*. (2025), who found that incorporation of hibiscus flower extract in kodo millet cup resulted in a darker shade with increased redness due to the pigment present in hibiscus flower.

ii. Optical Property of Flower-Enriched Sorghum Tableware

The L*, a*, b*, and ΔE parameters of unprocessed, roasted, and flower-enriched tableware was measured and the results is summarized in Table - XXX.

Table XXX

Optical Property of Flower-Enriched Sorghum Tableware

S. No	Parameters	Sorghum Unprocessed			Roasted Sorghum			F value
		SUT	SUHT	SURT	SRT	SRHT	SRRT	
1	L*	13.25 ± 2.28	12.5 ± 0.26	10.77 ± 0.31	9.74 ± 0.54	11.59 ± 0.31	14.57 ± 0.04	9.40*
2	a*	4.01 ± 0.17	3.42 ± 0.57	2.79 ± 0.41	2.01 ± 0.74	2.66 ± 0.16	1.38 ± 0.4	12.60*
3	b*	6.91 ± 0.04	5.54 ± 0.57	4.38 ± 0.6	5.74 ± 0.37	4.28 ± 0.58	7.53 ± 0.58	20.13*
4	ΔE	9.15 ± 0.14	4.79 ± 0.55	3.05 ± 0.62	3.55 ± 0.19	3.43 ± 0.56	8.18 ± 0.28	108.79*

*Significant, **Not Significant (*p<0.05*), L* Lightness (0 black to 100 White); a* (+60 red to -60 green); b* (+60 yellow to -60 blue)

The lightness of sorghum tableware varied between 9.74 (SRT) and 14.57 (SRRT). SRRT exhibited the highest L*, that reflected the influence of roasting and pigment interaction in sorghum tableware that enhanced brightness. The highest a* was observed in SUT (4.01) with redder hue, while roasted with flower enriched tableware led to reduced red hue, and SRRT showed the lowest a* (1.38) value. The b* value was highest in SRRT (7.53) and lowest in SRHT (4.28), indicated that SRRT had the highest yellow hue due to pigment stability and sugar-pigment interaction during roasting.

The ΔE values were highest in SUT (9.15), and flower enrichment and roasting showed moderate total colour difference (ΔE) whereas SRRT exhibited a ΔE of 8.18, which indicated a distinct colour difference that was influenced by processing and flower incorporation. Statistically significant F values ($p<0.05$) for all parameters were found and confirmed, that the roasting and flower enrichment in tableware altered the optical property of sorghum tableware which provides diverse appeal and visual characteristics. The result aligns with the findings of, Hernandez-Nava *et al*. (2023) and Weerasingha *et al*. (2021) found that, rose powder incorporated biscuits has exhibited increased redder shade due to pigment leaching. Dharshini & Meera (2023) found that the change in colour in millet was due to phenolic compound oxidation, or maillard reaction.

The roasted pearl millet and sorghum tableware with flower enrichment exhibited higher lightness compared to its unprocessed millet tableware. Sorghum tableware exhibited lower a* value as compared with pearl millet tableware whereas yellowness was increased in both pearl millet and sorghum tableware after flower enrichment. The colour difference was varied in unprocessed and roasted variations and all the parameters showed statistically significant difference.

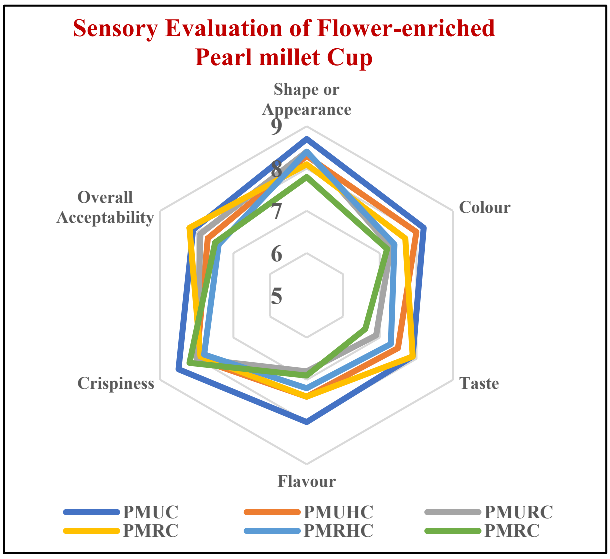
4.4.4 SENSORY EVALUATION OF FLOWER-ENRICHED MILLET TABLEWARE

The sensory attributes of the standardised millet tableware enriched with flower powder were evaluated using 9-point hedonic scale to measure the consumer preferences for various sensory parameters.

i. Sensory Evaluation of Flower-Enriched Millet Cup

The sensory evaluation of flower-enriched millet cup was conducted using a nine-point hedonic scale to assess consumer preferences for various sensory attributes, including shape or appearance, colour, taste, flavour, crispiness, and overall acceptability, is given in Figure - 16.

PMUC exhibited the highest score (8.7 ± 0.48) in appearance, similarly, PMRHC also scored, 8.4 ± 0.96, which showed that roasting and flower incorporation has not influenced the shape or appearance. The score for colour of PMUC was highest (8.2 ± 0.91), followed by PMRC (7.7 ± 0.82) whereas hibiscus-enriched cup (PMUHC and PMRHC) scored slightly lower due to the impact of hibiscus pigment. The taste preference showed that PMUC and PMRC scored the highest (7.9 ± 0.73 and 7.9 ± 1.10, respectively) and flower enrichment, especially PMURC and PMRRC exhibited moderate (6.9 ± 1.19 and 6.6 ± 0.84) scores. The flavour scores ranged from 6.8 ± 1.54 (PMURC) to 8 ± 0.94 (PMUC), with unprocessed cup showed higher acceptability followed by roasted cup with hibiscus and rose enrichment. The crispiness of PMUC and PMRC scored high (8.5 ± 1.08 and 7.9 ± 1.10) and the incorporation of hibiscus and rose powder exhibited slightly lower scores. The overall Acceptability of PMUC and PMRC were the most preferred (8.1 ± 1.10 and 8.2 ± 0.63, respectively), and hibiscus and rose enriched cup moderately influenced the overall acceptability, with PMRHC scored the lowest (7.4 ± 0.69) score.



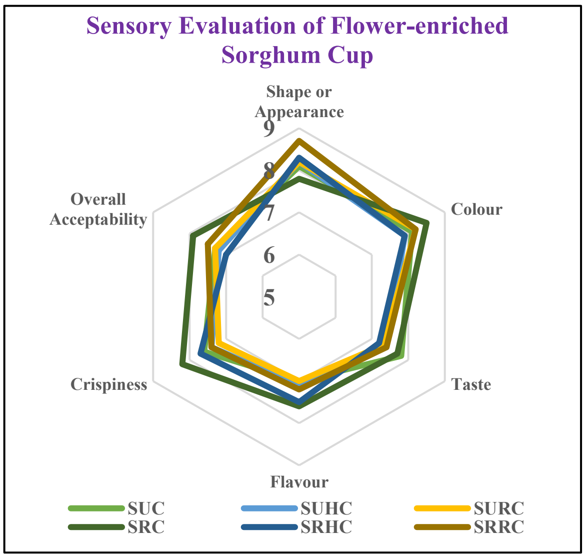


Figure - 16

Sensory Evaluation of Flower-Enriched Millet Cup

(PMUC- Unprocessed Pearl millet Cup, PMUHC-Unprocessed Pearl millet Hibiscus-enriched Cup, PMURC-Unprocessed Pearl millet Rose-enriched Cup, PMRC-Roasted Pearl millet Cup, PMRHC-Roasted Pearl millet Hibiscus-enriched Cup, PMRRC-Roasted Pearl millet Rose-enriched Cup, SUC-Unprocessed Sorghum Cup, SUHC-Unprocessed Sorghum Hibiscus-enriched Cup, SURC-Unprocessed Sorghum Rose-enriched Cup, SRC-Roasted Sorghum Cup, SRHC-Roasted Sorghum Hibiscus-enriched Cup, SRRC-Roasted Sorghum Rose-enriched Cup)

The shape or appearance of SRRC exhibited the highest score (8.7 ± 0.67) followed by SUC (8.1 ± 0.56), which demonstrated that flower enrichment did not affect shape or acceptance scores. The colour of SRC scored the highest (8.5 ± 0.70) and SRRC (8.2 ± 1.13) also exhibited liked very much category which showed that colour parameter was exhibited good scores. SUC (7.8 ± 1.12) and SRC (7.7 ± 1.49) scored the highest for taste, whereas hibiscus and rose enriched cup scored moderately less ranging from 7.2 ± 1.13 (SRHC) to 7.4 ± 1.50 (SRRC). SRC (7.6 ± 0.69), had the highest flavour score and flower enriched cup exhibited moderate scores, 7.5 ± 0.84 for SRHC and 7.2 ± 1.61 for SRRC. Crispiness of SRC (8.2 ± 1.31) was the highest score and flower-enriched variants showed slightly lower but acceptable scores. The overall acceptability score of SRC and SRRC (7.9 ± 0.87 and 7.5 ± 1.35, respectively), was the most preferred, followed by SUC (7.3 ± 0.67).

Appearance and colour of the roasted pearl millet and sorghum cup with flower enrichment has exhibited liked very much category. Taste, flavour, crispiness and overall acceptability was decreased in flower enriched cup and unprocessed and roasted cup showed better scores. The results were supported by the findings of, Mandal & Antarkar (2024) found that sorghum waffle cone scored high scores in colour and pearl millet waffle cone scored high scores in flavours and overall acceptability of the waffle cones were highly acceptable and inclusion of vanilla and strawberry flavours hadn't altered the sensory attributes. Meshram *et al*. (2025), who found that incorporation of hibiscus flower extract upto six per cent in kodo millet cup had positively influenced the sensory attribute, which was highly acceptable.

ii. Sensory Evaluation of Flower-Enriched Millet Bowl

The sensory evaluation of millet bowl in respect of the unprocessed, roasted, and flower-enriched variants was evaluated by semi-trained panel members and the scores are given in Figure - 17.

The appearance of the bowl was similar among all variations that scored between 7.9 to 8.3 and PMUB, PMRB and PMURB that exhibited the highest (8.3) score. PMUB exhibited the highest colour score (8.1 ± 0.73) whereas roasted pearl miller bowl and flower enriched bowl exhibited slightly lesser scores (PMRHB, 6.7 ± 0.82). The taste preference of PMUB and PMRRB scored highest (7.6 ± 0.84 and 7.3 ± 0.48) followed by hibiscus-enriched (PMUHB) bowl with slightly lower scores. PMUB exhibited the highest score in flavour (8.1 ± 0.87), while flower enriched bowl scored slightly reduced flavour acceptability (PMRHB, 6.9 ± 0.87). Crispiness was similar across all variations, with PMUHB scored highest (8.2 ± 0.91) score followed by PMRRB, PMUB and PMRB. The overall acceptability showed that, PMRB, PMUHB and PMUB scored the highest (7.7 ± 0.67 and 7.6 ± 0.96) as compared to flower-enriched bowl.

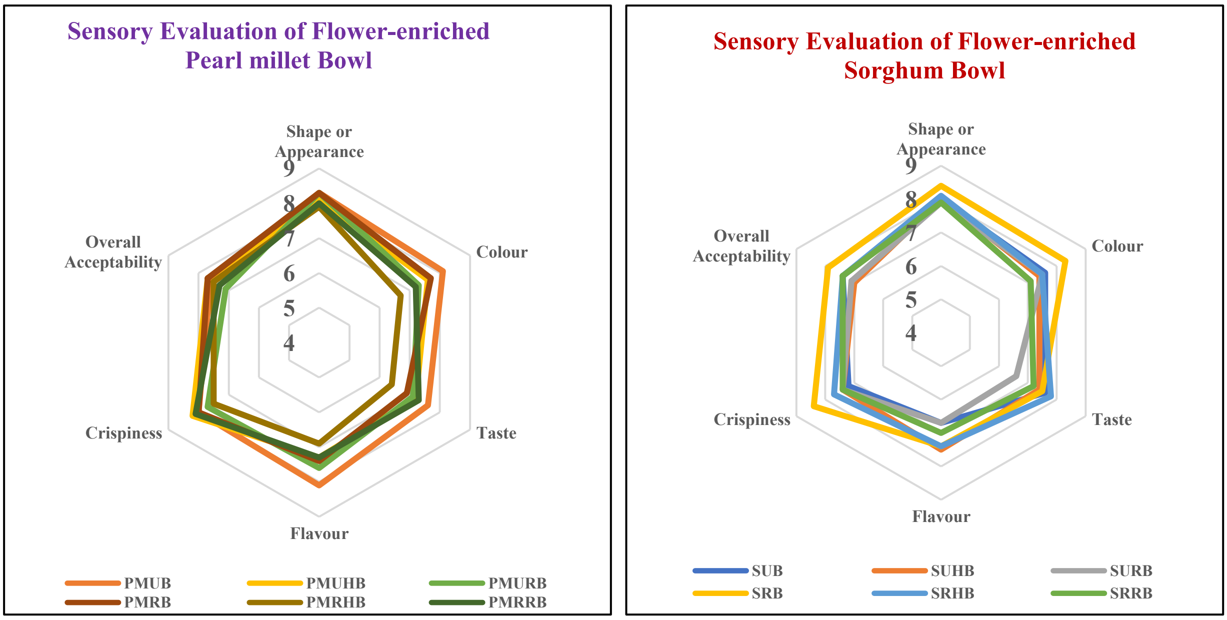


Figure - 17

Sensory Evaluation of Flower-Enriched Millet Bowl

(PMUB- Unprocessed Pearl millet Bowl, PMUHB-Unprocessed Pearl millet Hibiscus-enriched Bowl, PMURB-Unprocessed Pearl millet Rose-enriched Bowl, PMRB-Roasted Pearl millet Bowl, PMRHB-Roasted Pearl millet Hibiscus-enriched Bowl, PMRRB-Roasted Pearl millet Rose-enriched Bowl, SUB-Unprocessed Sorghum Bowl, SUHB-Unprocessed Sorghum Hibiscus-enriched Bowl, SURB-Unprocessed Sorghum Rose-enriched Bowl, SRB-Roasted Sorghum Bowl, SRHB-Roasted Sorghum Hibiscus-enriched Bowl, SRRB-Roasted Sorghum Rose-enriched Bowl)

Among sorghum bowl, SRB scored the highest (8.4 ± 0.84) score in shape or appearance and colour parameters and all the bowl scored between 7.9 to 8.4 for shape and 7.1 to 8.3 for colour. Taste preferences were consistent among all sorghum bowl with SRHB (7.8 ± 0.63) scored the highest preference whereas, SUB and SRB exhibited like moderately (7.6 ± 0.84 and 7.5 ± 0.84) scores. Flavour acceptability was highest in SUHB (7.5 ± 0.70) followed by SRB (7.4 ± 0.69) and SRRB (7 ± 0.81). The crispiness of SRB preferred more (8.4 ± 0.96), followed by SUB and SRHB. The overall acceptability of SRB scored the highest (7.9 ± 0.73), followed by unprocessed and flower enriched sorghum bowl.

Sensory preferences of flower-enriched pearl millet and sorghum bowl showed that, roasting millet or flower enrichment has not affected the shape or appearance and colour parameters. The panellists preferred an unflavoured bowl to a roasted and flower-enriched bowl. Crispiness showed that the unprocessed pearl millet bowl and roasted sorghum bowl showed the highest preference and flower-enriched bowl exhibited a decreased score in crispiness. Overall acceptability of the pearl millet and sorghum bowl with flower enrichment showed moderately liked scores. The result is consistent with the studies reported by, Kushwaha *et al*. (2023) who standardised wheat cutlery enhanced with jackfruit seed flower and found that the quantity of jackfruit seed flour and water added to it alters the sensory attributes and incorporation of jackfruit seed in higher quantity decreased the sensory attributes of the developed cutlery. Latha Ravi & Rana (2024) stated that, the sensory attributes and shelf life can be prolonged by roasting the millets.

iii. Sensory Evaluation of Flower-Enriched Millet Katori

The sensory evaluation of flower-enriched pearl millet and sorghum katori was assessed for its shape or appearance, colour, taste, flavour, crispiness, and overall acceptability that provides insights on consumer preferences and the results is provided in Figure - 18.

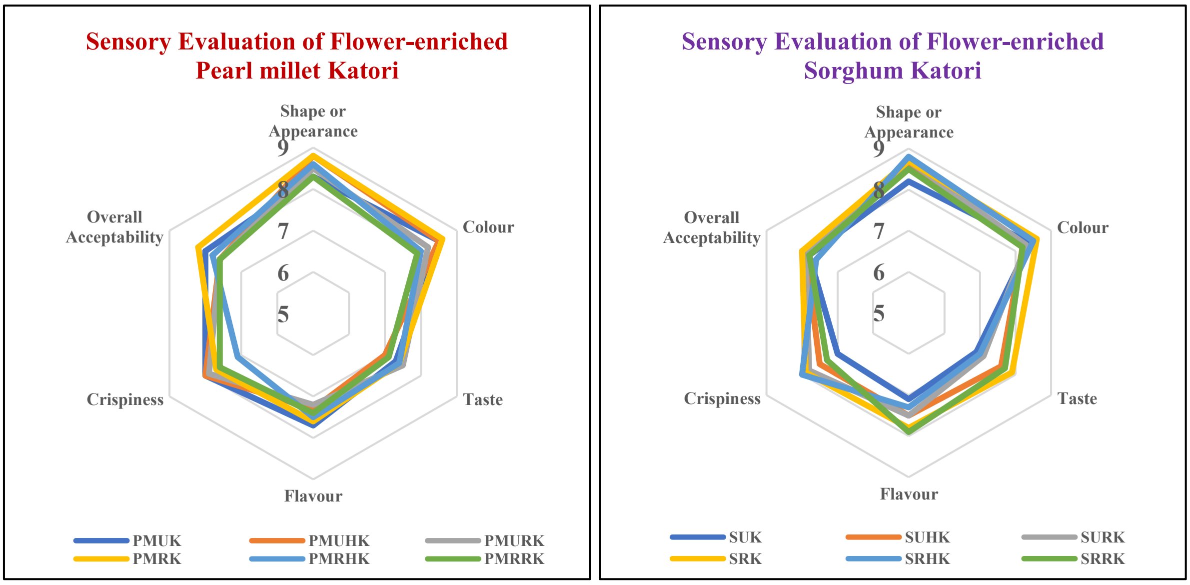


Figure – 18
Sensory Evaluation of Flower-Enriched Millet Katori
(PMUK- Unprocessed Pearl millet Katori, PMUHK-Unprocessed Pearl millet Hibiscus-enriched Katori, PMURK-Unprocessed Pearl millet Rose-enriched Katori, PMRK-Roasted Pearl millet Katori, PMRHK-Roasted Pearl millet Hibiscus-enriched Katori, PMRRK-Roasted Pearl millet Rose-enriched Katori, SUK-Unprocessed Sorghum Katori, SUHK-Unprocessed Sorghum Hibiscus-enriched Katori, SURK-Unprocessed Sorghum Rose-enriched Katori, SRK-Roasted Sorghum Katori, SRHK-Roasted Sorghum Hibiscus-enriched Katori, SRRK-Roasted Sorghum Rose-enriched Katori)

PMUHK (8.8 ± 0.42) and PMRK (8.8 ± 0.42), exhibited the highest score for shape or appearance, and all the katori scored between 8.3 to 8.8. The colour preference was highest for PMRK (8.6 ± 0.51) followed by PMUHK (8.5 ± 1.08) and PMUK (8.5 ± 0.52) showed that roasting millet and flower enrichment exhibited liked very much score. The taste preference was moderate across all variants, with PMURK (7.5 ± 1.08) and

PMRK (7.4 ± 1.07) showed highest score than its counterparts. The flavour of PMUK (7.7 ± 0.67) and PMRK (7.6 ± 0.96) showed the highest score followed by PMRHK (7.5 ± 0.84), which proved that flower enrichment provided unique flavour. PMUK and PMUHK (8 ± 1.05) exhibited highest score in crispiness, while roasted variants showed slightly lower crispiness levels (PMRK, 7.7 ± 1.25) and the crispiness was not affected by flower enrichment. PMRK (8.2 ± 0.78) showed the preferred overall acceptability, followed by the unprocessed katori (PMUK, 8 ± 0.94) while flower enrichment showed slightly reduced acceptability especially in, PMUHK (7.6 ± 1.17) and PMRHK (7.8 ± 0.91).

The shape or appearance of flower-enriched sorghum katori scored between 8.2 to 8.8 and SRHK (8.8 ± 0.42) and SRK (8.7 ± 0.48). The colour of SRK (8.6 ± 0.69) was highest followed by SRHK (8.5 ± 1.08). Taste of SRK, 7.9 ± 0.73 scored high followed by SUHK (7.6 ± 0.96) showed that flower powder enrichment has not affected the colour and taste preference. The flavour preference of SRK (7.8 ± 0.91) and SRRK (7.9 ± 0.73) were similar, but roasted varieties were slightly reduced. Hibiscus and rose enrichment slightly altered the flavour without changing the flavour of sorghum katori. Crispiness preference was highest for SRHK (8 ± 1.05) followed by SRK (7.9 ± 1.10). The overall acceptability of SRK (8 ± 0.81) showed highest score, followed by SUHK (7.9 ± 0.87).

Shape or appearance and colour of pearl millet and sorghum katori scored under liked very much category and flower enrichment and roasting of millets has not affected the shape and colour parameters. Whereas, the parameters including flavour, crispiness, taste and overall acceptability was slightly affected after flower enrichment and the semi-trained panel members preferred unprocessed and roasted pearl millet and sorghum katori as compared to flower enriched counterparts. The result of the present study is on par with the finding of Iqbal *et al*. (2022) have found the sensory scores were between 6 to 8 that indicated slightly to moderately liked by the consumers.

iv. Sensory Evaluation of Flower-Enriched Millet Spoon

The pearl millet and sorghum spoon enriched with flower powder showed distinct sensory characteristics and the scores of sensory attributes is given in Figure - 19. PMUS (8.6 ± 0.51) and PMRHS (8.7 ± 0.48) scored the highest for shape or appearance, and the score was ranging between, 8.3 to 8.7. The colour of PMUS (8.2 ± 0.78) and PMRHS (8.1 ± 0.87) exhibited highest score which indicated that unprocessed spoon scored high than its roasted counterparts. The taste of hibiscus (PMUHS, 7.3 ± 1.05) and rose (PMURS, 7.2 ± 1.39) enriched spoon exhibited liked moderately score which was lower than the unprocessed spoon (PMUS, 8.1 ± 0.73) and roasted spoon (PMRS, 7.4 ± 1.28). The flavour of PMUS (7.8 ± 1.13) exhibited highest score, whereas hibiscus and rose-enriched spoon were moderately liked by semi-trained panellists. The crispiness preference was higher in PMUS (8.3 ± 1.05), followed by PMRRS (7.9 ± 0.87). Flower enrichments slightly reduced crispiness, but all variants maintained acceptable levels. The PMUS (8.1 ± 0.87) and PMRS (8.1 ± 0.56) achieved the highest overall acceptability, and flower enrichment was moderately accepted, with PMUHS and PMRRS scored 7.7 ± 0.82 and 7.7 ± 0.67, respectively.

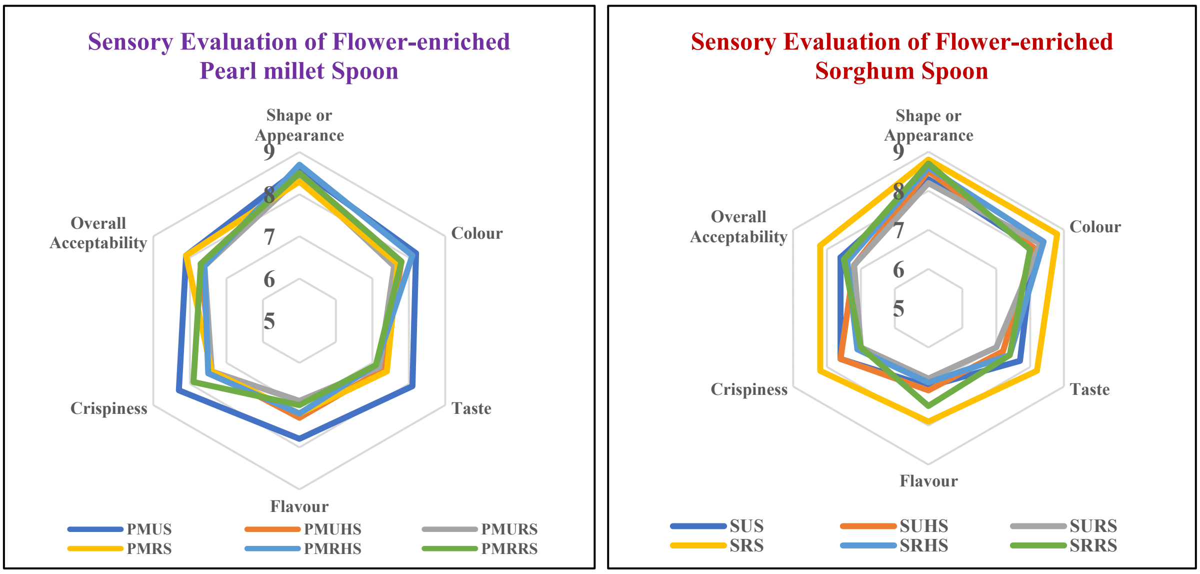


Figure – 19

Sensory Evaluation of Flower-Enriched Millet Spoon

(PMUS- Unprocessed Pearl millet Spoon, PMUHS-Unprocessed Pearl millet Hibiscus-enriched Spoon, PMURS-Unprocessed Pearl millet Rose-enriched Spoon, PMRS-Roasted Pearl millet Spoon, PMRHS-Roasted Pearl millet Hibiscus-enriched Spoon, PMRRS-Roasted Pearl millet Rose-enriched Spoon, SUS-Unprocessed Sorghum Spoon, SUHS-Unprocessed Sorghum Hibiscus-enriched Spoon, SURS-Unprocessed Sorghum Rose-enriched Spoon, SRS-Roasted Sorghum Spoon, SRHS-Roasted Sorghum Hibiscus-enriched Spoon, SRRS-Roasted Sorghum Rose-enriched Spoon)

The sorghum spoon score for shape or appearance was between 8.2 and 8.8 and the highest score was observed in SRS (8.8 ± 0.42) and SRRS (8.7 ± 0.67). SRS (8.8 ± 0.42) excelled in colour preference, that indicated roasting millet enhanced the visual appeal. Hibiscus (SUHS, 8.1 ± 0.56) and rose-enriched (SURS, 8.3 ± 0.82) spoons were also showed similar results as compared to SRS and exhibited a darker shade as compared to unprocessed variants. The roasted spoon (SRS, 8.2 ± 0.78) showed highest score in taste whereas flower enriched spoon showed slightly decreased taste preference (SURS, 7 ± 0.66), which was under liked very much category. SRS (7.9 ± 0.56) achieved the highest flavour score, similarly, SRRS (7.5 ± 0.84) and SUHS (7.1 ± 0.87) also exhibited under liked moderately category. Crispiness was highest for SRS (8.2 ± 1.03) and SUS, SUHS (7.6), indicated that roasting showed higher preference as compared to its unprocessed and flower enriched counterparts. The overall acceptability was highest for SRS (8.2 ± 0.78) followed by the unprocessed spoon (SUS, 7.6 ± 0.69) and flower-enriched spoon exhibited 7.4 ± 0.69 for SRHS and 7.5 ± 0.70 for SRRS which was moderately liked by sensory evaluators.

Flower-enriched pearl millet and sorghum spoon showed that shape or appearance and colour scored similar results whereas the other parameters including crispiness, flavour, taste and overall acceptability was slightly altered by flower powder enrichment and moderately liked by semi-trained panel members as compared to its unprocessed and roasted pearl millet and sorghum spoon. Parallel result is reported by Habla *et al*. (2023), who standardised tapioca edible spoon added with banana flour and the overall acceptability was moderately liked by the sensory evaluators whereas spoon developed from kappa carrageenan found to have decreased mean score of 6 (Agustin *et al*., 2020). The mean acceptability was between 7 to 8 for the spoon developed from alginate and crab shell flour as found by Annafiz *et al*. (2020).

v. Sensory Evaluation of Flower-Enriched Millet Plate

The sensory evaluation of pearl millet and sorghum plate enriched with hibiscus and rose flower powder was evaluated for sensory preferences using 9-point hedonic scale and the scores is provided in the Figure - 20.

The unprocessed pearl millet plate (PMUP, 8.9 ± 0.31) exhibited the highest scores for shape and appearance and all the variants showed scores ranging from 8.4 to 8.9 points which scored under like very much category. PMUP (8.6 ± 0.51) showed highest score in colour and PMRHP (7.4 ± 0.69) showed the reduced colour preference which was in moderately liked category. The highest taste preference was observed in PMUP (8.5 ± 0.52), followed by PMUHP (7.6 ± 0.84). Flower enrichment, rose and hibiscus scored 7.2 to 8.5 that exhibited liked very much to liked moderately category. The flavour of PMUP (8.7 ± 0.48) scored high while hibiscus-enriched roasted plate (PMRHP, 6.8 ± 1.22), exhibited liked slightly category. The highest crispiness score found in the unprocessed plate (PMUP, 8.5 ± 0.97) followed by PMRRP (8 ± 0.66). Roasting and flower enrichment slightly reduced crispiness but under liked very much category. PMUP (8.7 ± 0.67) showed highest overall acceptability and flower powder enrichment showed under moderately accepted category (PMUHP, 7.8 ± 0.78 and PMURP, 7.6 ± 0.96).

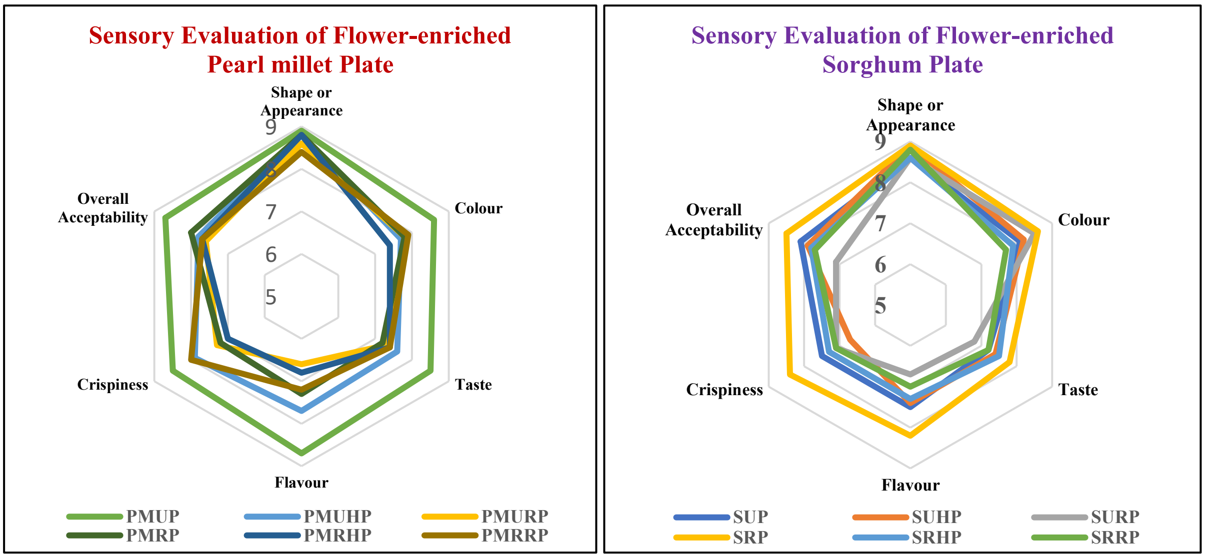


Figure - 20

Sensory Evaluation of Flower-Enriched Millet Plate

(PMUP- Unprocessed Pearl millet Plate, PMUHP-Unprocessed Pearl millet Hibiscus-enriched Plate, PMURP-Unprocessed Pearl millet Rose-enriched Plate, PMRP-Roasted Pearl millet Plate, PMRHP-Roasted Pearl millet Hibiscus-enriched Plate, PMRRP-Roasted Pearl millet Rose-enriched Plate, SUP-Unprocessed Sorghum Plate, SUHP-Unprocessed Sorghum Hibiscus-enriched Plate, SURP-Unprocessed Sorghum Rose-enriched Plate, SRP-Roasted Sorghum Plate, SRHP-Roasted Sorghum Hibiscus-enriched Plate, SRRP-Roasted Sorghum Rose-enriched Plate)

The shape and appearance of flower enriched unprocessed and roasted sorghum plate scored between 8.6 and 8.9 which was under liked very much category. The colour and taste of flower enriched sorghum plate was between 7.2 to 8.5 which showed a slight decrease as compared to SUP and SRP. The flavour scores were between 7 and 8.2, that indicated liked very much to liked moderately category and flower enrichment affected the flavour preferences. The crispiness was highest in roasted plate (8.4 ± 0.84) than unprocessed counterparts (7.5 ± 1.08). The overall acceptability was higher in SRP followed by the unprocessed and flower-enriched sorghum plate.

Sensory evaluation of the plate showed that the flower enrichment slightly decreased the taste, crispiness and flavour preference as compared to its unprocessed and roasted millet plate. Shape or appearance and colour of the plate was not affected by roasting the millet or flower powder enrichment. The result is similar with the findings of Matheswari & Arivuchudar (2024), found that the mean acceptable score for edible cutlery from composite flour was between liked moderately to liked very much category (7 to 8 scores).

4.4.5 FUNCTIONAL PROPERTIES OF FLOWER-ENRICHED MILLET TABLEWARE

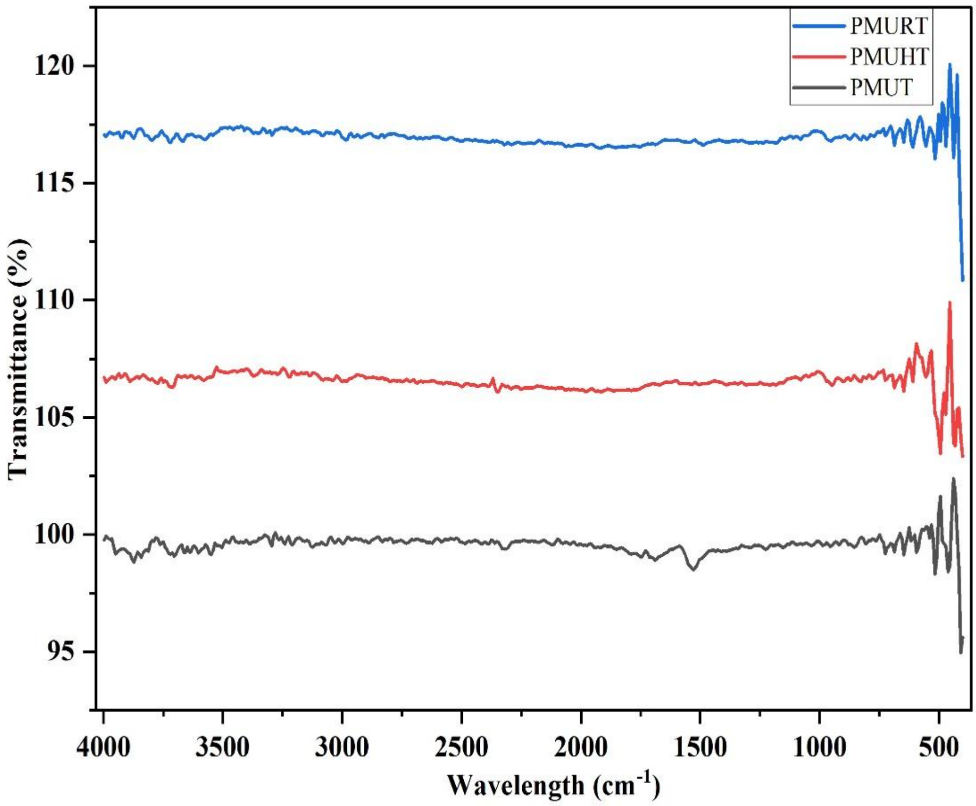
4.4.5.1 FTIR OF FLOWER-ENRICHED MILLET TABLEWARE

i. FTIR of Flower-Enriched Pearl millet Tableware

The FTIR spectra for flower-enriched pearl millet tableware revealed distinct peaks that reflected compositional and structural differences due to roasted pearl millet and flower enrichment and the obtained graph is given in Figure - 21.

PMUT showed sharp O-H stretching peaks at 3603 cm^{-1} and 3857 cm^{-1}, that indicated the presence of water and hydroxyl groups, similarly the peaks were weaker in PMRT which showed the reduced moisture content due to roasting. Across both PMUT and PMRT, peaks around 1689 cm^{-1} and 1527 cm^{-1} suggested minimal changes in protein structure. In the fingerprint region (600–400 cm^{-1}), PMUHT and PMURT exhibited strong peaks at 609.5 cm^{-1}, 648.08 cm^{-1}, and 688.66 cm^{-1}, that showed the presence of functional group. PMURT and PMUHT showed a sharper peak at 555.50 cm^{-1} and 516.62 cm^{-1}, that reflected the presence of functional compounds due to rose and hibiscus flower powder enrichment. PMRHT and PMRRT exhibited sharp peaks at 686.66 cm^{-1}, 648.08 cm^{-1}, 609.51 cm^{-1}, 555.50 cm^{-1}, and 493.78 cm^{-1}, and PMRHT displayed a broader range of additional peaks at 948.93 cm^{-1}, 725.23 cm^{-1}, and 432.05 cm^{-1}, due to the structural rearrangements of organic and inorganic components due to roasting and hibiscus enrichment. PMRRT showed slight peaks at 516.92 cm^{-1} and 439.77 cm^{-1} due to rose flower powder enrichment.

The FTIR spectra demonstrated that roasted pearl millet and enrichment with hibiscus or rose flower powder significantly influenced the structural and functional properties of the tableware. Unprocessed forms retain more moisture and hydroxyl groups, while roasted variants exhibit molecular rearrangements, especially in polysaccharides, lipids, and aromatic compounds and flower powder enrichment showed additional peaks that confirmed the presence of functional compounds.



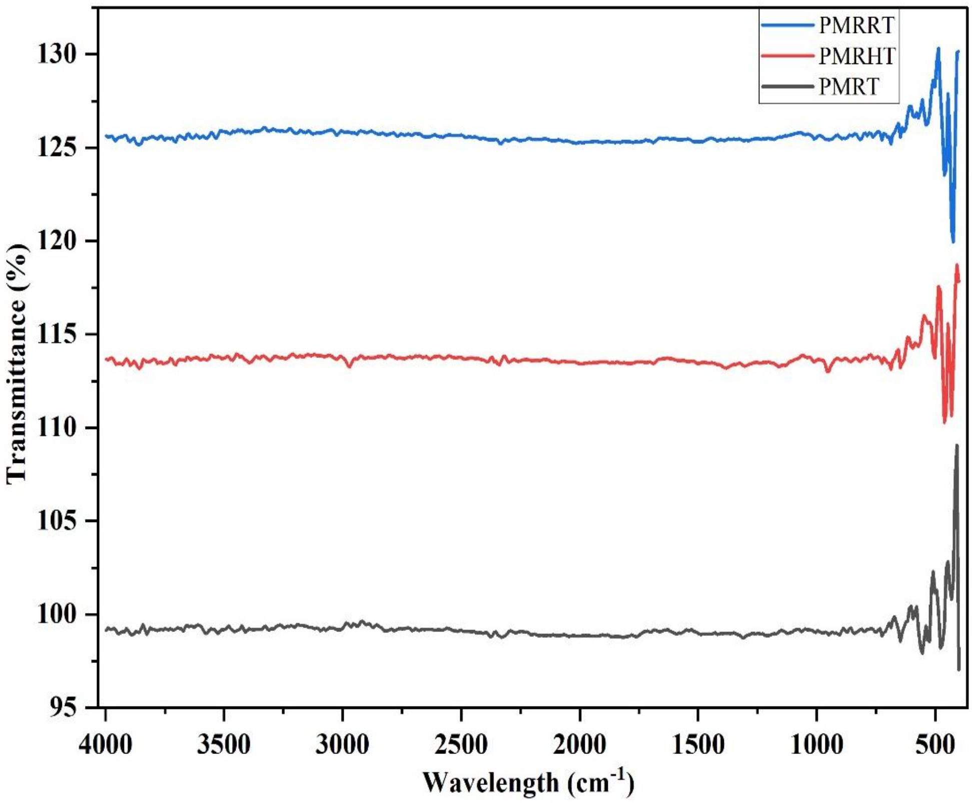


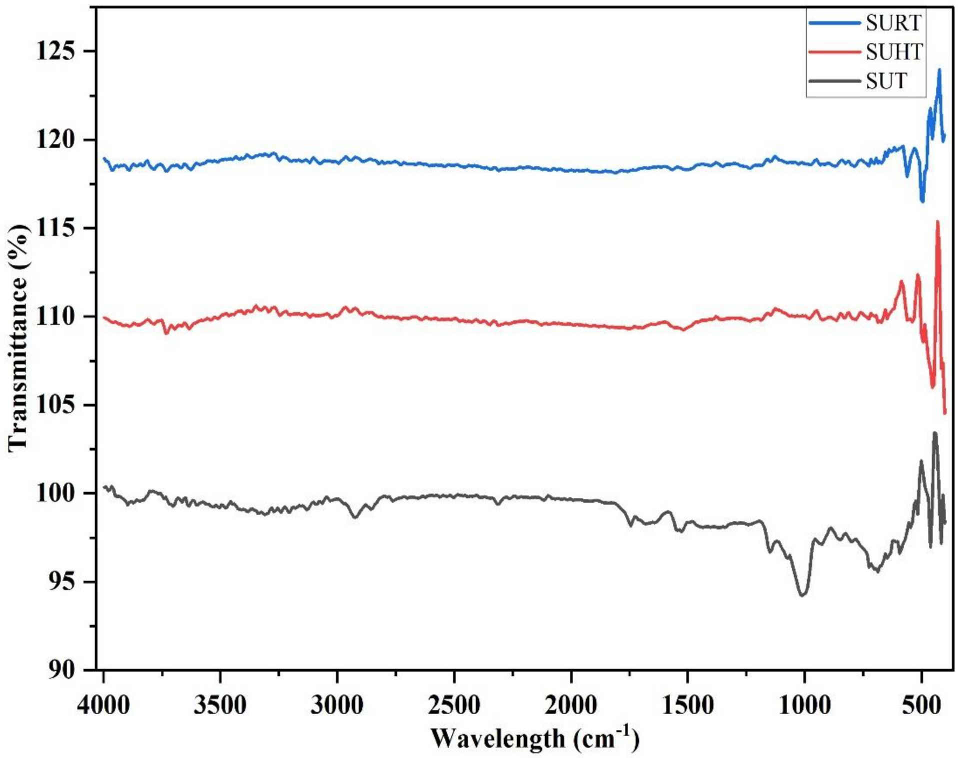
Figure – 21

FTIR peaks of Flower-Enriched Pearl millet Tableware

ii. FTIR of Flower-Enriched Sorghum Tableware

The FTIR of sorghum-based tableware (SUT, SRT, SUHT, SURT, SRRT and SRHT) revealed significant compositional and structural differences influenced by roasting sorghum and flower powder enrichment. Figure – 22 shows the FTIR graph of unprocessed and roasted sorghum tableware enriched with hibiscus and rose flower powder.

The SUT exhibited prominent organic functional group peaks at 3703 cm^{-1} (O–H stretching from hydroxyl groups), 2924 cm^{-1} (C–H stretching of aliphatic compounds), 1743 cm^{-1} (C=O stretching associated with esters or carboxylic acids), and 1527 cm^{-1} (N–H bending indicative of amides). Peaks in the 1149 to 1010 cm^{-1} range suggested the presence of C–O stretching (carbohydrates or esters), while the peaks at 800 to 400 cm^{-1} reflected the presence of C–H bending or skeletal vibrations. In contrast, the SRT spectrum, showed strong peaks at 648, 594, 547, and 439 cm^{-1} which showed the presence of mineral residues or inorganic components.



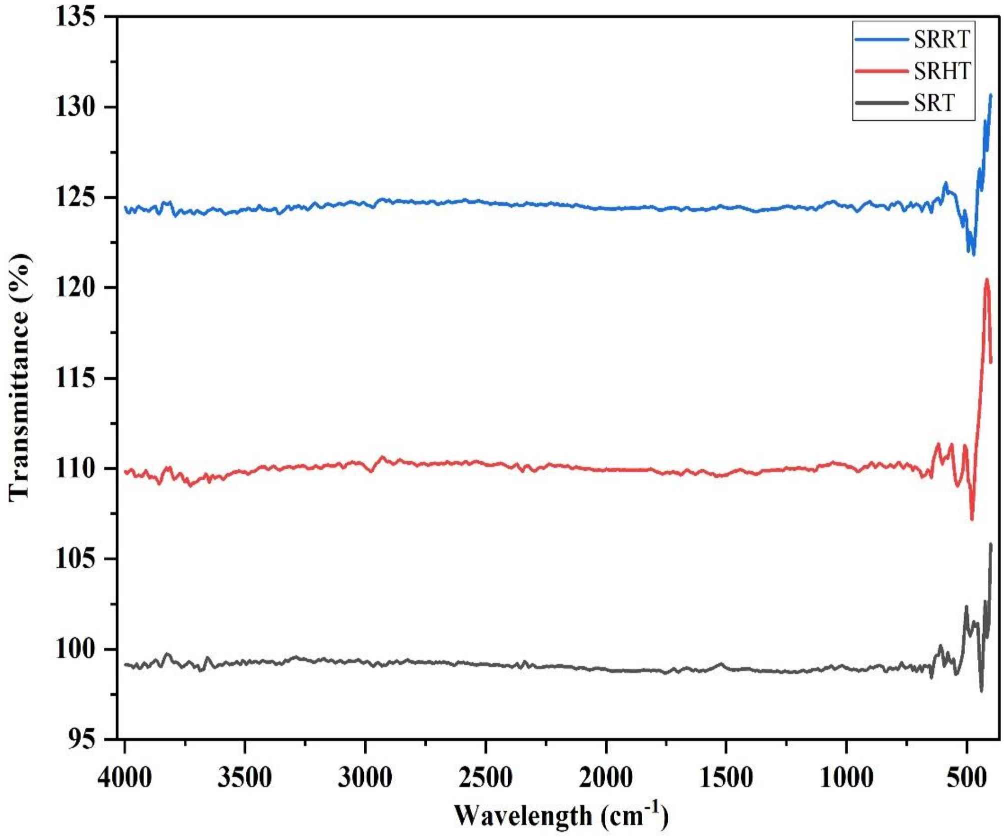


Figure – 22

FTIR of Flower-Enriched Sorghum Tableware

SUHT and SURT showed a broad O–H stretching band around 3700–3600 cm^{-1} (hydroxyl groups from polysaccharides or phenolic compounds) and peaks at 455–493 cm^{-1} (inorganic or complex biomolecular vibrations). SUHT exhibited additional peaks at 648 and 671 cm^{-1}, showed the presence of aromatic compounds from hibiscus flowers, while SURT and SRRT showed a peak at 786 cm^{-1}, which showed the presence of aromatic ring vibrations due to rose flower powder. The SRHT showed a broad O–H stretching peak at 3726 cm^{-1}, a C–H stretching peak at 2978 cm^{-1}, and aromatic peaks at 648 and 668 cm^{-1} due to the hibiscus flower. Peaks at 540 cm^{-1} and 478 cm^{-1} showed the presence of inorganic compounds.

Both pearl millet and sorghum tableware enriched with edible flower powder showed different sharp to broad and weak peaks that confirmed the presence of O-H stretching, C–H stretching of aliphatic compounds, C=O stretching associated with esters or carboxylic acids, and N–H bending indicative of amides. The result of the present study is confirmed by the findings of, Sharanagat *et al*. (2019), the stretching peak between 3800 to 3700 cm^{-1} was due to the breaking of functional compounds during thermal reactions, including roasting and baking. Lin *et al*. (2021) recorded the peaks between 1110 to 990 cm^{-1} were due to the presence of polysaccharides.

4.4.5.2 TGA OF FLOWER-ENRICHED MILLET TABLEWARE

i. TGA of Flower-Enriched Pearl millet Tableware

The TGA result for flower-enriched pearl millet tableware (PMUT, PMUHT, PMURT, PMRT, PMRHT, and PMRRT) revealed distinct thermal degradation with increased temperature from 20ºC to 1000ºC and the obtained peak is given in Figure- 26. The sample weight of 11.30 mg, 4.86 mg, 10.63 mg, 7.787 mg, 6.20 mg, and 5.38 mg of PMUT, PMUHT, PMURT, PMRT, PMRHT, and PMRRT was taken to analyse the thermal degradation of flower-enriched pearl millet tableware. The first peak (20°C–200°C), attributed to moisture and volatile organic compound loss, ranged from 5.1 per cent (PMUT) to 7.7 per cent (PMRRT), that indicated the initial dehydration and thermal degradation of volatile compounds. The second peak (300°C–680°C), indicated the organic decomposition (cellulose, hemicellulose, and lignin breakdown), that exhibited highest mass reduction in PMUHT (74.8%) and PMURT (74.4%), that showed the degradation of organic compounds. The third peak exhibited moderate mass reduction (3.0%–7.6%), which showed loss of minimal inorganic compounds. The total weight loss (20°C–980°C) ranged from 77.6 per cent (PMUT) to 123.7 per cent (PMRT), that highlighted the significant compositional degradation due to roasting of pearl millet.

Flower-enriched unprocessed pearl millet (PMUHT, PMURT) exhibited higher thermal degradation as compared to its unprocessed pearl millet tableware. PMUT, PMUHT and PMURT showed a residue of 2.53 mg, 0.53 mg and 1.87 mg, respectively, which indicated the presence of inorganic compounds. Roasted pearl millet tableware (PMRT) showed complete decomposition, as PMRHT and PMRRT resulted in 1.24 mg and 0.93 mg of residue. A study by Meshram *et al*. (2025) reported that the incorporation of hibiscus flower extract in kodo millet cup exhibited thermal stability that could be suitable for hot beverage serving.

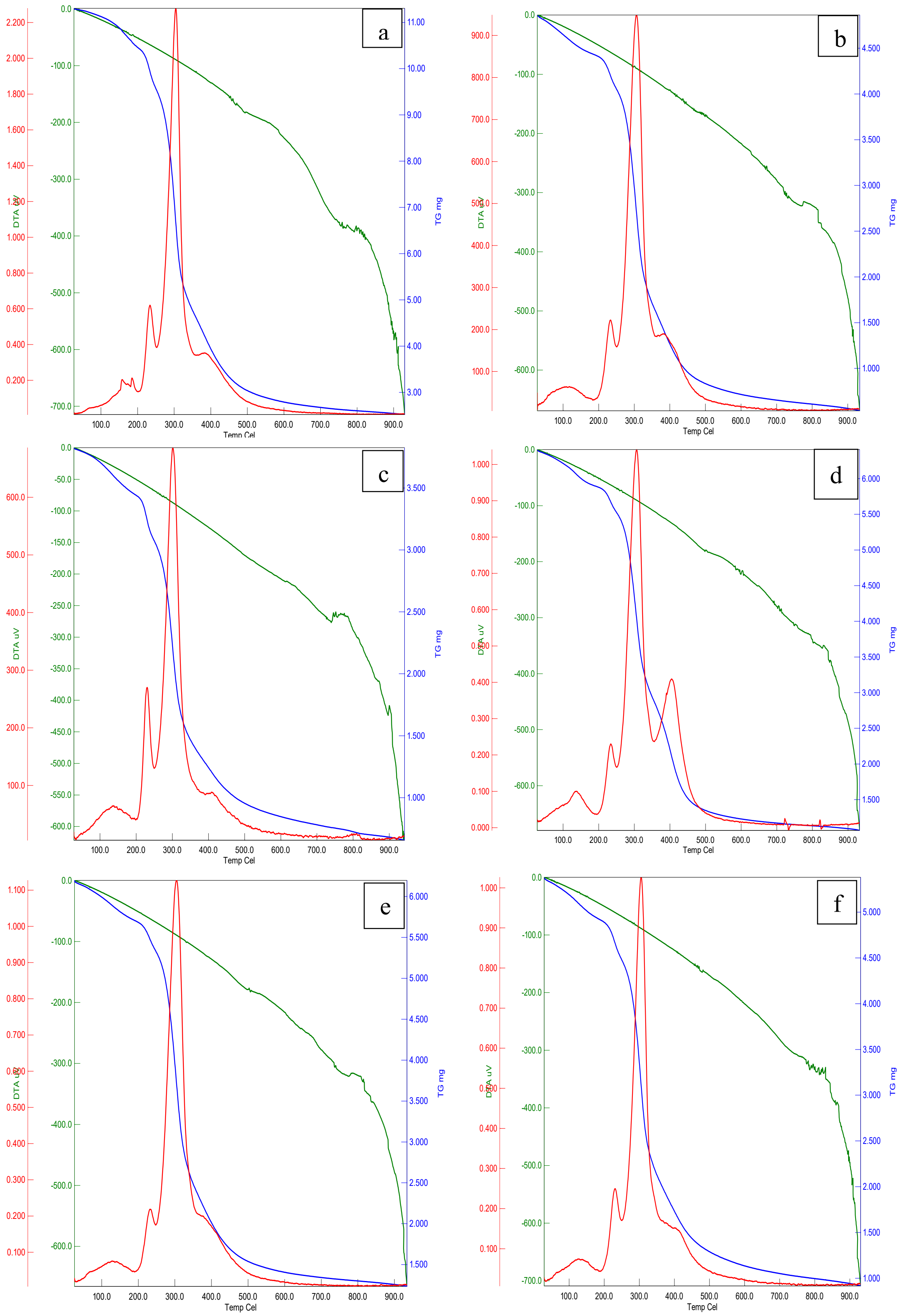


Figure – 23

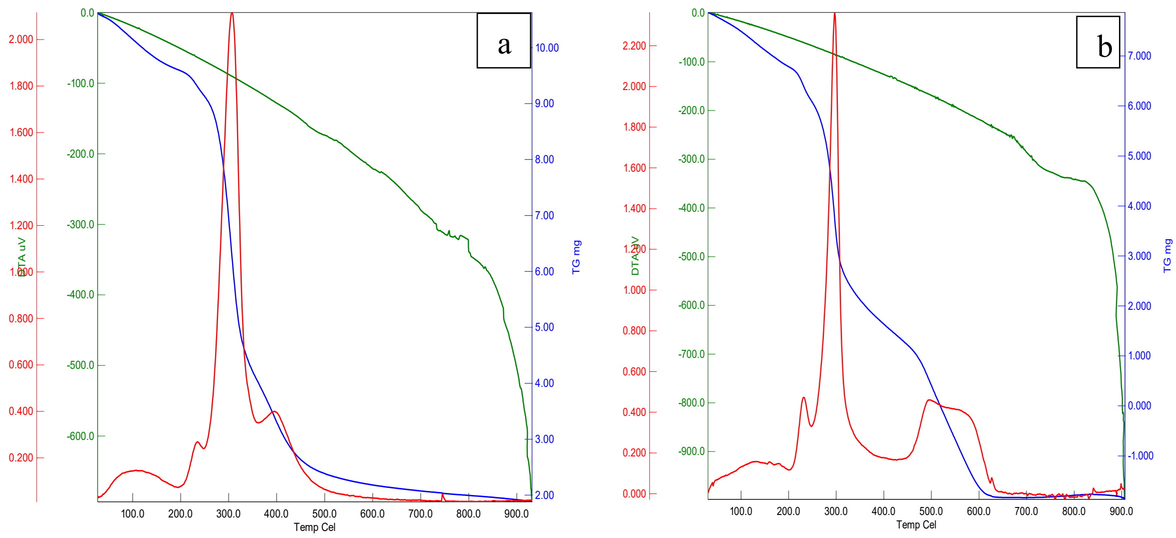
TGA of Flower-Enriched Pearl millet Tableware, a. PMUT, b. PMUHT, c. PMURT, d. PMRT, e. PMRHT, f. PMRRT

ii. TGA of Flower-Enriched Sorghum Tableware

A sample weight of 3.82 mg, 6.40 mg, 8.27 mg, 8.57 mg, 6.41 mg, and 6.30 mg of SUT, SUHT, SURT, SRT, SRHT and SRRT respectively, was taken to analyse the thermal degradation of flower-enriched sorghum tableware and discussed in Figure – 24.

The first peak between 20°C and 200°C, was associated with the loss of moisture content and volatile organic compound evaporation and the sorghum tableware showed a mass reduction that ranged from 6.9 per cent (SUT) to 8.9 per cent (SRRT). The second peak, between 300°C and 680°C, indicated the degradation of organic components such as polysaccharides and lignin, and SRT (78%) showed the highest mass reduction and least mass reduction was found in SURT (68.2%). The third peak (700°C–980°C) showed the decomposition or oxidation of organic and inorganic compounds, that ranged from 1.7 per cent (SRT) to 10.9 per cent (SRRT), with SRRT that showed the presence of significant organic compounds. The highest total mass loss and thermal degradation was found in SRT (100.3 per cent), and SURT (79.5 per cent) exhibited the lowest mass reduction.

The result showed, the impact of flower enrichment and roasting of sorghum on the thermal and compositional characteristics of sorghum tableware. Roasting and flower enrichment in sorghum tableware increased the percentage of thermal degradation which showed the presence of more organic compounds and the least quantity of inorganic compounds. The result is on par with the studies of Costa *et al*. (2023) and Yen *et al*. (2021), who stated that the initial phase of weight loss was due to moisture loss, followed by degradation of organic and inorganic compounds between 300 to 1000ºC.



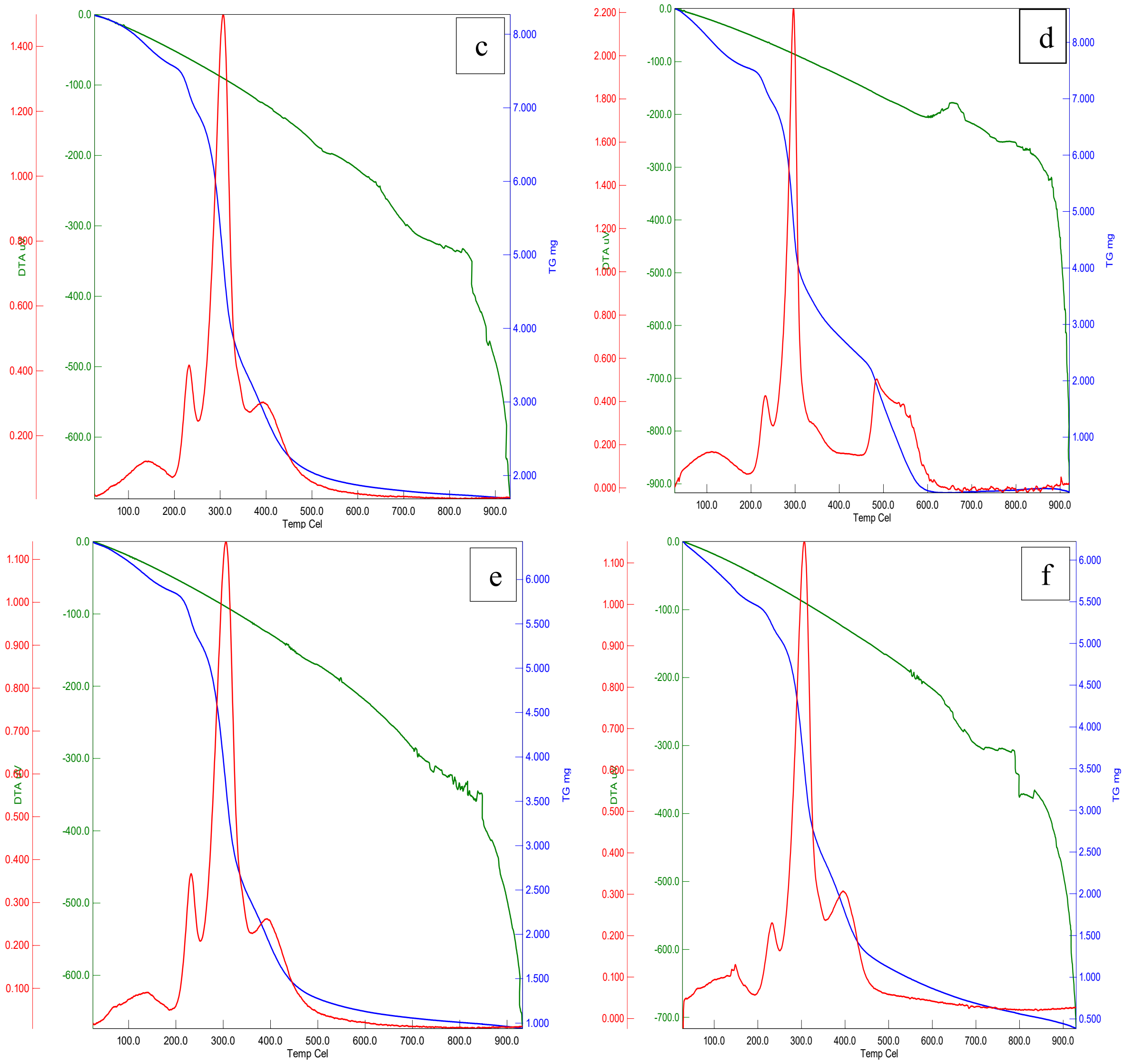


Figure – 24

TGA of Flower-Enriched Sorghum Tableware, a. SUT, b. SUHT, c. SURT, d. SRT, e. SRHT, f. SRRT

4.4.5.3 EXPOSURE TEST OF FLOWER-ENRICHED MILLET TABLEWARE

The exposure test of pearl millet and sorghum tableware enriched with hibiscus and rose flower powder was done by exposing the tableware at ambient (30°C), hot (80°C), and cold (4°C) temperatures for 60 minutes and the results were discussed as follows.

i. Exposure Test of Flower-Enriched Millet Cup

Flower-enriched unprocessed cup (PMUHC, SUHC) could hold water at ambient temperature for 15 minutes and hot water for 12 minutes without water absorption. Flower-enriched roasted cup (PMRHC, SRHC), held ambient and hot water for 25 and 20 minutes without any structural change. Then, the outer surface of the cup softened by absorbing water and started to leak after 30 minutes. Cold water (ice cubes) showed no leakage across all variants for one hour. The standardised unprocessed (PMUC, SUC) and roasted cup (PMRC, SRC) remained unchanged for 20 to 25 minutes at ambient and hot temperatures. After 25 minutes, the outer surface of the cup softened, and started to absorb more water that led to leakage after 30 minutes. Both hibiscus and rose flower powder enriched pearl millet and sorghum showed similar and flower enrichment exhibited decreased water holding duration when compared to PMUC, SUC, PMRC and SRC.

Flower-enriched pearl millet and sorghum cup was exposed to rose milk, fruit juice (ambient), milk, tea, and coffee (hot), and ice cream (cold) that showed the similar results of water. Flower-enriched cup was suitable for serving beverages and liquid foods for 12–20 minutes without deformation. The result of the present study was similar to the findings of, Mhatre *et al*. (2022) demonstrated that composite flour cones could hold ice cream for 37 minutes.

ii. Exposure Test of Flower-Enriched Millet Bowl

The exposure test of the standardised flower-enriched pearl millet and sorghum bowl was done by pouring water at 32ºC and 80ºC and ice cubes at 4ºC for an hour and the changes were monitored. At ambient temperature, unprocessed and roasted pearl millet and sorghum bowl (PMUB, PMRB, SUB, and SRB) exhibited no absorption for 40 minutes. Then, after 45 minutes, PMUB, PMRB, SUB, and SRB started to absorbed water. Flower enriched pearl millet and sorghum, PMUHB, PMURB, PMRHB, PMRRB, SUHB, SURB, SRHB and SRRB showed similar results as unprocessed and roasted pearl millet and sorghum standardised bowl which showed that flower enrichment in millet bowl has not influence the water absorption at ambient temperature. At hot temperature, PMUB, SUB, PMRB and SRB showed no absorption till 30 minutes of exposure. Flower enriched pearl millet and sorghum exhibited no absorption till 25 minutes of exposure which was slightly lesser than its non-enriched counterparts. At cold temperature, all bowls, showed a negligible amount of water absorption till 60 minutes.

The standardised flower enriched millet bowl was exposed to a variety of snacks (boiled pulses, fruit salads, vada, pani puri, cakes), syrups, ice cream, curries, and soups. The flower-enrich bowl showed no absorption or structural changes when exposed to dry snacks including deep fried food items and salads. Wet foods and liquids exhibited that the inner wall of the bowl started to absorb moisture after 40 minutes of exposure, especially when exposed to hot food items. The results highlighted that the flower-enriched millet bowl was suitable for food service sectors, especially to serve snacks, savouries and cold food items. The result is in par with the findings of Kushwaha *et al*. (2023) found that cutlery made up of wheat flour and jackfruit seeds became soggy within 30 minutes of exposure at ambient temperature whereas Nehra *et al*. (2024) found that edible bowl from millets and spent coffee grain absorbed water with structural change after 30 minutes of exposure to water. Rishi *et al*. (2024) found that bowl standardised with ragi, rice and wheat became soggy within 30 minutes when exposed to water at ambient temperature and the millet bowl standardised in the study exhibited better results.

iii. Exposure Test of Flower-Enriched Millet Katori

At ambient temperature (32ºC), unprocessed and roasted pearl millet and sorghum katori (PMUK, PMRK, SUK, SRK) withstood temperature fluctuations without any noticeable changes in its structure or appearance for 40 minutes and then, it tend to absorb the moisture at the corners and base when exposed for more than 40 minutes and became soggy at the end of one hour whereas flower-enriched pearl millet and sorghum katori (PMUHK, PMURK, SUHK, SURK) withstood for 30 minutes and PMRHK, PMRRK, SRHK, and SRRK showed the similar results of PMRK and SRK without any absorption and after 40 minutes, and it started to absorbed water and became soggy.

At hot temperature (80°C), unprocessed and roasted pearl millet and sorghum katori resisted for 25 minutes without any absorption, gradual moisture absorption at the margins at 45 minutes of exposure, and total structural disruption at 60 minutes. Flower incorporated pearl millet and sorghum katori started to absorb and became soggy after 35 minutes. At cold temperature (4°C), all the katori withstood for 60 minutes that has not shown any difference or changes in its structure. At ambient and hot temperature, flower enriched pearl millet and sorghum katori exhibited slightly lesser duration in exposure test as compared to its standardised unprocessed and roasted counterparts.

Exposed to various snacks and wet foods, flower-enriched katori were suitable for serving side dishes and individual portions for up to 40 minutes under ambient conditions and 25 minutes for hot items without compromising its structural integrity. The result of the present study aligns with the findings of, Wulandari *et al*. (2023), where cutlery made from papaya peel pectin with gelatin powder withstood hot and cold temperature for 20 minutes and 31 minutes.

Exposure test of Millet Cup

Exposure test of Millet Bowl, Katori

Exposure test of Millet Spoon

Exposure test of Millet Plate

Plate – 25

Exposure test of Flower-Enriched Millet Tableware

iv. Exposure Test of Flower-Enriched Millet Spoon

Unprocessed flower-enriched pearl millet and sorghum spoon, could hold ambient, and hot temperature for 20 minutes, which was similar to the results of standardised unprocessed variants. Roasted flower-enriched pearl millet and sorghum spoon could hold for 25 minutes without any structural integrity and then it slowly tended to absorbed water and became soggy. At cold temperature, flower-enriched unprocessed, roasted pearl millet and sorghum has not absorbed water till 45 minutes and then slowly the spoon tended to soften and its structure dissolved after 50 minutes of exposure. The flower-enriched pearl millet and sorghum spoon showed no water absorption till 20 minutes, 25 minutes and 45 minutes at ambient, hot and cold temperatures which was slightly lesser than its standardised unprocessed and roasted variants.

The flower-enriched pearl millet and sorghum spoon were exposed to juice, smoothie, hot soup, and ice cream for 60 minutes. Spoon have a holding capacity of up to 20 minutes in lemon juice and mixed fruit smoothie, 15 minutes in hot soups, and 45 minutes in ice cream without losing functionality. Flower-enriched millet spoon can also be utilized in spreading jam or butter on bread and sandwiches without any structural change that withstood break force. Flower-enriched millet spoon is a sustainable and convenient solution for a wide range of culinary applications and an ideal choice for serving both hot soups, and ice cream and to consume smoothies or mixing of juices. The result of the present study is on par with the findings of, Semere *et al*. (2023), who formulated spoon from raw tapioca and banana that showed structural integrity for 30 minutes under ambient condition. The result of present study is better than the findings of Siddiqui *et al*. (2023), who reported that, spoon made of mosambi peel and sago powder withstood 5 to 15 minutes without structural disintegration.

v. Exposure Test of Flower-Enriched Millet Plate

Unprocessed flower-enriched pearl millet and sorghum plate was exposed to ambient, hot and cold temperatures, exhibited no absorption till 35 minutes, 30 minutes and 45 minutes respectively and later it started to absorbed water and the walls and base started to soften and became soggy. At ambient, hot and cold temperature, flower-enriched roasted pearl millet and sorghum plate has not absorbed water for 40 minutes, 30 minutes and 60 minutes respectively, and later it started to became soggy by absorbing water. The observation showed that flower-enriched pearl millet and sorghum plate has lesser withstandability to exposure test at different temperature as compared to standardised unprocessed and roasted millet plate.

Standardised flower-enriched millet plate was suitable to serve small meals and side dishes as it can be utilized as side plate or meal plate and to serve snacks as well. Dry and less moisture foods or snacks has not affected the structural integrity of the flower-enriched unprocessed and roasted millet plate upto 35 to 40 minutes at ambient and hot conditions. Cold foods showed no structural deformities upto 45 minutes of exposure.

Nehra *et al*. (2024); Rishi *et al*. (2024) and Siddiqui *et al*. (2023) found that, the water absorption capacity of the standardised tableware was due to the ability of protein and carbohydrate (both were hydrophilic in nature) to attract, absorb and retain water and also also found that inclusion of pectin, sago and other fiber rich materials decreased the water absorption percentage. The exposure test of the present study demonstrated the applications of flower-enriched pearl millet and sorghum tableware in sustainable food service applications, offering versatility for dry, wet, and liquid foods across varying temperatures.

4.4.5.4 WATER ABSORPTION RATE OF FLOWER-ENRICHED MILLET TABLEWARE

The water absorption rate of flower-enriched pearl millet and sorghum tableware was evaluated to understand its functional properties under different temperature conditions, ambient (30°C), hot (80°C), and cold (4°C).

i. **Water Absorption Rate of Flower-Enriched Millet Cup**

The water absorption rate of flower-enriched pearl millet and sorghum cup was assessed at different temperature, including ambient (30°C), hot (80°C), and cold (4°C) and the results were tabulated and discussed in Table XXXI.

The water absorption rate of flower-enriched pearl millet cup exhibited that, at ambient temperature, PMRRC exhibited the lowest absorption at 20 minutes (3.01%) and hibiscus-enriched unprocessed cup (PMUHC) showed the highest (17.80% at 30 minutes) water absorption rate. At hot temperature, the water absorption rate was increased significantly, PMURC, showed the highest absorption at 30 minutes (45.02%), while roasted cup (PMRC) showed the least (35.87%) absorption rate. At cold temperature, all pearl millet cup exhibited minimal absorption, with values ranging from 0.72 per cent to 2.95 per cent.

The sorghum cup demonstrated distinct water absorption patterns. At ambient temperature, SRC showed the least absorption and the highest water absorption was observed in SRRC at 40 minutes followed by SURC. At hot temperature, the highest water absorption rate was observed in SURC and sorghum cup showed that 25 to 35 per cent of water was observed when exposed for 40 minutes. At cold temperature, the sorghum cup revealed minimal absorption, with all variants absorbing less than 2.5 per cent, indicating high suitability for serving chilled beverages.

Water absorption rate showed that cup absorbed highest amount of water when exposed to hot temperature followed by exposure at ambient and cold temperatures. Pearl millet showed highest absorption rate as compared to sorghum and flower enrichment increased the water absorption rate at all the three temperatures. Roasted pearl millet and sorghum cup enriched with flower powder, generally exhibited lower water absorption rate, especially at ambient and hot temperatures, enhancing the durability and functional efficiency, while all variants performed excellently in cold conditions, making it a viable eco-friendly option for diverse food service applications.

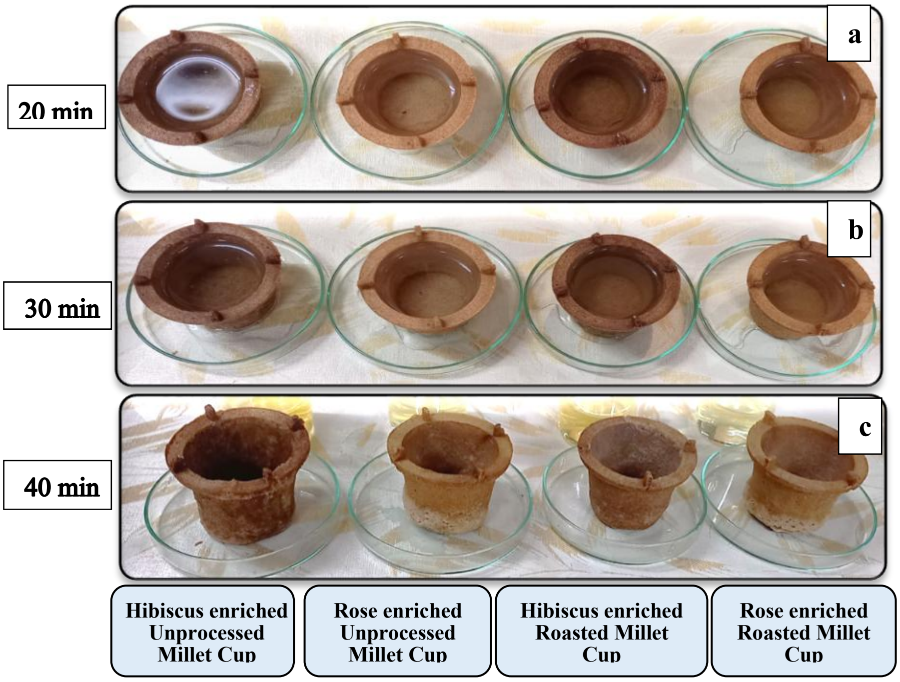


Plate - 26

Water Absorption Rate of Flower-Enriched Millet Cup, a. water absorption rate of cups, a. at 20 min, b. at 30 min, c. at 40 min

Table XXXI

Water Absorption Rate of Flower-Enriched Millet Cup

Water Absorption Rate (%)	Pearl millet Cup						Sorghum Cup					
	PMUC	PMUHC	PMURC	PMRC	PMRHC	PMRRC	SUC	SUHC	SURC	SRC	SRHC	SRRC
Ambient temperature (32^{o}C)												
20 min	3.86	17.76	9.93	9.40	14.46	3.01	6.60	12.63	14.07	3.31	11.04	12.70
30 min	2.79	6.70	6.02	8.59	12.08	9.35	6.63	8.18	16.74	4.27	3.98	15.19
40 min	4.97	17.80	23.86	10.83	8.33	18.71	9.54	10.76	8.67	4.61	2.87	11.91
Hot temperature (80^{o}C)												
20 min	10.74	17.12	18.75	7.33	11.14	13.54	7.83	9.68	10.21	6.52	8.74	9.12
30 min	25.86	20.11	13.57	24.11	15.68	19.84	19.56	13.15	17.58	17.65	15.02	14.78
40 min	37.45	42.11	45.02	35.87	40.78	42.53	27.34	33.58	35.45	25.91	28.69	29.01
Cold temperature (4^{o}C)												
20 min	0.82	0.91	0.95	0.79	0.85	0.93	0.74	0.89	0.92	0.72	0.91	0.81
30 min	1.72	1.84	1.65	1.28	1.94	2.02	1.21	1.34	1.19	1.08	1.47	2.53
40 min	2.45	2.87	2.95	1.98	2.57	2.89	1.82	2.01	2.42	1.75	1.92	2.02

ii. Water Absorption Rate of Flower-Enriched Millet Bowl

Table XXXII exhibited the water absorption rate of flower-enriched millet bowl. Pearl millet bowl showed that water absorption percentage at ambient temperature, observed that, PMRHB (13.72%) and PMURB (12.08%) has the highest absorption at 10 minutes, while PMRB (5.17%) exhibited the lowest at 20 minutes. After 30 minutes, absorption ranged from 7.35 per cent (PMUB) to 12.12 per cent (PMUHB). At hot conditions, water absorption significantly increased and PMUHB showed 33.25 per cent and PMRRB showed 30.57 per cent of water absorption after 30 minutes of exposure, while PMRB had relatively lower absorption (24.58%). At cold temperatures, absorption rates were more consistent, with PMUB (22.96%) and PMRHB (20.89%) showed the highest rate after 30 minutes of exposure to water, while PMRRB remained lower (17.85%) water absorption rate.

The flower-enriched sorghum bowl displayed moderate absorption at ambient condition, with SURB (12.28%) showed the highest absorption at 10 minutes and SRRB (5.08%) exhibited the lowest after 30 minutes. At hot temperature, bowl showed significant increase in water absorption, with SURB (31.86%) showed the highest rate and SRB (22.78%) exhibited the lowest rate at 30 minutes. At cold temperature, absorption rate was consistent among all variants, with SURB (22.43%) and SRB (21.84%) that exhibited the highest rate at 30 minutes, while SRRB exhibited lower absorption (19.82%) rate.

Both pearl millet and sorghum bowl exhibited higher water absorption rate in hot temperature. Pearl millet hibiscus-enriched bowl (PMUHB and PMRHB) exhibited higher absorption rates across all temperatures, indicated that addition of flower powder influenced the water absorption rate. Sorghum bowl demonstrated more consistent performance, with rose-enriched samples (SURB and SRRB) that showed higher water absorption rates, particularly under hot and cold conditions.

Table XXXII

Water Absorption Rate of Flower-Enriched Millet Bowl

Water Absorption Rate (%)	Pearl millet Bowl						Sorghum Bowl					
	PMUB	PMUHB	PMURB	PMRB	PMRHB	PMRRB	SUB	SUHB	SURB	SRB	SRHB	SRRB
Ambient temperature (32ºC)												
20 min	10.5	10.71	12.08	5.17	13.72	7.54	7.54	8.01	12.28	7.20	8.92	5.76
30 min	7.93	6.45	6.15	4.91	10.34	14.03	12.28	9.25	7.81	9.25	6.55	7.27
40 min	7.35	12.12	8.69	7.81	7.81	9.23	10.93	6.77	7.24	8.47	9.23	5.08
Hot temperature (80ºC)												
20 min	11.25	17.85	19.63	10.12	14.25	16.85	10.43	11.56	12.53	9.87	12.85	11.79
30 min	19.96	22.45	19.52	17.25	18.75	17.52	18.86	19.65	22.63	16.43	14.12	16.75
40 min	26.72	33.25	30.12	24.58	27.89	30.57	25.14	27.58	31.86	22.78	26.53	27.89
Cold temperature (4ºC)												
20 min	9.58	10.32	9.63	7.58	9.63	10.58	8.54	9.52	10.23	7.71	9.65	10.49
30 min	14.52	9.63	11.52	12.54	13.05	14.63	15.21	13.49	13.87	14.92	15.85	16.54
40 min	22.96	20.74	20.21	20.84	20.89	17.85	20.75	21.78	22.43	21.84	20.65	19.82

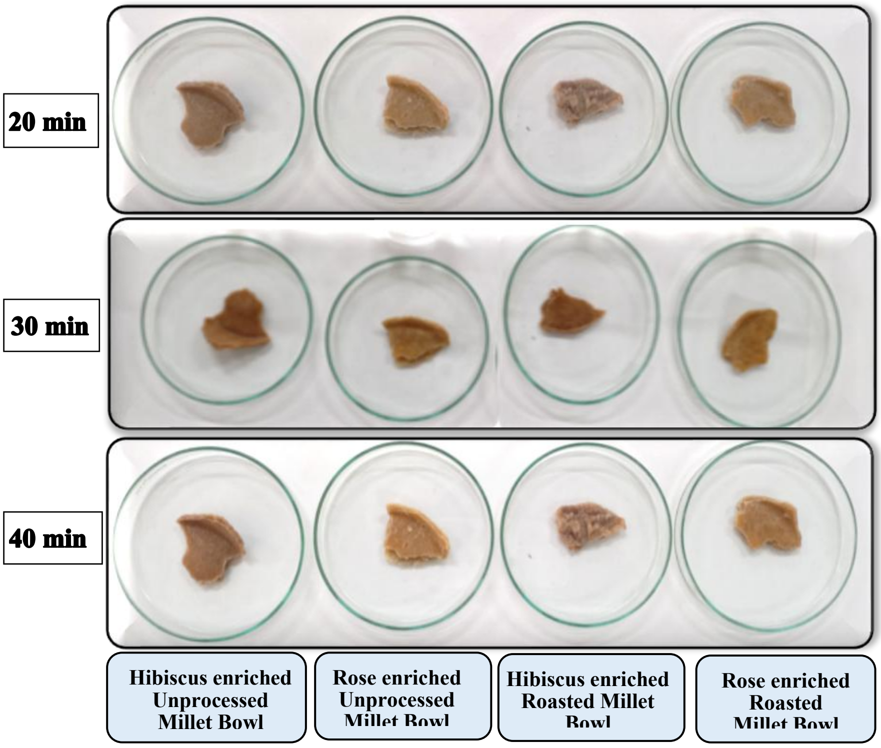


Plate - 27

Water Absorption Rate of Flower-Enriched Millet Bowl

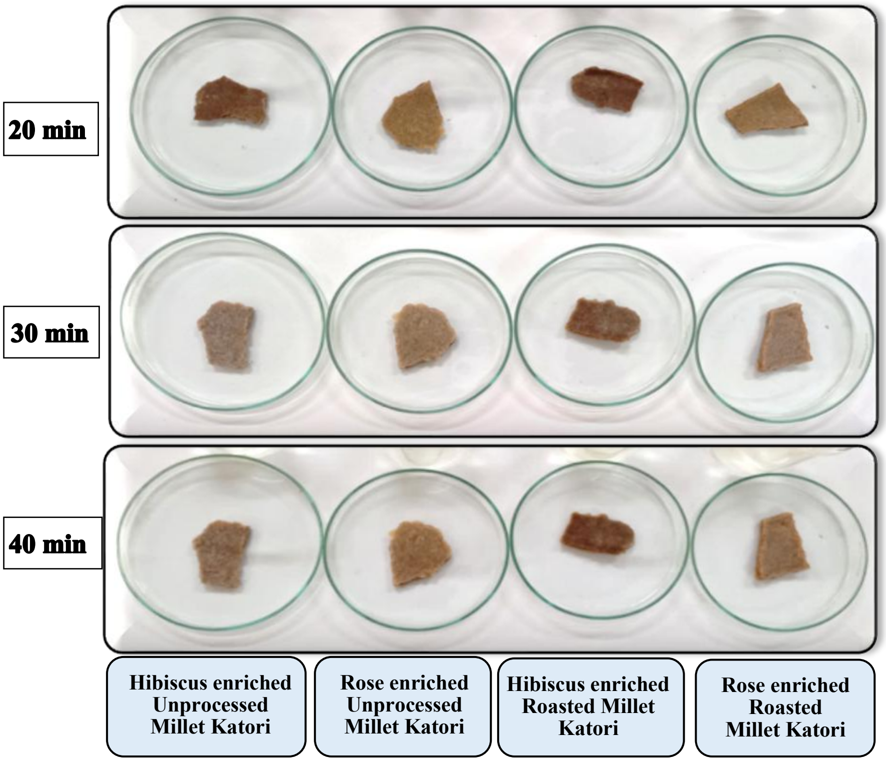


Plate - 28

Water Absorption Rate of Flower-Enriched Millet Katori

iii. Water Absorption Rate of Flower-Enriched Millet Katori

The water absorption rates of flower-enriched pearl millet and sorghum katori were measured at ambient (30°C), hot (80°C), and cold (4°C) temperatures and the results is given in Table XXXIII and Plate - 28.

Water absorption rate of pearl millet katori at ambient temperature, showed that highest quantity of water was absorbed in the initial stage (20 minutes) and slightly reduced when exposed for about 30 to 40 minutes. PMURK (10.90%) and PMRRK (10.71%) showed the highest rate and PMUHK (7.01 %) showed the least water absorption rate. At hot temperature, all samples exhibited significantly increased water absorption, with PMURK (34.87%) and PMRK (34.51%) exhibited the highest rate. At cold temperatures, PMURK (21.87%) showed highest, while PMRRK showed the lowest (19.68%) water absorption rate.

The water absorption rate of sorghum katori, at ambient temperature absorption was consistent in all the variants, while SRRK (10.93%) showed the highest and SRK showed the least water absorption rate. Flower enrichment and roasting of sorghum showed an impact on water absorption rate and unprocessed sorghum katori exhibited lower water absorption rate. At hot temperature, water absorption increased across all sorghum katori and the highest was observed in SUK (35.41 %) followed by SUHK (31.25%) and SRHK (31.02%), which was contracting to the observation of water absorption rate at ambient temperature as the roasted sorghum variant showed least water absorption. At cold temperature SURK (21.75%) and SRHK (21.32%) showed the highest and SUHK (19.56 %) showed the least water absorption rate.

Both pearl millet and sorghum katori exhibited significant water absorption rate under hot conditions, where pearl millet katori showed higher percentage of water absorption. Sorghum katori showed a consistent water absorption rate across ambient and cold conditions. Flower enrichment (rose and hibiscus) showed that rose flower powder enriched katori showed higher percentage of water absorption as compared to hibiscus enriched counterparts.

Table XXXIII

Water Absorption Rate of Flower-Enriched Millet Katori

Water Absorption Rate (%)	Pearl millet Katori						Sorghum Katori					
	PMUK	PMUHK	PMURK	PMRK	PMRHK	PMRRK	SUK	SUHK	SURK	SRK	SRHK	SRRK
Ambient temperature (32^{o}C)												
20 min	8.62	7.01	10.90	7.27	8.62	10.71	8.92	8.92	9.80	11.76	8.47	7.27
30 min	9.52	6.55	9.83	8.47	7.93	11.29	8.19	7.52	8.92	7.01	10.93	8.47
40 min	7.24	7.69	8.21	7.81	8.82	7.24	9.09	9.09	9.83	8.19	8.45	10.93
Hot temperature (80^{o}C)												
20 min	13.51	15.24	16.57	11.86	14.54	14.98	10.24	9.57	11.12	8.25	9.56	10.11
30 min	23.02	18.54	21.75	22.68	17.43	19.84	19.73	20.45	19.57	15.24	17.45	16.51
40 min	31.95	33.25	34.87	34.51	32.97	31.45	35.41	31.25	29.56	25.87	31.02	30.89
Cold temperature (4^{o}C)												
20 min	7.52	8.12	17.41	6.52	12.24	9.54	8.02	9.53	10.02	8.42	9.67	10.23
30 min	13.85	18.45	14.5	14.15	15.63	14.83	14.84	13.57	14.72	13.72	14.59	17.91
40 min	21.42	20.75	21.87	20.98	21.85	19.68	19.94	19.56	21.75	20.53	21.32	20.12

iv. Water Absorption Rate of Flower-Enriched Millet Spoon

Water absorption rate of flower-enriched millet spoon is given in Table – XXXIV and Plate - 29. The flower enriched pearl millet spoon, at ambient temperature exhibited that, water absorption percentage was highest for PMRS (16%) showed the highest water absorption followed by roasted and flower enriched spoon at 40 minutes of water exposure. At hot temperature unprocessed and flower enriched variants showed highest water absorption as compared to its roasted spoon. At cold temperature, spoon showed the least water absorption as compared to hot and ambient temperature with flower-enriched spoon (PMUHS and PMRHS, PMRRS) showed the highest water absorption percentage.

The flower enhanced sorghum spoon, at ambient temperature showed that water absorption was relatively moderate, ranging from 11.11 per cent (SRHS) to 15.25 per cent (SUHS). At hot temperature, water absorption percentage was increased across all variations as compared to ambient temperature whereas, SURS (40.14%) demonstrated the highest absorption percentage, followed by SUS (36.75%) and SUHS (35.14%). The highest water absorption percentage in sorghum spoon was observed in SURS (14.05%) while SRHS (10.08%) and SRS (9.25%) exhibited the lowest rate at cold temperature.

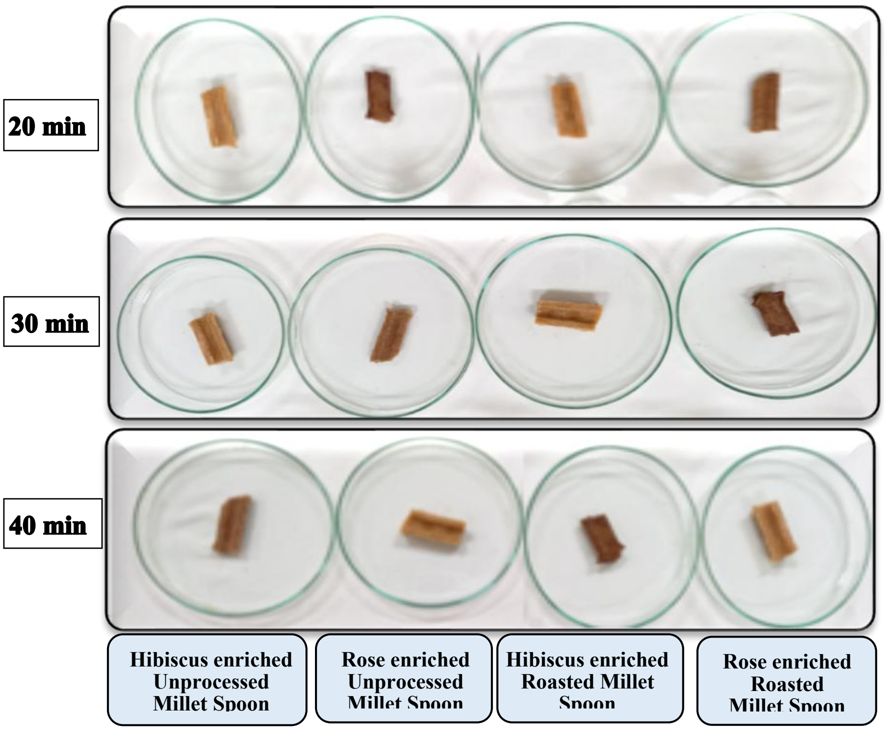


Plate - 29

Water Absorption Rate of Flower-Enriched Millet Spoon

Table XXXIV

Water Absorption Rate of Flower-Enriched Millet Spoon

Water Absorption Rate (%)	Pearl millet Spoon						Sorghum Spoon					
	PMUS	PMUHS	PMURS	PMRS	PMRHS	PMRRS	SUS	SUHS	SURS	SRS	SRHS	SRRS
Ambient temperature (32°C)												
20 min	17.39	19.04	19.23	16.01	14.81	20.83	14.80	16.66	10.71	12.5	14.81	9.52
30 min	18.51	16.00	19.35	17.24	12.90	13.79	12.90	14.28	16.12	14.8	16.12	17.39
40 min	15.62	10.34	13.51	16.0	11.42	12.12	14.28	15.25	13.88	12.90	11.11	14.81
Hot temperature (80°C)												
20 min	24.64	22.52	19.85	21.02	20.97	21.04	22.54	21.14	20.76	17.18	19.05	18.74
30 min	32.15	30.21	31.24	28.15	30.05	22.47	33.28	29.54	31.02	29.76	21.12	24.07
40 min	40.96	41.17	40.98	37.58	34.51	31.24	36.75	35.14	40.14	34.12	32.89	33.35
Cold temperature (4°C)												
20 min	6.52	7.25	6.97	6.24	7.54	7.40	5.37	6.15	7.09	5.72	6.54	7.09
30 min	8.96	11.21	10.52	8.56	10.89	11.05	9.62	10.34	9.13	7.12	8.52	8.64
40 min	11.54	15.24	13.81	10.98	14.06	15.24	12.5	13.52	14.05	9.25	10.08	11.24

Pearl millet and sorghum spoon exhibited the highest water absorption under hot conditions, where pearl millet absorbed slightly more water than sorghum. Among pearl millet spoon, unprocessed hibiscus and rose-enriched variants showed superior water absorption, while unprocessed and roasted variants of sorghum (SURS and SUS) absorbed the most. At cold temperature, water absorption rate of pearl millet spoon showed slightly higher water absorption rate. Flower enrichment, particularly rose, enhanced water absorption especially under hot and cold conditions. Sorghum spoon demonstrated more consistent in ambient absorption as compared to pearl millet spoon.

v. Water Absorption Rate of Flower-Enriched Millet Plate

Table XXXV and Plate - 30 showed the water absorption rate of flower-enriched millet plate. The highest water absorption at ambient temperature was found in PMURP (9.83%) after exposure to 40 minutes followed by PMRRP and PMRHP and the least absorption was observed in PMUHP (7.46%). Water absorption percentage was increased significantly in hot temperature across all variations, and the highest percentage was noted in PMURP (30.15%), followed by PMUHP (29.06%) and the least was observed in PMUP (24.48 %). Exposure of pearl millet plate at cold temperature showed a minimal absorption rate as compared to exposure at ambient and hot temperature and PMURP noted the highest rate (27.57%) followed by PMUP (26.15%) after 40 minutes of cold water exposure.

Water absorption rate at ambient temperature, were generally lower, and consistent, ranging between 7.24 per cent (SURP) and 9.46 per cent (SUP). All sorghum plate showed an increase in water absorption under hot temperature exposure, with SRHP showed the highest rate (30.12%). Sorghum plate at cold temperature, SUP and SRRP (24.57% and 24.18%, respectively) being absorbed the highest percentage of water after exposed upto 40 minutes.

Flower enrichment enhanced absorption, with rose-enriched (PMURP and SURP) and hibiscus-enriched plate (PMUHP and SUHP) than its unprocessed and roasted counterparts.

Table XXXV

Water Absorption Rate of Flower-Enriched Millet Plate

Water Absorption Rate (%)	Pearl millet Plate						Sorghum Plate					
	PMUP	PMUHP	PMURP	PMRP	PMRHP	PMRRP	SUP	SUHP	SURP	SRP	SRHP	SRRP
Ambient temperature (32^{o}C)												
20 min	7.14	10.90	7.27	5.26	7.54	7.01	6.77	9.25	6.77	6.89	7.84	6.89
30 min	8.33	9.83	10.90	6.25	7.01	8.19	6.34	8.47	8.69	8.06	7.27	8.06
40 min	7.69	7.46	9.83	7.81	8.19	9.09	9.46	7.81	7.24	7.46	8.47	8.95
Hot temperature (80^{o}C)												
20 min	10.47	12.05	14.52	9.73	10.11	10.21	12.43	16.17	14.98	10.07	11.12	9.48
30 min	18.52	20.45	21.08	16.29	16.87	14.36	19.14	21.42	20.85	17.81	18.56	19.52
40 min	24.48	29.06	30.15	27.45	24.53	28.51	27.56	26.51	24.12	29.14	30.12	29.07
Cold temperature (4^{o}C)												
20 min	10.12	11.47	12.07	9.35	10.92	11.01	7.27	8.64	8.03	8.53	9.12	8.57
30 min	18.87	18.12	17.03	15.82	14.54	16.72	16.72	12.71	15.58	13.67	11.52	12.58
40 min	26.15	25.15	27.57	22.64	20.95	21.14	24.57	23.18	22.17	22.73	23.54	24.18

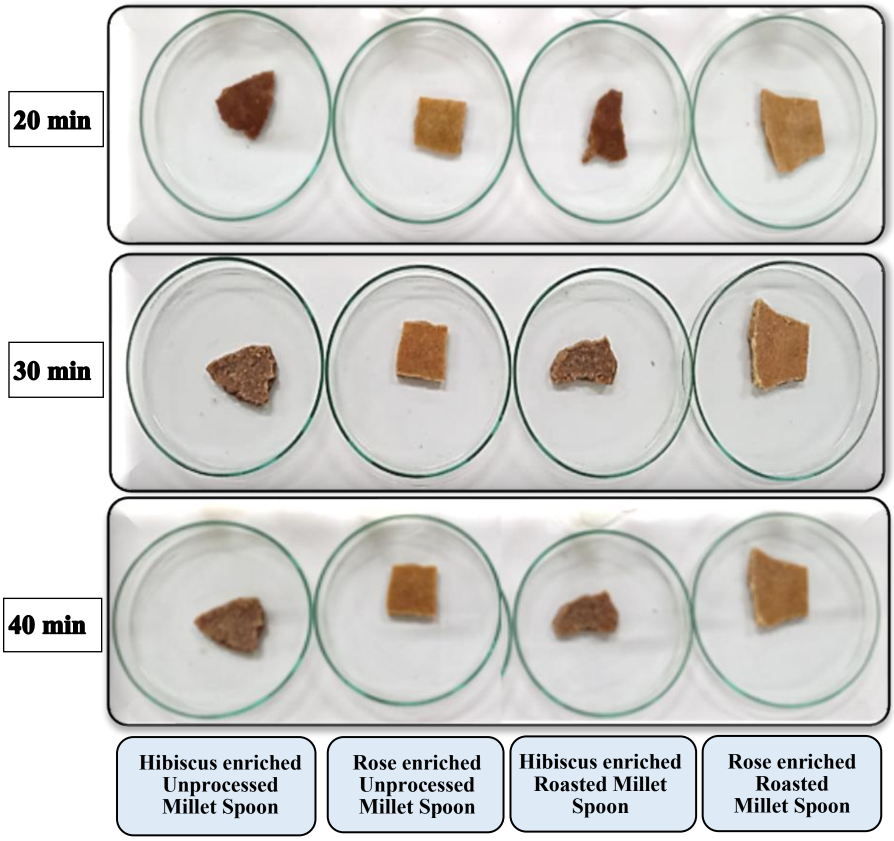


Plate - 30

Water Absorption Rate of Flower-Enriched Millet Plate

4.4.6 TEXTURE ANALYSIS OF FLOWER-ENRICHED MILLET TABLEWARE

4.4.6.1 TEXTURE ANALYSIS OF FLOWER-ENRICHED MILLET TABLEWARE

i. Texture Analysis of Flower-Enriched Millet Cup

Texture analysis provides a detailed comparison of the hardness and elastic force of hibiscus and rose flower-enriched pearl millet and sorghum cup and the obtained result is tabulated in Table XXXVI.

The unprocessed pearl millet cup (PMUC) exhibited a hardness of 44.25 ± 1.29 N, which was increased in flower-enriched cups, as, PMUHC and PMURC that showed an increased hardness of 56.33 ± 2.54 N and 65.13 ± 1.44 N, respectively. Roasting millets exhibited decreased hardness force as PMRC exhibited 40.15 ± 2.26 N which was lower than PMUC. Flower-enriched roasted cup (PMRHC and PMRRC) showed an increase in hardness force (49.70 ± 1.28 N and 52.44 ± 2.36 N, respectively). The significant F-value (56.74) of hardness or break force indicated that, roasting millet and flower enrichment had an impact on hardness force. The unprocessed cup (PMUC) exhibited minimal elastic force

(0.07 ± 0.04 N/mm²), and flower enrichment showed an increased elastic force particularly in hibiscus-enriched (PMUHC, 144.83 ± 9.47 N/mm²) and rose-enriched (PMURC, 189.30 ± 2.83 N/mm²) cup whereas flower-enriched roasted pearl millet cup (PMRHC, PMRRC) showed a decreased elastic force but higher than PMRC. The F-value (879.10) highlighted the significant influence of flower enrichment and roasting millet on elastic force.

Table XXXVI

Texture Analysis of Flower-Enriched Millet Cup

Parameter	**Unprocessed**			**Roasted**			**F value**
Pearl millet Cup	**PMUC**	**PMUHC**	**PMURC**	**PMRC**	**PMRHC**	**PMRRC**	
Hardness and Break force (N)	44.25 ± 1.29	56.33 ± 2.54	65.13 ± 1.44	40.15 ± 2.26	49.70 ± 1.28	52.44 ± 2.36	56.74*
Elastic force (N/mm^2)	0.07 ± 0.04	144.83 ± 9.47	189.3 ± 2.83	0.06 ± 0.02	72.56 ± 2.69	73.19 ± 3.69	879.10 *
Sorghum Cup	**SUC**	**SUHC**	**SURC**	**SRC**	**SRHC**	**SRRC**	
Hardness and Break force (N)	41.39 ± 0.38	86.28 ± 1.13	76.29 ± 1.95	40.17 ± 0.23	60.89 ± 2.11	65.26 ± 1.13	554.24 *
Elastic force (N/mm^2)	54.66 ± 2.08	177.07 ± 2.27	136.50 ± 1.03	13.67 ± 1.1	160.71 ± 1.45	145.50 ± 2.37	3886.1 1*
*Significant, **Not Significant (*p<0.05*)							

The hardness of SUC (41.39 ± 0.38 N) was higher than SRC (40.17 ± 0.23 N) and flower-enriched cups showed an increased hardness and break force. Unprocessed sorghum cup enriched with hibiscus (SUHC, 86.28 ± 1.13 N) and rose (SURC, 76.29 ± 1.95 N) demonstrated an increased hardness force than its roasted sorghum flower-enriched cups (SRHC, 60.89 ± 2.11 N, and SRRC, 65.26 ± 1.13 N respectively). The statistically significant F-value (554.24) showed the effect of enrichment and roasting on sorghum cups. The elastic force of sorghum cup exhibited a similar results of hardness force. SUC and its hibiscus-enriched cup showed highest elastic force as compared to its roasted and flower-enriched cup. The F-value (3886.11) reflected the considerable influence of enrichment and roasting on elasticity.

Flower enrichment in pearl millet and sorghum cup significantly enhanced the hardness, break force and elastic force. The F-values across all parameters confirmed that the effect of roasting which was slightly decreased and flower-enrichment (hibiscus or rose) showed an increased textural property. Similar studies showed that edible cones made from wheat flour exhibited 8 N to 21 N hardness force, which was influenced by the addition of jackfruit seed flour (Kushwaha *et al*., 2023). The hardness force and elastic force increased after roasting of millets due interaction between starch and gluten as stated by Sharanagat *et al*. (2024).

ii. Texture Analysis of Flower-Enriched Millet Bowl

The texture analysis of flower-enriched unprocessed and roasted millet bowl is given in Table XXXVII and its hardness, break force, and elastic force was measured.

Table XXXVII

Texture Analysis of Flower-Enriched Millet Bowl

Parameter	Unprocessed			Roasted			F value
Pearl millet Bowl	**PMUB**	**PMUHB**	**PMURB**	**PMRB**	**PMRHB**	**PMRRB**	
Hardness and Break force (N)	32.68 ± 7.43	48.25 ± 8.02	40.76 ± 3.78	21.71 ± 2.76	44.59 ± 3.29	33.67 ± 7.83	32.67*
Elastic force (N/mm^2)	153.21 ± 5.66	125.77 ± 7.29	94.57 ± 2.72	103.86 ± 7.54	156.82 ± 9.19	70.55 ± 12.98	333.38*
Sorghum Bowl	**SUB**	**SUHB**	**SURB**	**SRB**	**SRHB**	**SRRB**	
Hardness and Break force (N)	44.52 ± 7.31	58.4 ± 4.38	47.09 ± 6.34	50.94 ± 6.92	40.72 ± 2.52	49.53 ± 3.34	83.26*
Elastic force (N/mm^2)	158.7 ± 2.38	373.87 ± 4.99	229.39 ± 3.22	373.16 ± 8.17	216.49 ± 9.51	199.75 ± 14.61	546.71*
*Significant, **Not Significant (p<0.05)							

The unprocessed pearl millet bowl (PMUB) showed a moderate hardness of 32.68 ± 7.43 N, which increased significantly with hibiscus enriched (PMUHB, 48.25 ± 8.02 N) and rose enriched (PMURB, 40.76 ± 3.78 N) bowl. Roasted pearl millet bowl showed a decreased hardness force (PMRB, 21.71 ± 2.76 N) when compared to its unprocessed bowl. However, flower enrichment in roasted bowl enhanced the hardness, with hibiscus enriched bowl (PMRHB) exhibited 44.59 ± 3.29 N and rose enriched bowl (PMRRB) showed 33.67 ± 7.83 N. The F-value (32.67) indicated a statistically significant difference in roasted millet and flower-enriched bowl on hardness. The elastic force of the unprocessed bowl (PMUB, 153.21 ± 5.66 N/mm²) was decreased with flower enrichment as PMUHB (125.77 ± 7.29 N/mm²) and PMURB (94.57 ± 2.72 N/mm²) exhibited lower values. Roasted pearl millet bowl (PMRB, 103.86 ± 7.54 N/mm²) also showed a decreased elastic force as compared to PMUB but flower enriched roasted bowl (PMRHB, 156.82 ± 9.19 N/mm², and PMRRB, 70.55 ± 12.98 N/mm², respectively) exhibited an increased elastic force than SRB.

The unprocessed bowl (SUB) exhibited 44.52 ± 7.31N hardness force which was increased after flower enrichment as, hibiscus (SUHB, 58.4 ± 4.38 N) and rose (SURB, 47.09 ± 6.34 N) exhibited higher hardness force. Roasted sorghum bowl (SRB, 50.94 ± 6.92 N) also exhibited higher hardness force than SUB. Contradictorily, flower enrichment in roasted sorghum bowl exhibited decreased hardness force, with hibiscus-enriched (SRHB) at 40.72 ± 2.52 N and rose-enriched (SRRB) at 49.53 ± 3.34 N. The elastic force of SUB was 158.7 ± 2.38 N/mm², which was further enhanced by flower powder enrichment and roasting the sorghum. SUHB and SURB showed 373.87 ± 4.99 N/mm² and 229.39 ± 3.22 N/mm² respectively. Roasted sorghum and flower enrichment also increased the elastic force. The F-value (546.71) was significant that reflected the profound effect of flower enrichment and roasting millet.

Sorghum bowl showed higher hardness than pearl millet bowl, with flower enrichment, particularly hibiscus, further enhanced hardness in unprocessed and roasted forms. While roasting millet reduced elasticity in pearl millet bowl and showed an increased elastic force in sorghum bowl. Hibiscus enriched bowl showed highest hardness and elastic force than rose enriched bowl. The F-value across of hardness and elastic force showed significant difference that confirmed the significant role of roasting millet and flower enrichment in millet bowl. The finding of the present study is similar with the results of, Nehra *et al*. (2024) who found that the texture properties of biobased edible bowl increased with increasing concentration of spent coffee grain bowl from 5 to 19 kgf.

iii. Texture Analysis of Flower-Enriched Millet Katori

Table XXXVIII, discusses the texture analysis of flower-enriched millet katori with unprocessed and roasted variants. The hardness force of pearl millet katori ranged from 62.47 ± 2.69 N in PMUK to 68.14 ± 14.98 N in PMRK, with hibiscus-enriched (PMUHK: 50.61 ± 3.12 N, PMRHK: 72.66 ± 1.07 N) and rose-enriched (PMURK: 64.49 ± 3.64 N, PMRRK: 68.92 ± 6.98 N) that showed statistically significant difference. Rosted pearl millet and flower-enriched katori showed increased hardness and break force as compared to unprocessed katori. Elastic force for pearl millet katori significantly increased after roasting, with values such as 112.2 ± 5.56 N/mm² in PMRK compared to 40.87 ± 2.49 N/mm² in PMUK, and hibiscus and rose enrichment also increased the elastic force.

Table XXXVIII

Texture Analysis of Flower-Enriched Millet Katori

Parameter	Unprocessed			Roasted			F value
Pearl millet Katori	PMUK	PMUHK	PMURK	PMRK	PMRHK	PMRRK	
Hardness and Break force (N)	62.47 ± 2.69	50.61 ± 3.12	64.49 ± 3.64	68.14 ± 14.98	72.66 ± 1.07	68.92 ± 6.98	24.57*
Elastic force (N/mm^2)	40.87 ± 2.49	56.41 ± 3.53	60.55 ± 3.11	112.2 ± 5.56	56.23 ± 2.91	76.32 ± 3.36	140.01*
Sorghum Katori	SUK	SUHK	SURK	SRK	SRHK	SRRK	
Hardness and Break force (N)	47.84 ± 0.3	64.56 ± 0.74	39.6 ± 0.51	49.32 ± 1.04	76.27 ± 2.00	100.51 ± 2.41	279.32*
Elastic force (N/mm^2)	55.58 ± 0.82	53.1 ± 3.84	38.18 ± 1.09	70.47 ± 2.15	56.26 ± 1.15	47.68 ± 2.07	279.32*
*Significant, **Not Significant (p<0.05)							

Hardness force of SUK showed 47.84 ± 0.3 N which was enhanced in SRK (49.32 ± 1.04 N). Flower enrichment in sorghum katori significantly increased the hardness force both in hibiscus and rose enriched variants and the highest hardness force was found in SRRK, (100.51 ± 2.41 N). Elastic force exhibited that roasted sorghum with hibiscus and rose enriched katori showed higher elastic force as compared to its unprocessed with flower-enriched counterparts and the highest elastic force was found in SRK (70.47 ± 2.15 N/mm²) and lowest in SURK (38.18 ± 1.09 N/mm²). The F- value for both the hardness and elastic force of unprocessed and roasted flower-enriched katori showed a significant difference that indicated the impact of roasting millet and flower powder enrichment.

Flower enriched pearl millet and sorghum katori showed that, roasting and flower enrichment increased the hardness elastic force. Rose-enriched in unprocessed and hibiscus-enriched in roasted katori showed an increased hardness force and the elastic force was highest in rose enriched as compared to hibiscus enriched pearl millet katori. Conversely, sorghum hibiscus enriched in unprocessed and rose enriched in roasted sorghum exhibited highest hardness force as compared to its counterparts and elastic force was highest in roasted katori. The finding is supported by, Razack et al. (2020) who stated that roasting of millets and flower incorporation in food products improved the hardness and fracturability due to starch integrity and glute-starch network.

iv. Texture Analysis of Flower-Enriched Millet Spoon

The texture analysis of flower-enriched millet spoon is discussed in Table XXXIX.

Table XXXIX

Texture Analysis of Flower-Enriched Millet Spoon

Parameter	Unprocessed			Roasted			F value
Pearl millet Spoon	**PMUS**	**PMUHS**	**PMURS**	**PMRS**	**PMRHS**	**PMRRS**	
Hardness and Break force (N)	31.48 ± 2.79	51.2 ± 4.27	48.77 ± 1.85	35.44 ± 2.21	64.20 ± 3.28	53.69 ± 2.23	52.68*
Elastic force (N/mm^2)	77.87 ± 5.91	82.09 ± 2.02	65.36 ± 2.16	94.68 ± 4.18	83.86 ± 3.76	78.22 ± 2.52	36.67*
Sorghum Spoon	**SUS**	**SUHS**	**SURS**	**SRS**	**SRHS**	**SRRS**	
Hardness and Break force (N)	31.01 ± 1.7	48.18 ± 1.00	47.28 ± 0.66	32.94 ± 6.73	52.92 ± 0.23	52.67 ± 0.56	244.50*
Elastic force (N/mm^2)	83.78 ± 5.1	57.32 ± 0.72	68.55 ± 0.73	97.76 ± 0.84	68.69 ± 0.9	77.5 ± 0.54	275.12*
*Significant, **Not Significant (p<0.05)							

The texture analysis of flower-enriched millet spoon revealed that highest hardness force was found in roasted flower enriched spoon as compared to its unprocessed flower-enriched variants. PMRHS (64.20 ± 3.28 N) exhibited the highest hardness force among pearl millet spoon and the lowest was found in PMUS (31.48 ± 2.79 N). Elastic force of the pearl millet spoon showed that hibiscus enriched millet spoon showed better elastic force as compared to its rose enriched variants and also roasted pearl millet spoon showed an increased elastic force than its unprocessed variants. The highest elastic force was found in PMRS (94.68 ± 4.18 N/mm^2) and the least force was observed in PMURS (65.36 ± 2.16 N/mm^2). F- value of hardness force and elastic force showed statistically significant difference.

Sorghum spoon showed that SRS exhibited increased hardness force than its unprocessed spoon (SUS). Further, flower enrichment also enhanced the hardness force whereas, roasted spoon with hibiscus and rose enrichment showed increased hardness force than unprocessed spoon with flower enrichment. The highest hardness force was found in SRHS (52.92 ± 0.23 N) followed by SRRS and the lowest was found in SUS (31.01 ± 1.7 N). The elastic force of sorghum spoon showed that SRS (97.76 ± 0.84 N/mm²) showed the highest force followed by SUS (83.78 ± 5.1 N/mm²). Flower enrichment in sorghum spoon showed a decreased elastic force as compared to its roasted and unprocessed spoon as addition of flower powder had a negative impact.

Spoon exhibited a least hardness and elastic force as compared to other standardised tableware including cup, bowl and katori. Pearl millet and sorghum spoon showed an increased hardness and break force in flower-enriched variants as well as roasting of millets also showed an increase in hardness force. Pearl millet spoon after flower enrichment and roasting exhibited an increased elastic force, whereas in sorghum spoon, roasting of sorghum increased the elastic force but it got decreased after flower enrichment in sorghum spoon. The result is on par with the findings of Yodkum & Yokesahachart (2024) who stated that the textural properties of spoon has increased with addition of rice bran in composite spoon due to its reinforced effect. The hardness force was 7 N in sorghum spoon which was coated with rice and wheat flour and addition of vegetable extracted has increased the hardness force to 15 N (Sindhu *et al*., 2023).

v. Texture Analysis of Flower-Enriched Millet Plate

The texture analysis of flower-enriched millet plate was analysed and the obtained results are tabulated in Table XL.

The unprocessed pearl millet plate (PMUP), exhibited a hardness of 43.15 ± 2.77 N, which got increased by flower enrichment whereas, hibiscus and rose enriched plate exhibited 52.71 ± 2.01 N and 48.06 ± 2.14 N respectively. Roasted pearl millet plate (PMRP, 49.35 ± 3.85 N) showed increased hardness as compared to PMUP whereas hibiscus and rose enriched plate exhibited, 55.72 ± 1.66 N and 50.62 ± 3.04 N respectively with an F-value of 7.61 highlighted statistically significant differences. The elastic force was highest in PMUHP (176.99 ± 4.20 N/mm^2) followed by PMRHP (146.31 ± 3.74 N/mm^2). Roasted pearl millet plate exhibited decreased elastic force than PMUP.

Table XL

Texture Analysis of Flower-Enriched Millet Plate

Parameter	Unprocessed			Roasted			F Value
Pearl millet Plate	**PMUP**	**PMUHP**	**PMURP**	**PMRP**	**PMRHP**	**PMRRP**	
Hardness and Break force (N)	43.15 ± 2.77	52.71 ± 2.01	48.06 ± 2.14	49.35 ± 3.85	55.72 ± 1.66	50.62 ± 3.04	7.61*
Elastic force (N/mm^2)	145.47 ± 4.31	176.99 ± 4.20	109.52 ± 1.96	95.58 ± 3.35	146.31 ± 3.74	112.64 ± 3.08	272.95*
Sorghum Plate	**SUP**	**SUHP**	**SURP**	**SRP**	**SRHP**	**SRRP**	
Hardness and Break force (N)	46.5 ± 3.60	55.93 ± 0.80	49.48 ± 1.43	51.57 ± 0.57	66.47 ± 0.68	76.06 ± 0.81	135.90*
Elastic force (N/mm^2)	144.45 ± 1.11	275.64 ± 3.33	253.08 ± 3.60	178.06 ± 1.91	193.39 ± 1.15	126.37 ± 1.06	3936.43*
*Significant, **Not Significant ($p<0.05$)							

Hardness and break force of roasted sorghum with flower enriched plate showed increased force as compared to its unprocessed and flower enriched variants. The highest and lowest hardness force was found in SRRP (76.06 ± 0.81 N) and SUP (46.5 ± 3.60 N) respectively. Hibiscus enriched in unprocessed and rose enriched in roasted sorghum plate was found to be higher. The elastic force was ranging from 126.37 ± 1.06 N/mm^2 (SRRP) to 275.64 ± 3.33 N/mm^2 (SUHP) which showed that rose enriched in roasted and hibiscus enhanced in unprocessed plate showed the highest and lowest elastic force followed by unprocessed and roasted sorghum plate. The F-value for hardness and elastic force showed statistically significant differences that exhibit the impact of roasting millet and flower enrichment in millet plate.

The texture analysis of flower enhanced millet plate highlighted the significant difference between roasting and flower enrichment, with hibiscus enriched plate showed highest hardness force than rose enriched millet plate, and roasting millet also enhanced the textural properties. Elastic force of pearl millet and sorghum exhibited different results as, roasted pearl millet showed decreased elastic force whereas roasted sorghum plate exhibited increased elastic force and flower enrichment showed that hibiscus enriched showed highest elastic force than rose enhanced millet plate.

The texture analysis of the millet tableware showed that sorghum exhibited highest hardness and break force as compared to pearl millet tableware in unprocessed, roasted and flower-enriched variations. Among, flower-enriched millet tableware, hibiscus enriched tableware showed better hardness force than its rose enriched counterparts. Elastic force of the tableware exhibited different results that in bowl and spoon especially in sorghum variants, elastic force was decreased after flower powder enrichment and roasting also showed decreased elastic force in roasted pearl millet and sorghum cup, roasted pearl millet bowl and plate.

4.4.6.2 DROP TEST OF FLOWER-ENRICHED MILLET TABLEWARE

i. Drop Test of Flower-Enriched Millet Cup

The drop test of flower-enriched pearl millet and sorghum cup evaluates its structural integrity when dropped from different heights (70 cm to 130 cm), and the obtained result is tabulated in Table XLI and Plate - 31.

Table XLI

Drop Test of Flower-Enriched Millet Cup

Drop Test (cm)	Unprocessed			Roasted		
	PMUC	PMUHC	PMURC	PMRC	PMRHC	PMRRC
70	No cracks	No cracks	No cracks	No cracks	No cracks	No cracks
80	No cracks	First crack	First crack	No cracks	First crack	First crack
90	First crack	Corners cracked	Corners cracked	No cracks	Corners cracked	Bottom cracked
100	Corners cracked	Bottom broken	Broken	First crack	Bottom cracked	Edges cracked
110	Broken	Broken	Broken	Broken	Broken	Broken
	SUC	SUHC	SURC	SRC	SRHC	SRRC
70	No cracks	No cracks	No cracks	No cracks	No cracks	No cracks
80	First crack	First crack	Corners cracked	No cracks	Corners cracked	Bottom cracked
90	Cracked	Corners cracked	Bottom cracked	No cracks	Bottom cracked	Broken
100	Corners cracked	Bottom cracked	Broken	No cracks	Broken	Broken
110	Broken	Broken	Broken	First crack	Broken	Broken

Drop test of pearl millet cup showed that, PMUC remained intact up to 80 cm, corner cracked at 100 cm and completely broken at 110 cm. Flower-enriched unprocessed cup (PMUHC, PMURC) showed reduced durability, with the first cracks appeared at 80 cm and complete breakage at 100 cm and 110 cm. Roasting pearl millet significantly enhanced resilience and found that PMRC withstood up to 90 cm, started to crack and break at 100 cm. Hibiscus (PMRHC) and rose-enriched roasted cup (PMRRC) showed similar patterns, that has not shown any deformities when dropped upto 70 cm and completely broken at 110 cm.

Sorghum cup exhibited that, SUC showed similar results to PMUC, that withstood drop resistance upto 70 cm and completely broken at 110 cm. Flower-enriched unprocessed sorghum cup exhibited that SUHC showed similar results like SUC, whereas, SURC showed its first crack at 80 cm and found to be broken completely at 100 cm. SURC exhibited least drop resistance among SUC and SUHC. The roasted sorghum cup (SRC) exhibited the highest drop resistance, with no damage observed upto 100 cm, and completely broken at 130 cm. Roasted hibiscus (SRHC) and rose-enriched sorghum cup (SRRC) showed reduced drop resistance as compared to SRC, which started to crack at 80 cm and completely broken within 100 cm.

Therefore, roasting millets improved the structural integrity in both pearl millet and sorghum cup, and flower enrichment started to break before 80 to 90 cm. Flower enrichment, particularly in unprocessed forms had better drop resistance as compared to its roasted counterparts and the drop resistance of flower enriched cup showed that SRC can withstood upto 100 cm and other variants damaged before 90 cm.

Hibiscus enriched Unprocessed Millet Cup | **Rose enriched Unprocessed Millet Cup** | **Hibiscus enriched Roasted Millet Cup** | **Rose enriched Roasted Millet Cup**

Plate – 31

Drop Test of Flower-Enriched Millet Cup (Completely Broken)

ii. Drop Test of Flower-Enriched Millet Bowl

The Table XLII and Plate - 32, presents the drop test observations of flower-enriched pearl millet and sorghum bowl.

Table XLII

Drop Test of Flower-Enriched Millet Bowl

Drop Test (cm)	Unprocessed			Roasted		
	PMUB	**PMUHB**	**PMURB**	**PMRB**	**PMRHB**	**PMRRB**
120	No cracks	No cracks	No cracks	No cracks	No cracks	No cracks
130	Edges cracked	Bottom cracked	First crack	First crack	Bottom cracked	First crack
140	Cracked at bottom	Broken	Edges crack	Corners cracked	Edges Cracked	Bottom cracked
150	Broken	Broken	Broken	Cracked at bottom	Broken	Broken
	SUB	**SUHB**	**SURB**	**SRB**	**SRHB**	**SRRB**
120	No cracks	No cracks	No cracks	No cracks	No cracks	No cracks
130	First crack	Corners cracked	Corners cracked	No cracks	No cracks	First crack
140	Corners cracked	Bottom cracked	Broken	First crack	Corners cracked	Bottom cracked
150	Broken	Broken	Broken	Corners cracked	Bottom cracked	Broken

Drop test of pearl millet bowl showed that, PMUB showed good resilience up to 120 cm without crack, edge cracked at 130 cm, and bottom cracked at 140 cm and completely broken at 150 cm. PMUHB exhibited the lowest drop resistance that broken completely at 140 cm. Similarly, PMURB developed crack at 130 cm and broken fully at 150 cm. Roasted pearl millet bowl (PMRB) improved the structural integrity among all variants that withstood upto 120 cm and fully broken at 160 cm. PMRHB and PMRRB withstood upto 120 cm without any cracks and found to be completely broken at 150 cm. Drop resistance of pearl millet bowl exhibited that roasted pearl millet showed the highest drop resistance force and flower enrichment led to broken easier at 130 to 140 cm.

Sorghum bowl demonstrated that SUB, remained stable upto a height of 120 cm, and developed its first crack at 130 cm, and broken fully at 150 cm. Flower-enriched unprocessed variants (SUHB, SURB) exhibited slightly lowered drop resistance that showed corner and bottom cracked at 130 - 140 cm and entirely broken at 140 - 150 cm. Roasted sorghum bowl (SRB), showed better drop resilience, that withstood upto 130 cm, corner cracked at 150 cm and completely broken at 170 cm. Hibiscus-enriched roasted bowl (SRHB) and rose-enriched roasted bowl (SRRB) also exhibited enhanced drop resistance as compared to unprocessed counterparts, with bottom cracked at 140 - 150 cm and completely broken at 150 - 160 cm.

Roasting significantly improved the impact of drop resistance for both pearl millet and sorghum bowl and exhibited highest durability without any structural change. Flower enrichment slightly reduced the drop resistance in unprocessed bowl but exhibited better results in roasted variants. The findings of flower-enriched millet bowl highlighted that roasting millet enhanced the structural integrity upto 130 cm and flower enrichment slightly decreased the drop resistance.

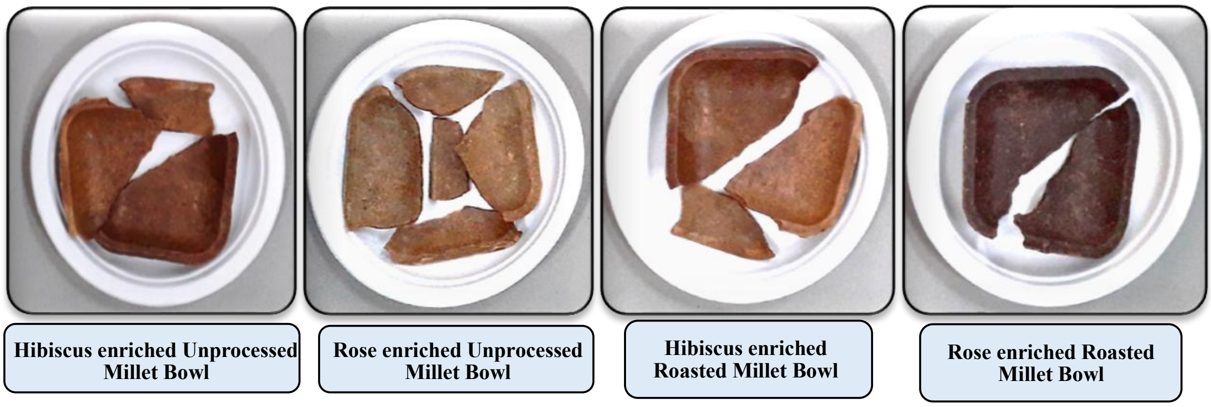


Plate – 32

Drop Test of Flower-Enriched Millet Bowl (Completely Broken)

iii. Drop Test of Flower-Enriched Millet Katori

The drop test for flower-enriched pearl millet and sorghum katori was measured to evaluate the drop or fallen resistance of katori and the obtained results is given in Table XLIII and Plate - 33.

Table XLIII

Drop Test of Flower-Enriched Millet Katori

Drop Test (cm)	Unprocessed			Roasted		
	PMUK	**PMUHK**	**PMURK**	**PMRK**	**PMRHK**	**PMRRK**
90	No cracks	No cracks	No cracks	No cracks	No cracks	No cracks
100	Edges cracked	Edges cracked	First crack	First crack	First crack	First crack
110	Bottom cracked	Bottom cracked	Bottom cracked	Corners cracked	Edges cracked	Bottom cracked
120	Broken	Broken	Broken	Cracked at bottom	Bottom cracked	Broken
	SUK	**SUHK**	**SURK**	**SRK**	**SRHK**	**SRRK**
90	No cracks	No cracks	No cracks	No cracks	No cracks	No cracks
100	First crack	No cracks	First crack	No cracks	First crack	Bottom broken
110	Corners cracked	First crack	Bottom cracked	First crack	Bottom cracked	Broken
120	Broken	Bottom cracked	Broken	Corners cracked	Broken	Broken

Drop resistance of pearl millet katori demonstrated that, PMUK withstood up to 90 cm without any crack, and edge cracked at 100 cm followed by bottom cracked at 110 cm, and broken fully at 120 cm. PMUHK and PMURK showed that, first crack was found at 100 cm and completely broken before 130 cm. Roasting of pearl millet improved structural integrity and PMRK withstood upto 90 cm without any crack and bottom cracked at 120 cm and fully broken at 130 cm. Rose-enriched (PMRRK) roasted katori demonstrated the similar drop resistance and found first crack at 100 cm and broken entirely at 120 cm whereas, hibiscus-enriched (PMRHK) cracked at bottom at 120 cm.

Drop resistance of sorghum katori demonstrated that, SUK remained stable without any crack upto 90 cm, showed its first crack at 100 cm, corner cracked at 110 cm, and broken fully at 120 cm. SUHK exhibited no cracks upto 100 cm and started to crack at 110 cm, while rose-enriched unprocessed katori (SURK) developed its first cracks at 100 cm and broken completely by 120 cm. Roasted variants, SRK exhibited enhanced drop resistance, that showed no cracks until 100 cm and only corner cracks at 120 cm and fully broken at 130 cm. Hibiscus-enriched (SRHK) and rose-enriched (SRRK) roasted katori exhibited earlier crack at 100 cm to 110 cm, with completely broken at 110-120 cm.

The drop test of flower-enriched katori exhibited that, roasting millet significantly improved the drop resistance of both pearl millet and sorghum katori. Flower enrichment showed slightly reduced durability when dropped from 90 cm to 120 cm than its unprocessed katori but maintained comparable resilience when combined with roasted millet katori.

Hibiscus enriched Unprocessed Millet Katori | Rose enriched Unprocessed Millet Katori | Hibiscus enriched Roasted Millet Katori | Rose enriched Roasted Millet Katori

Plate - 33

Drop Test of Flower-Enriched Millet Katori (Completely Broken)

iv. Drop Test of Flower-Enriched Millet Spoon

The Table XLIV and Plate - 34, discusses the drop test of flower-enriched pearl millet and sorghum spoon to evaluate the structural integrity of spoon when dropped from a height of 30 cm to 80 cm.

Table XLIV

Drop Test of Flower-Enriched Millet Spoon

Drop Test (cm)	Unprocessed			Roasted		
	PMUS	PMUHS	PMURS	PMRS	PMRHS	PMRRS
30	No cracks	No cracks	No cracks	No cracks	No cracks	No cracks
40	No cracks	No cracks	First crack	No cracks	No cracks	No cracks
50	First crack	First crack	Hand cracked	First crack	First crack	No cracks

60	Hand cracked	Edges cracked	Broken	Edges cracked	Hand cracked	First crack
70	Broken	Broken	Broken	Hand cracked	broken	Broken
	SUS	**SUHS**	**SURS**	**SRS**	**SRHS**	**SRRS**
30	No cracks	No cracks	No cracks	No cracks	No cracks	No cracks
40	No cracks	No cracks	First crack	No cracks	No cracks	No cracks
50	No cracks	Edges broken	Edges broken	No cracks	First crack	Edges cracked
60	First crack	Broken	Hand broken	Edges broken	Edges cracked	Head broken
70	Hand cracked	Broken	Broken	Broken	Broken	Broken

Drop resistance of PMUS showed that, it remained stable upto 40 cm, demonstrated its first crack at 50 cm, hand cracked at 60 cm, and broken entirely by 70 cm. Hibiscus-enriched unprocessed spoon (PMUHS) exhibited similar results of PMUS where first crack was observed at 50 cm and broken completely at 70 cm, while PMURS showed reduced durability as it started to crack when dropped from 40 cm and was broken entirely at 60 cm. Roasting significantly improved drop resistance as PMRS withstood crack upto 40 cm, and its edges cracked at 60 cm and hand cracked at 70 cm and completely broken at 80 cm. Hibiscus-enriched (PMRHS) and rose-enriched (PMRRS) roasted spoon demonstrated enhanced durability and PMRRS withstood crack upto 40 cm and exhibited its first crack at 50-60 cm.

The unprocessed sorghum spoon (SUS) showed strong resistance upto 50 cm, and the first crack appeared at 60 cm and hand cracked at 70 cm and completely broken at 80 cm. Flower-enriched unprocessed spoon (SUHS, SURS) exhibited similar performance as the first crack was observed when dropped from 50 cm and completely broken at 60 cm to 70 cm. Roasted sorghum spoon (SRS) exhibited improved durability as compared to its unprocessed counterparts, that resisted crack upto 50 cm and showed breakage when dropped at 70 cm. Hibiscus-enriched (SRHS) and rose-enriched (SRRS) roasted spoon follow a similar pattern, with edges cracked at 60 cm and completely broken at 70 cm.

The drop resistance of millet spoon showed that, roasted millet spoon enhanced the structural integrity of both pearl millet and sorghum spoon, with roasted variants (PMRS, SRS) outperforming its unprocessed counterparts. Flower enrichment in unprocessed spoon showed slightly reduced resilience when dropped from 30 cm to 70 cm and found to be broken at 60 cm whereas flower-enriched roasted spoons showed better drop resistance that started to crack after 50 cm and broken fully at 70 cm.

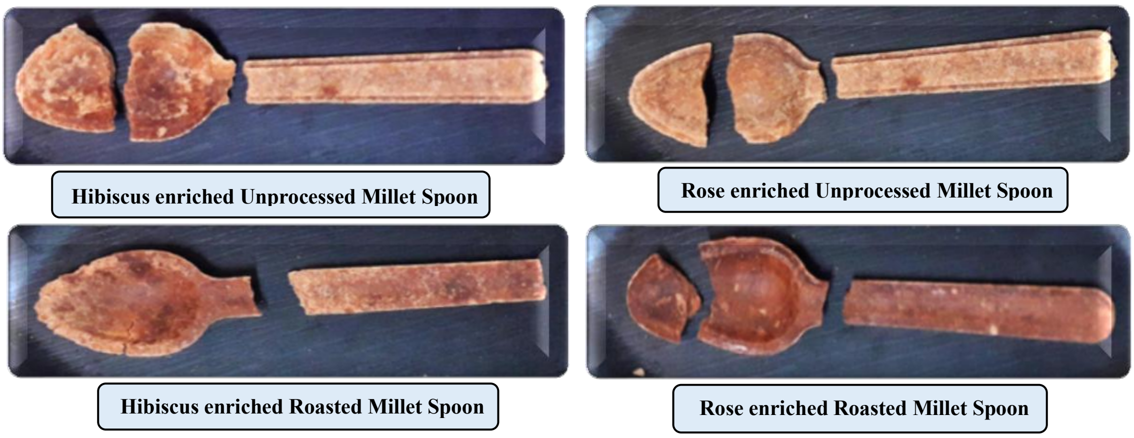


Plate – 34

Drop Test of Flower-Enriched Millet Spoon (Completely Broken)

v. Drop Test of Flower-Enriched Millet Plate

The drop test of flower-enriched pearl millet and sorghum plate demonstrated the structural durability of free-falling nature up to 140 cm, and findings is given in Table XLV and Plate – 35.

Table XLV

Drop Test of Flower-Enriched Millet Plate

Drop Test (cm)	Unprocessed			Roasted		
	PMUP	PMUHP	PMURP	PMRP	PMRHP	PMRRP
80	No cracks	No cracks	No cracks	No cracks	No cracks	No cracks
90	No cracks	No crack	First crack	No cracks	No cracks	No cracks
100	No cracks	First crack	Edges cracked	No cracks	No cracks	No cracks
110	Edges cracked	Bottom cracked	Broken	First crack	First crack	First crack

120	Bottom Cracked	Broken	Broken	Corners cracked	Bottom cracked	Edges cracked
130	Broken	Broken	Broken	Bottom Cracked	Broken	Broken
	SUP	**SUHP**	**SURP**	**SRP**	**SRHP**	**SRRP**
80	No cracks	No cracks	No cracks	No cracks	No cracks	No cracks
90	No cracks	No cracks	First crack	No cracks	First crack	No cracks
100	No cracks	First crack	Edges cracked	No cracks	Edges cracked	First crack
110	First crack	Bottom Cracked	Bottom Cracked	No cracks	Edges Cracked	Bottom Cracked
120	Corners cracked	Broken	Broken	First crack	Broken	Broken
130	Broken	Broken	Broken	Corners cracked	Broken	Broken

Pearl millet plate showed notable resilience when dropped from 80 cm to 140 cm. PMUP showed no crack upto 100 cm, where edges cracked at 110 cm, and broken completely at 140 cm. Hibiscus-enriched (PMUHP) and rose-enriched (PMURP) unprocessed plate showed reduced durability as PMUHP developed first crack at 100 cm and broken at 120 cm, while PMURP cracked at the edges when dropped from 100 cm and broken entirely at 110 cm. Roasting pearl millet improved the impact resistance of plate and PMRP found to be stable until 100 cm, with corner cracked at 120 cm and bottom crack was observed when dropped from 130 cm and completely broken at 140 cm. Roasted pearl millet plate enriched with hibiscus (PMRHP) and rose (PMRRP), exhibited similar results like PMRP that showed first crack at 110 cm and completely broken at 130 cm.

Sorghum plate demonstrated that, SUP resisted crack until 100 cm, where first cracks appeared at 110 cm, and broken fully at 130 cm. Hibiscus-enriched (SUHP) and rose-enriched (SURP) unprocessed variants displayed slightly reduced drop resistance with SUHP cracked at the bottom by 110 cm and completely broken at 120 cm, while SURP cracked earlier when dropped from 90 cm and entirely broken at 130 cm. Roasted sorghum plate outperformed its unprocessed counterparts as, SRP remained intact until 110 cm and cracked at corners when dropped from 130 cm and entirely broken at 140 cm. Hibiscus-enriched (SRHP) and rose-enriched (SRRP) roasted sorghum plate sustained until 90 cm to 100 cm, edge or bottom cracked at 110 cm and broken entirely at 120 cm.

The drop test of a flower-enriched millet plate revealed that roasting increased the structural durability of both pearl millet and sorghum plate. Flower enrichment slightly reduced the durability of unprocessed plate but exhibited better drop resistance in roasted counterparts.

Plate – 35

Drop Test of Flower-Enriched Millet Plate (Completely Broken)

PHASE V

4.5 ANALYSIS OF SHELF LIFE, TOXICITY, AND BIODEGRADABILITY OF MILLET TABLEWARE

4.5.1 SHELF-LIFE ANALYSIS OF MILLET TABLEWARE

4.5.1.1 MICROBIAL LOAD OF MILLET TABLEWARE

The microbial load analysis of millet tableware was evaluated for 120 days at the interval of 30 days and the assessed total plate count was given at Table XLVI and Figure - 36.

Unprocessed millet tableware, such as PMUT and SUT, showed an increased microbial count. PMUT exhibited an increase from 2×10^{1} CFU/g on 30^{th} day to 21×10^{1} CFU/g on 120^{th} day, whereas SUT counted 2×10^{1} CFU/g on day 30 to 13×10^{1} CFU/g on 120^{th} day that indicated significant microbial growth over the storage period. Enrichment with hibiscus or rose (PMUHT, PMURT, SUHT, SURT) moderated the microbial growth as compared to its unprocessed counterparts but showed notable microbial growth. Flower powder enrichment has not increased the microbial growth over 120 days in unprocessed millet tableware. Over the storage of 120 days, hibiscus enriched unprocessed millet tableware (12×10^{1} CFU/g in PMUHT and 12×10^{1} CFU/g in SUHT on 120^{th} day) showed a decreased microbial count as compared to its rose enriched counterparts (17 x 10^1 CFU/g in PMURT and 15 x 10^1 CFU/g in SURT on 120^{th} day).

Table XLVI

Microbial Load of Millet Tableware

Edible Tableware	Day 30 (CFU/g)	Day 60 (CFU/g)	Day 90 (CFU/g)	Day 120 (CFU/g)
PMUT	2 x 10^1	4 x 10^1	15 x 10^1	21 x 10^1
PMUHT	2 x 10^1	4 x 10^1	8 x 10^1	12 x 10^1
PMURT	5 x 10^1	11 x 10^1	14 x 10^1	17 x 10^1
PMRT	2 x 10^1	6 x 10^1	9 x 10^1	14 x 10^1
PMRHT	2 x 10^1	6 x 10^1	8 x 10^1	12 x 10^1
PMRRT	1 x 10^1	4 x 10^1	6 x 10^1	12 x 10^1
SUT	2 x 10^1	4 x 10^1	9 x 10^1	13 x 10^1
SUHT	4 x 10^1	4 x 10^1	10 x 10^1	13 x 10^1
SURT	2 x 10^1	5 x 10^1	11 x 10^1	15 x 10^1
SRT	0 x 10^1	0 x 10^1	0 x 10^1	1 x 10^1
SRHT	2 x 10^1	4 x 10^1	9 x 10^1	10 x 10^1
SRRT	3 x 10^1	5 x 10^1	9 x 10^1	11 x 10^1

Roasted tableware (PMRT, SRT) demonstrated decreased microbial load as compared to its unprocessed millet tableware (PMUT, SUT). PMRT exhibited 2 x 10^1 CFU/g microbial growth till 30 days and showed a microbial count of 14 x 10^1 CFU/g on 120^{th} day whereas SRT showed no colony forming units till 90 days of storage and showed 1 x 10^1 CFU/g on 120^{th} day. Roasted and flower-enriched variants, such as PMRHT, PMRRT, SRHT, and SRRT, also exhibited decreased total microbial count when compared to its unprocessed flower-enriched counterparts. PMRHT and PMRRT showed 12 x 10^1 CFU/g on 120^{th} day whereas, SRHT and SRRT exhibited 10 x 10^1 CFU/g and 10 x 10^1 CFU/g on 120^{th} day respectively.

Sorghum tableware generally exhibited a decreased colony count than pearl millet tableware and roasting of millets further reduced the microbial load. SRT was the superior variant with decreased microbial load and flower powder enrichment has not also increased the microbial load as compared to its unprocessed and roasted millet tableware that indicated the anti-microbial activity of selected edible flowers. The obtained results are supported by the findings of Mandal & Antarkar (2024) who had developed a waffle cone made from sorghum, pearl millet and finger millet that exhibited a total plate count between 1900 to 2050 CFU/ml on 0^{th} day which showed an increase to 2650 to 3600 CFU/ml on 30^{th} day and the present study showed lesser total plate count that the results obtained from the previous study. Sunil *et al.* (2024) also stated that, roasting and baking of millets decreased the moisture content and exhibited lowest microbial count. Wilczyńska *et al*. (2021) investigated the presence of *E. coli, Salmonella* sp., *S.aureus,* moulds and yeasts in the native flower of Poland and declared that *E.Coli* was found in certain flower, whereas, S. *aureus* was >3 log CFU g^{-1} and the total yeast and mould loads were >6 log CFU g^{-1} which was under the permissible limit.

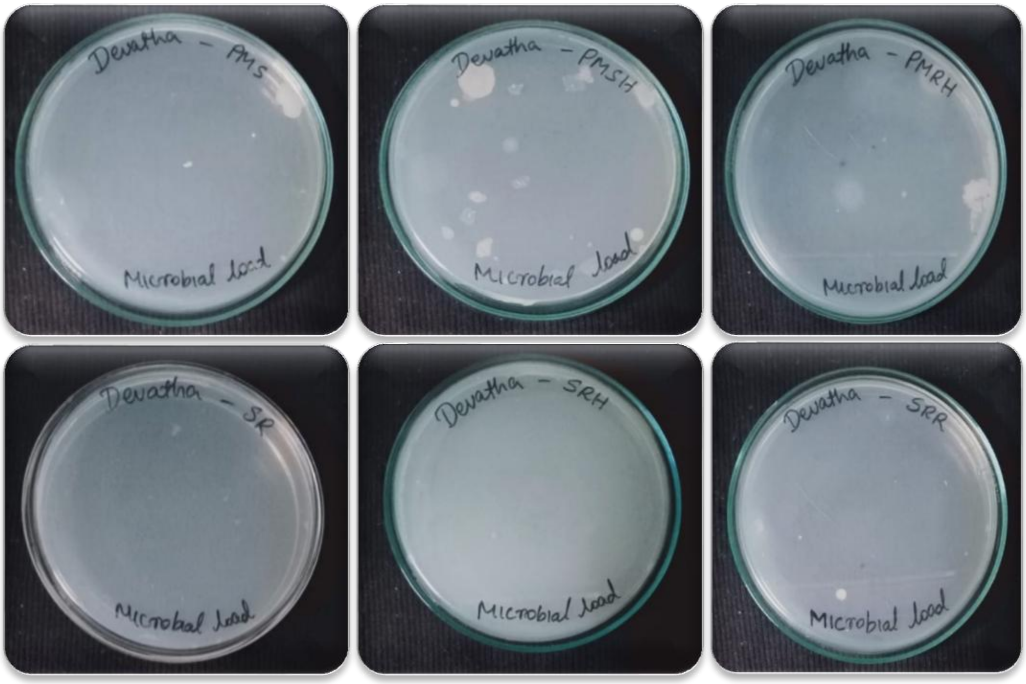


Plate – 36

Total Microbial Count of Millet Tableware on 120th day

4.5.1.2 CHANGE IN WEIGHT OF MILLET TABLEWARE

Change in weight and moisture absorption was measured for 120 days as shelf-life indicator. The standardised millet tableware was stored in an airtight container at ambient room temperature during the shelf-life analysis period.

i. Change in Weight of Millet Cup

The Figure - 25, presents the change in weight of various sorghum and pearl millet edible cup over 120 days, indicates the moisture retention or absorption trends.

The pearl millet cup, PMUC (Unprocessed Pearl millet Cup) showed a slight increase of weight from 16.44 g to 16.83 g over the 120 days, while hibiscus enriched, PMURC and PMUHC exhibited slight increase in weight, from 12.30 g and 13.57 g on first day to 12.64 g and 14.02 g on 120th day respectively. PMRC (Roasted Pearl millet Cup) recorded a weight increase, from 17.6 g to 17.93 g respectively whereas, PMRRC (Roasted Pearl millet Rose enriched Cup) and PMRHC (Roasted Pearl millet Hibiscus-enriched Cup) demonstrated a moderate weight gain of 14.41 g to 15.03 g and 15.53 g to 16.14 g, respectively.

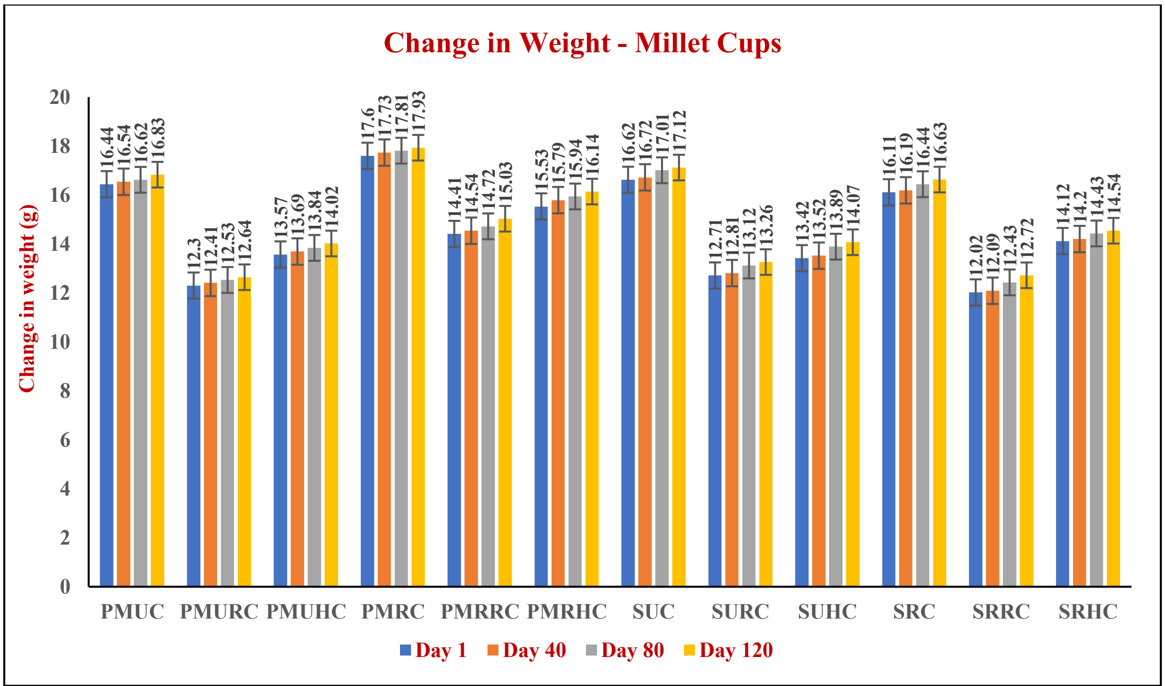


Figure - 25

Change in Weight of Millet Cup

Among the sorghum cups, SUC (Unprocessed Sorghum Cup) exhibited a consistent increase in weight that showed, 16.62 g on day 1 to 17.12 g on day 120, indicating steady moisture gain. SURC (Unprocessed Roasted Sorghum Cup) and SUHC (Unprocessed Sorghum with Hibiscus Cup) exhibited an increase in weight, from 12.71 g to 13.26 g and

13.42 g to 14.07 g, respectively, highlighting its relatively better stability against moisture absorption. SRC (Roasted Sorghum Cup) exhibited a gradual rise from 16.11 g to 16.63 g, while SRRC (Roasted Sorghum Rose-enriched cup) and SRHC (Roasted Sorghum Hibiscus-enriched Cup) had minimal weight increase, reaching 12.72 g and 14.54 g on 120th day from 12.02 g and 14.12 g on first day, respectively which proved the absorption of atmospheric moisture in minimal range as compared to its unprocessed variants.

The change in weight of millet cup showed that, the roasted and hibiscus-enriched cup of both sorghum and pearl millet were more resistant to moisture absorption, indicating greater stability over time than its unprocessed counterparts. The result of present study is supported by the findings of Mandal and Antarkar (2024) who found that, pearl millet and sorghum waffle cone showed increasing percentage of weight and moisture from 5.7 per cent to 5.8 per cent and 4.8 per cent to 5.8 per cent due to moisture and atmospheric gas absorption.

ii. Change in Weight of Millet Bowl

The Figure - 26, presents the change in weight of sorghum and pearl millet bowl over a 120-day period. The data showed a general upward trend in weight increase across all millet bowl.

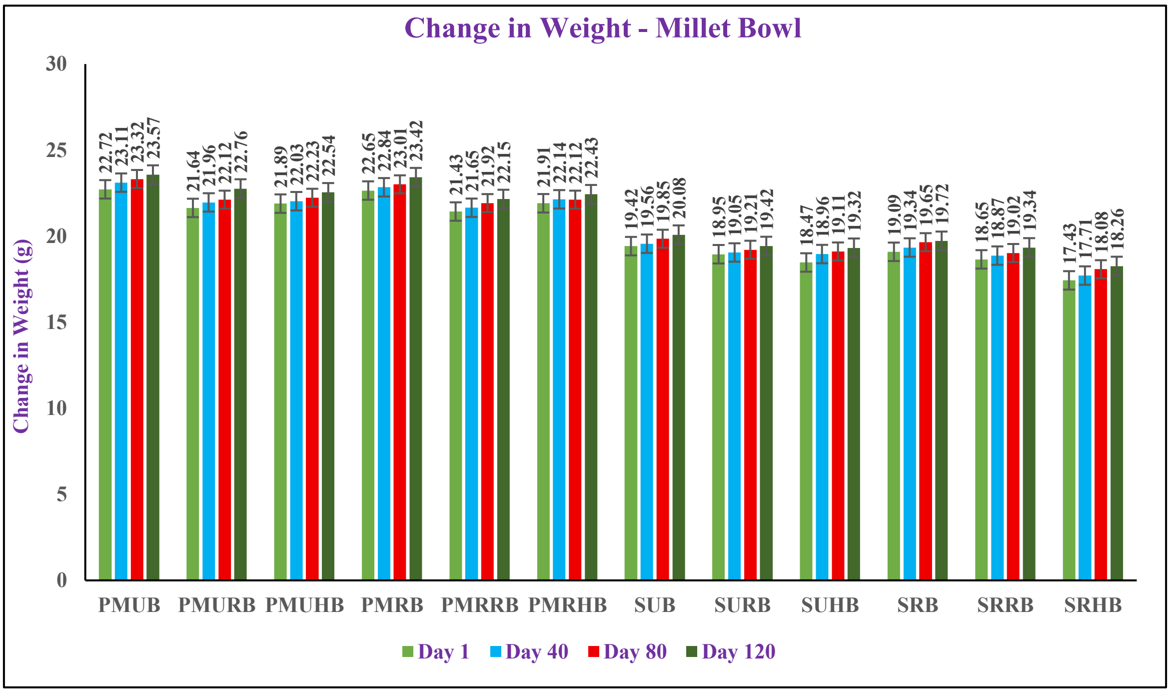


Figure – 26

Change in Weight of Millet Bowl

Change in weight of pearl millet bowl demonstrated that, PMUB exhibited an increase from 22.72 g on first day to 23.57 g on 120th day whereas PMURB and PMUHB rising steadily from 21.64 g and 21.89 g to 22.76 g and 22.54 g respectively. The percentage of weight change on 120th day from first day for PMUB, PMURB and PMUHB were 3.7 per cent, 5.17 per cent and 2.96 per cent respectively. On day 1, 22.65g, 21.43g and 21.91 g of PMRB, PMRHB and PMRRB was taken and the weight was increased to 23.42 g, 22.15 g and 22.43 g on 120th day showed a weight gain percentage of 3.39 per cent, 3.35 per cent and 2.37 per cent respectively.

Sorghum bowl showed that, on day 1, 19.42 g of SUB was increased to 20.08 g on 120th day whereas 18.95 g and 18.47 g of SURB and SUHB was increased to 19.42 g and 19.32 g. SUB, SURB and SUHB exhibited 0.66 g, 0.47 g and 0.85 g of increased weight from first day to 120th day. Similarly, SRB, SRRB and SRHB showed an increase in weight from 19.09 g, 18.65 g and 17.43 g to 19.72 g, 19.34 g and 18.26 g respectively. A total weight gain of 0.63 g, 0.69 g, and 0.83 g was observed in SRB, SRRB and SRHB on 120th day with a percentage of 3.3 per cent, 3.69 per cent and 4.76 per cent respectively.

Weight change of bowl indicated that, both sorghum and pearl millet bowl showed a gradual but consistent increase in weight across the 120-day storage period whereas pearl millet bowl showed slightly higher weight increase than sorghum bowl. Hibiscus flower enriched bowl exhibited higher change in weight in sorghum variants and rose flower enriched bowl showed higher weight change in pearl millet which was due to the atmospheric oxygen or gas absorption.

iii. Change in Weight of Millet Katori

The Figure - 27, presents the change in weight of different sorghum and pearl millet katori over a period of 120 days. The data revealed that the weight increased consistently across all flower-enriched millet katori as follows.

The pearl millet katori (PMUK, PMURK, PMUHK, PMRK, PMRRK, PMRHK) showed a steady increase in weight, with PMUHK demonstrated the highest percent of increase in weight by 120 days of storage. PMUK and PMRK showed a weight gain of 19.11 g and 19.45 g to 19.31 g and 19.71 g with a weight increase of 0.20 g and 0.26 g (1.04 % and 1.33 % respectively). Flower enriched pearl millet also showed a stable increase in weight from 19.65 g and 18.62 g to 19.89 g and 18.92 g respectively on day 1 to day 120 in PMURK and PMUHK. Similarly, PMRHK and PMRRK showed an increase in weight from 19.12 g to 19.32 g and 19.3 g to 19.53 g with 1.04 per cent and 1.19 per cent of weight gain.

The sorghum katori (SUK, SURK, SUHK, SRK, SRRK, SRHK) also showed a gradual weight gain, when SURK showed the highest weight gain on 120 days of storage. SUK exhibited an increase of 0.24 g with 1.24 per cent of weight gain whereas, SURK and SUHK gained 0.37 (2.02 %) and 0.23 g (1.21 %) respectively. The roasted variants also showed an increasing trend of weight gain, SRK increased 0.2 g with 1.08 per cent of weight gain. Similarly, SRRK showed an increase of 0.22 g (1.18 %) and SRHK showed 0.24 g (1.26%) of increased weight on storage period (120 days).

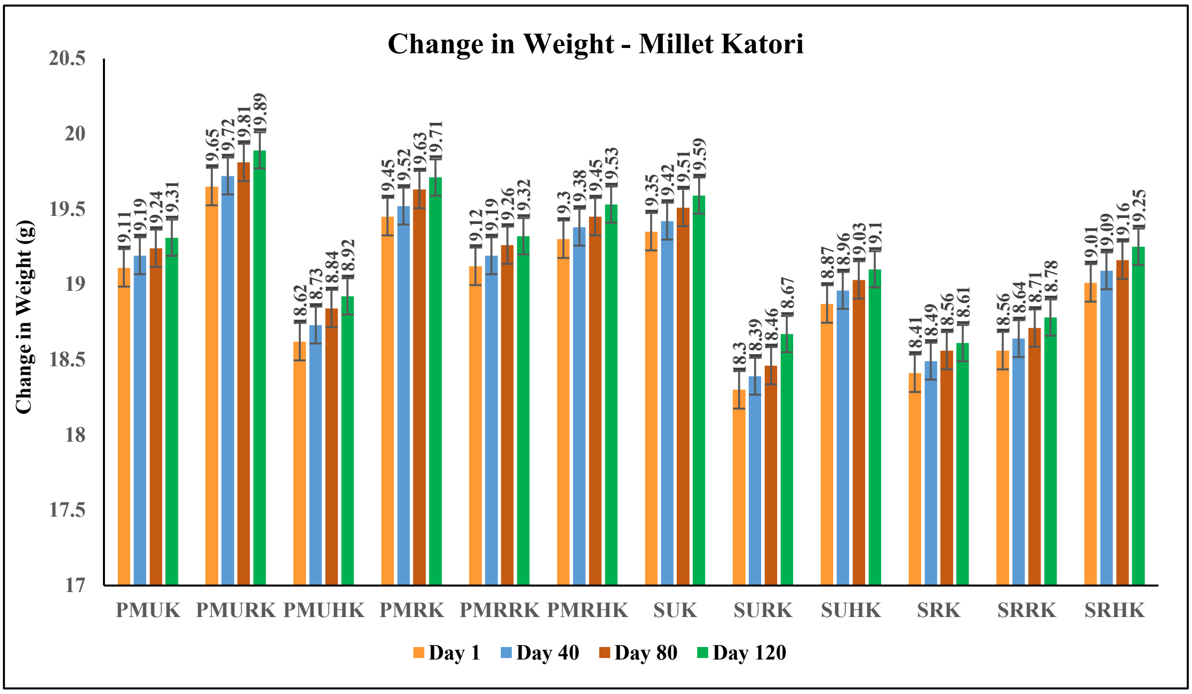


Figure - 27

Change in Weight of Millet Katori

The pearl millet katori achieved slightly higher and consistent weight gain as compared to sorghum katori. Flower-enriched pearl millet and sorghum katori has also exhibited weight gain due to the moisture absorbing nature of raw materials used and it was gradual without any structural changes that indicated the stable moisture absorption.

iv. Change in Weight of Millet Spoon

The Figure - 28, illustrates the change in weight of various sorghum and pearl millet spoon over a 120-day period. Among the pearl millet spoon, PMUS showed an increased weight, from 8.92 g on first day to 9.26 g on day 120 with in weight gain of 0.34 g (3.81 %) whereas PMURS, showed 4.42 per cent of weight gain (0.38 g); PMUHS showed 3.32 per cent (0.29 g) of increased weight. A total weight gain of 3.92 per cent, 3.83 per cent and 3.69 per cent was observed in PMRS, PMRRS and PMRHS respectively.

Across the sorghum spoon, SRHS had the highest weight gain that was found to gain 0.45 g of weight with 5.76 percentage of increased weight. SRRS and SRS showed a weight gain of 0.37 g (4.95%) and 0.33 g (4.65 %) respectively. SUS showed an increased weight of 0.30 g (3.79%). Similarly, SURS and SUHS observed a lowest weight gain with 0.22 g (3.04%) and 0.22 g (2.72%), respectively.

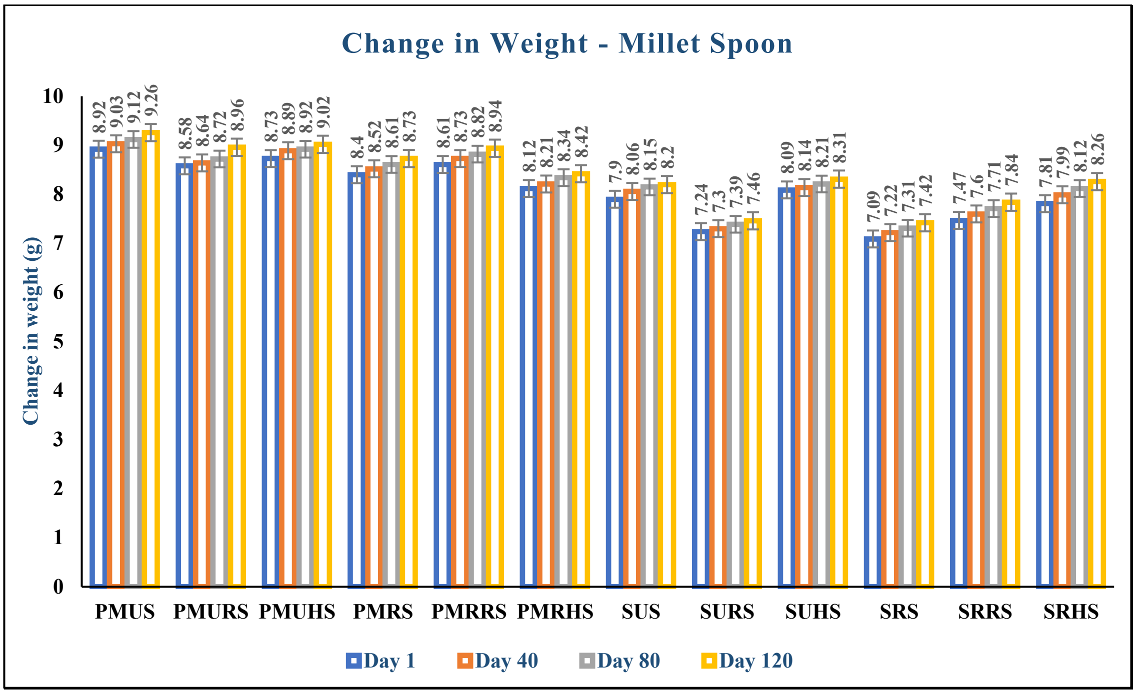


Figure - 28
Change in Weight of Millet Spoon

The change in weight of millet spoon indicated a gradual weight gain over a storage of 120 days at ambient room temperature, that confirms the moisture absorption. Pearl millet spoon especially, PMURS showed the highest weight gain similarly, among sorghum spoon SRS and SRRS showed the increased weight.

v. Change in Weight of Millet Plate

The Figure - 29, shows the weight changes of various sorghum and pearl millet plate with the interval of, day 1, day 40, day 80, and day 120.

The change in weight of pearl millet plate showed gradual weight gain over the storage period. PMUP, PMURP and PMUHP showed a steady increase in weight with 0.34 g, 0.37 g and 0.36 g of total weight gain over 120 days. Similarly, a total weight gain of 0.35 g was observed in PMRP and PMRRP and PMRHP showed a weight gain of 0.34 g and 0.36 g. Pearl millet plate was showed an increased weight ranging between 0.34 g and 0.37 g that showed atmospheric oxygen absorption by standardised plate. Flower-enriched and roasted pearl millet plate showed a similar increase in weigh that indicated addition of flower and roasted has no significant influence on moisture absorption during storage.

Among, sorghum plate, its unprocessed variants, SUP showed a gradual increase in weight from 46.17 g on day 1 to 46.47 g on day 120 with a total weight gain of 0.30 g. Similarly, SURP and SUHP also showed a modest increase of 0.35 g and 0.39 g from 47.71 g to 48.06 g in SUHP and 48.22 g to 48.61 g in SUHP respectively. Similarly, SRP showed a weight gain, from 45.09 g on 1st day to 45.62 g on 120th day whereas SRRP and SRHP showed an increase of 0.37 g and 0.34 g of weight respectively.

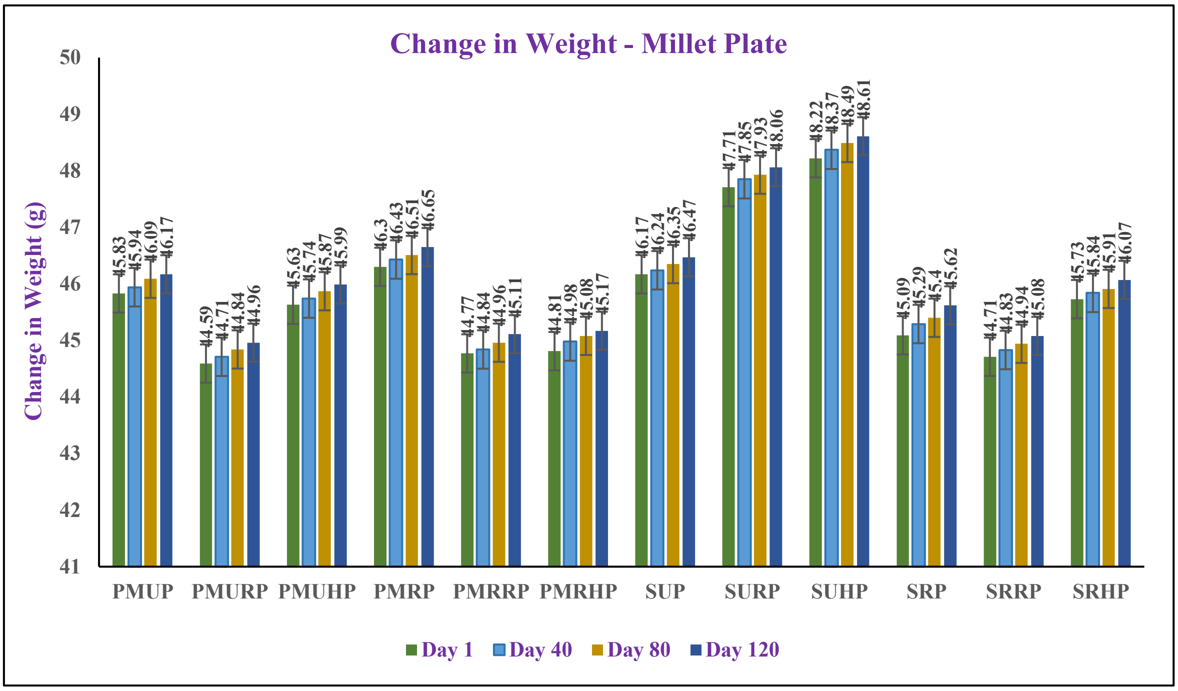


Figure – 29
Change in Weight of Millet Plate

Among all standardised pearl millet and sorghum plate, change in weight showed a minimal rise or stability, with some variation between unprocessed, roasted and flower powder enrichment. Millet plate exhibited the lowest increase in weight among millet cup, bowl, and katori and similar with millet spoon standardised in the present study.

The findings of change in weight in standardised millet tableware is supported by Mandal & Antarkar (2024) who confirmed that, after 15 days, minimal moisture gain was observed in the sorghum and mixed millet wafer premixes, while finger millet and pearl millet premixes showed no changes. By 30 days, moisture content increased in pearl millet, sorghum, and mixed millet premixes, but all remained within permissible limit of the FSSAI regulations and standards for millet and millet products which allows upto 16 per cent of moisture content by weight.

4.5.2 TOXICITY ANALYSIS OF MILLET TABLEWARE

4.5.2.1 BRINE SHRIMP LETHALITY ASSAY OF PEARL MILLET TABLEWARE

The brine shrimp lethality assay assesses the toxicity of pearl millet tableware extracts at different concentrations of 250 µg/ml, 500 µg/ml, 1000 µg/ml, and 1500 µg/ml over 24 hours and the observed results is tabulated in Table XLVII.

Table XLVII

Brine Shrimp Lethality Assay of Pearl millet Tableware

Millet Tableware	Mortality of Brine Shrimp (h)	Concentration (µg/ml)			
		250	**500**	**1000**	**1500**
Blank (Saline Water)	**% Mortality (24 h)**	**0**	**0**	**0**	**0**
PMUT	2	0	0	0	0
	6	0	0	**1**	**1**
	24	0	**1**	**1**	**1**
	% Mortality (24 h)	0	**3**	**3**	**3**
PMUHT	2	0	0	0	0
	6	0	0	1	1
	24	0	0	**1**	**3**
	% Mortality (24 h)	0	0	**3**	**10**
PMURT	2	0	0	0	0
	6	0	0	0	0
	24	0	0	**2**	**3**
	% Mortality (24 h)	0	0	**7**	**10**
PMRT	2	0	0	0	0
	6	0	0	**1**	**1**
	24	0	**1**	**1**	**1**
	% Mortality (24 h)	0	**3**	**3**	**3**
PMRHT	2	0	0	0	0
	6	0	0	0	0
	24	0	0	**1**	**2**
	% Mortality (24 h)	0	0	**3**	**7**
PMRRT	2	0	0	0	0
	6	0	0	1	1
	24	0	0	**2**	**3**
	% Mortality (24 h)	0	0	**7**	**10**
$K_2Cr_2O_7$ (1 mg/ml) is the control and showed 100% of mortality percent within 1 hour					

Pearl millet Tableware, at 2 hours, observed no mortality at any concentration in unprocessed, roasted and flower-enriched tableware, that indicated no immediate toxic effect. By 6 hours, slight mortality was observed in PMRT at 1000 µg/ml showed three per cent mortality. After 24 hours, the mortality rate varied across pearl millet tableware, PMUT showed three per cent of mortality at 1500 µg/ml concentration. PMUHT demonstrated minimal mortality at the higher concentrations, that exhibited 10 per cent at 1500 µg/ml, as well as, PMURT and PMRRT also showed 10 per cent mortality at 1500 µg/ml. PMRHT showed a progressive increase in mortality rate, that exhibited 7 per cent of mortality rate at 1500 µg/ml. Brine shrimp lethality assay of pearl millet tableware, exhibited low lethality at lower concentrations upto 750 µg/ml, which was slightly increased at higher concentrations (1000 and 1500 µg/ml).

4.5.2.2 BRINE SHRIMP LETHALITY ASSAY OF SORGHUM TABLEWARE

The brine shrimp lethality assay was conducted to evaluate the cytotoxicity of SUT, SUHT, SURT, SRT, SRHT, and SRRT over 24 hours and the results is given in Table - XLVIII. The results indicated minimal cytotoxicity across sorghum tableware.

Table XLVIII

Brine Shrimp Lethality Assay of Sorghum Tableware

Millet Tableware	Mortality of Brine shrimp (h)	Concentration (µg/ml)			
		250	500	1000	1500
SUT	2	0	0	0	0
	6	0	0	0	0
	24	0	0	**1**	**2**
	% Mortality (24 h)	0	0	**3**	**7**
SUHT	2	0	0	0	0
	6	0	0	0	0
	24	0	0	**1**	**3**
	% Mortality (24 h)	0	0	**3**	**10**
SURT	2	0	0	0	0
	6	0	0	0	0
	24	0	0	**1**	**3**
	% Mortality (24 h)	0	0	**3**	**10**
SRT	2	0	0	0	0
	6	0	0	0	0
	24	0	0	0	1
	% Mortality (24 h)	0	0	0	**3**
SRHT	2	0	0	0	0
	6	0	0	0	0
	24	0	0	**1**	**2**
	% Mortality (24 h)	0	0	**3**	**7**

SRRT	2	0	0	0	0
	6	0	0	0	0
	24	0	0	**1**	**2**
	% Mortality (24 h)	0	0	**3**	**7**

Brine shrimp lethality assay of sorghum millet tableware exhibited that all the brine shrimp was alive at 100 mg/ml and 500 mg/ml concentration after 24 hours of sorghum tableware exposure. Even at a higher concentration of 1000 mg/ml, SRT showed no mortality, while SUT and the flower powder-incorporated sorghum bowl exhibited only 3 per cent mortality rate. When the concentration increased to 1500 mg/ml, SRT showed a slight increase in mortality (3%), SUT, SRHT and SRRT showed 7 per cent mortality rate, and SUHT and SURT exhibited 10 per cent mortality. The brine shrimp lethality assay demonstrated a minimal cytotoxic effect on brine shrimp nauplii, with a trend of increased mortality rate corresponding to the higher concentrations. The mortality rate was below 10 per cent across all six-sorghum bowl, and impossible to calculate the LC_{50} value for concentrations ranging from 100 to 1500 µg/ml for the roasted and edible flower powder-enhanced sorghum tableware that showed low toxicity.

The result of the present is supported by the findings of Osama *et al*. (2020) who observed a 16.66 per cent mortality rate at a concentration of 1000 µg/ml in rose extracts. The cytotoxicity is primarily attributed to the presence of bioactive compounds such as alkaloids, flavonoids, and tannins (Osama *et al*., 2020; Kalauni *et al.,* 2024). The LC_{50} value in the brine shrimp assay for sorghum and hibiscus aqueous extract was reported to be between 3.7 and 4.6 µg/ml, respectively (Fagbohoun *et al*., 2022).

4.5.3 BIODEGRADABILITY ANALYSIS OF MILLET TABLEWARE

Biodegradability analysis of millet tableware was analysed by soil burial test and the result is discussed in the Table XLIX and Plate - 37.

The soil burial test of PMUT decreased from 1.98 ± 0.09 g on Day 1 to 0.51 ± 0.02 g on Day 9, and similar results were observed for PMUHT and PMURT, though PMURT retained slightly more weight (0.60 ± 0.01 g on Day 9), possibly due to rose enrichment. Roasted pearl millet tableware with its flower enrichment (PMRT, PMRHT, PMRRT) showed weight loss due to degradation, with PMURT had highest residual weight (0.60 ± 0.01 g) due to its enriched composition.

Table XLIX

Biodegradability analysis of Millet Tableware

S. No	Tableware	Day 1 (g)	Day 3 (g)	Day 6 (g)	Day 9 (g)
1	PMUT	1.98 ± 0.09	1.55 ± 0.12	0.94 ± 0.06	0.51 ± 0.02
2	PMUHT	1.97 ± 0.07	1.6 ± 0.02	0.92 ± 0.06	0.46 ± 0.04
3	PMURT	2.02 ± 0.31	1.62 ± 0.04	1 ± 0.02	0.60 ± 0.01
4	PMRT	1.97 ± 0.06	1.52 ± 0.04	0.93 ± 0.03	0.47 ± 0.1
5	PMRHT	2.04 ± 0.22	1.54 ± 0.07	0.89 ± 0.07	0.52 ± 0.03
6	PMRRT	2.11 ± 0.10	1.63 ± 0.05	0.99 ± 0.02	0.58 ± 0.03
7	SUT	1.99 ± 0.1	1.58 ± 0.12	0.98 ± 0.02	0.52 ± 0.05
8	SUHT	2.36 ± 0.26	1.66 ± 0.07	1.02 ± 0.06	0.61 ± 0.05
9	SURT	2.02 ± 0.09	1.61 ± 0.04	0.99 ± 0.02	0.53 ± 0.05
10	SRT	2.07 ± 0.09	1.61 ± 0.08	1.03 ± 0.07	0.54 ± 0.10
11	SRHT	2.28 ± 0.18	1.68 ± 0.03	1 ± 0.02	0.58 ± 0.03
12	SRRT	1.97 ± 0.13	1.52 ± 0.09	0.97 ± 0.07	0.56 ± 0.04

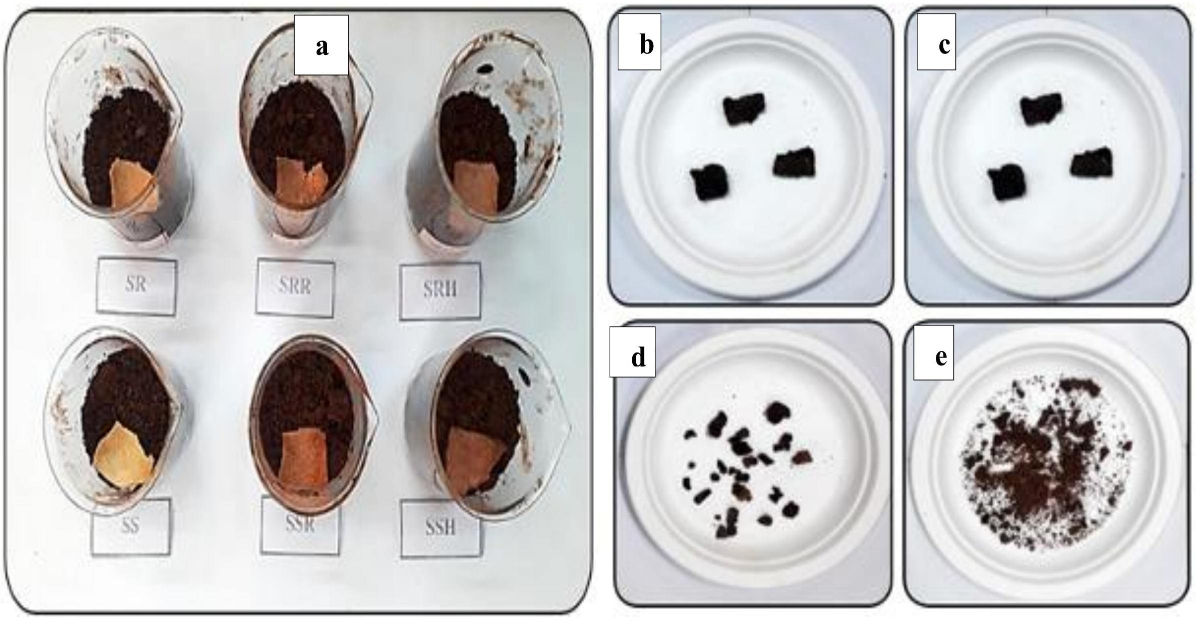


Plate - 37

Soil Burial Test of Millet Tableware, a. burial in beaker containing soil, b. Day 1, c. Day 3, d. Day 6, e. Day 9

Sorghum tableware also exhibited effective biodegradability, with unprocessed (SUT) and enriched (SUHT, SURT) variants reducing similarly to its pearl millet counterparts, while roasted tableware with flower-enriched (SRT, SRHT, SRRT) tableware showed a gradual weight loss, SRHT exhibited higher residual weight (0.58 ± 0.03 g) as compared to its counterparts. The tableware was not found in soil on 12th day. Hibiscus and rose enrichment moderately affect biodegradability, possibly due to the flower powder addition. Pearl millet and sorghum tableware are highly biodegradable, with slight variations based on preliminary process like roasting and flower powder enrichment. All the tableware were completely degradable within 12 days in wet top soil. The finding of the present study is supported by, Thagunna *et al.* (2023) who, formulated cutlery using wheat flour, finger millet, and rice flour exhibited complete biodegradation within 5 days.

4.5.4 FEASIBILITY ANALYSIS OF MILLET TABLEWARE

Product Cost Calculation of Millet Tableware

Cost calculation of millet tableware was done by estimating the cost of raw material, its procurement, transportation, manpower, and tableware making charges (for molds). Table L, presents the cost of millet tableware per 100 pieces.

The cost for unprocessed tableware was around Rs.150/- for cup, Rs.180/- for bowl and katori, Rs.100/- for spoon and Rs.200/- for plate respectively. Rs. 10 for roasted millet tableware and Rs.15/- for flower-enriched tableware was increased as the processing and raw material cost. Hence, the cost of the millet cup per piece is Rs.1.5/- to Rs. 1.65/-; for bowl and katori, Rs.1.80/- to Rs.1.95/-, for spoon, Rs.1/- to Rs.1.15/- and for plate, Rs.2/- to Rs.2.15/- respectively.

Table L

Product Cost Calculation of Millet Tableware

S.No	Tableware	Unprocessed Tableware (Rs.)	Roasted Tableware (Rs.)	Flower-enriched Tableware (Rs.)
1	**Cup**	150	160	165
2	**Bowl**	180	190	195
3	**Katori**	180	190	195
4	**Spoon**	100	110	115
5	**Plate**	200	210	215

The cost of the finalized standardised product was derived based on the cost of raw material, processing, manpower and mould utilization. According to Minimum Support Prices for Kharif Crops for Marketing Season 2024 – 2025, in India, the cost of sorghum and pearl millet is Rs.33.7/- per kg (Rs.3,371/- per quintal) and Rs.22.47/- per kg (Rs.2,247/- per quintal) respectively. From a kg of millet flour, 50 cups, 40 bowls and katori, 100 spoons and 20 plates can be produced. The fresh flowers were procured at the cost of Rs.70/- to Rs.220/- per kg during the peak flowering season which yield around 190 g to 210 g of powder after shade dried. Only, 1.5 g to 8 g of flower powder were used for tableware enrichment. Procurement of flowers directly from farms and utilizing semi-automatic or fully automatic machines with multiple molds and producing in larger quantities will reduce the cost further.

The result is supported by the finding of, Molu *et al.* (2024a), stated that, the cost of the selected edible tableware made from wheat and maize flour was Rs.30.56 per 100 g. Mukherjee & Raju (2023) demonstrated that one tablespoon formulated from wheat, foxtail millet, and roasted bengal gram can be cost around Rs.2/-. The cost of preparing one edible cup includes the expenses for raw ingredients as well as fuel and appliance usage (Matheswari & Arivuchudar, 2024).