CHAPTER III

METHODOLOGY

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,

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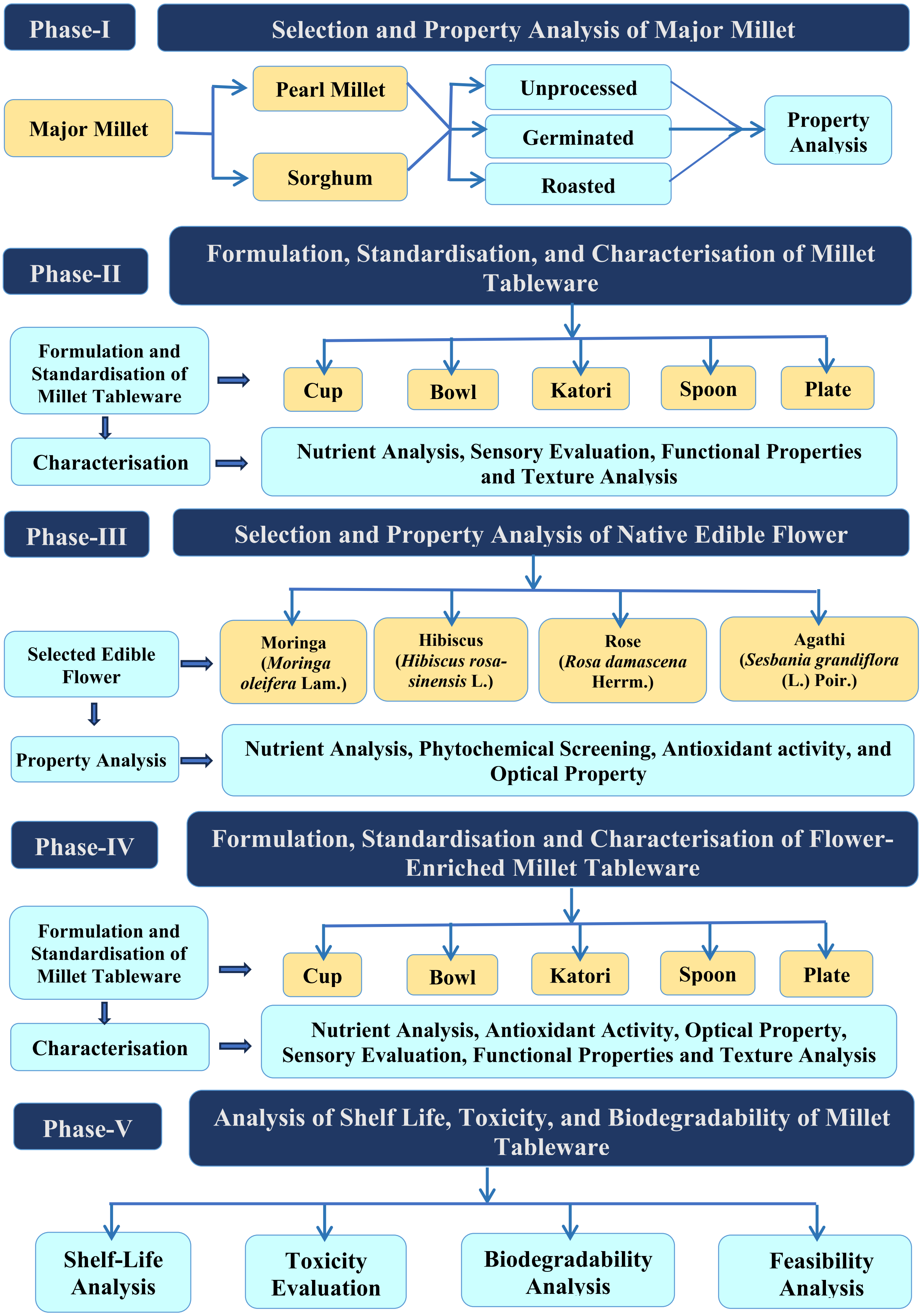


Figure – 2 Research Design of the Study

PHASE - I

3.1 SELECTION AND PROPERTY ANALYSIS OF MAJOR MILLET

3.1.1 Selection and Processing of Major Millet

A. Selection of Major Millet

Millet is a resilient cereal crop from the grass family (Poaceae), often known as the "miracle grain" or "crop of the future". Millet grown in marginal soils with minimal resources, and adapts to a diverse climatic condition with low irrigation needs, proved it to be a sustainable crop (Chaurasia *et al.,* 2023; Mohod *et al.,* 2023). Sorghum, pearl millet and finger millet are the major millets and barnyard millet, proso millet, kodo millet, little millet, and foxtail millet are the minor millets. These are the commonly cultivated millets in India which suits to various agroclimatic conditions (Kumari *et al.,* 2023; Sukumaran Sreekala *et al.,* 2023).

Globally, millet were the highly cultivated species and over 20 per cent of the world's millet were produced in India. The two most common millet crops were sorghum and pearl millet, accounting for 90 per cent of global millet output. Sorghum is the most popular produced millet that account for 65 per cent of the global millet production (Sachan *et al.,* 2023; Sathish Kumar *et al.,* 2022; Bhatt *et al.,* 2022; Singh *et al.,* 2020). Pearl millet (*Cenchrus americanus* (L.) Morrone) and sorghum (*Sorghum bicolor* (L.) Moench) are the two widely cultivated and consumed millet which was selected for the study. The selection of millet was further based on its nutritional benefits and cost-effectiveness.

The study was conducted after obtaining approval from the Institutional Human Ethical Committee (approval number: AUW/IHEC/FSN-21-22/XPD-31), and the certificate is enclosed in Appendix I. The authentication of millet was received from the Director, The Rapinat Herbarium and Centre for Molecular Systematics (RHT) at St. Joseph's College in Tiruchirappalli, India. It houses thousands of plant specimens and was considered as the plant taxonomic library in South India. Authentication numbers were assigned as D.S.M 005 for sorghum and D.S.M 006 for pearl millet (Appendix II a and II b).

i. Pearl millet

Globally, pearl millet is the sixth most cultivated and produced grain, and the fourth tropical cereal grain produced in India after paddy, maize, and sorghum. It is grown and cultivated in marginal, arid and semiarid tropical and subtropical regions. It is rich in essential nutrients like folate, iron, copper, zinc, magnesium, calcium and Vitamin B complex, and unsaturated fatty acids (Bhatt *et al.,* 2022; Saini *et al.,* 2021). Pearl millet is a sustainable alternative for persons with celiac disease and gluten intolerance as it is gluten free. It exhibits a better texture and water-holding properties, making it as an excellent option in different food applications including baking, extrusion and fortification (Meena *et al*., 2024).

Pearl millet CO 7 variety was selected for the formulation and standardization of millet tableware. Good quality pearl millet without any dirt and debris was purchased from a supermarket in Coimbatore, Tamil Nadu. The purchased pearl millet was ensured for husk removal and then, it was sorted, cleaned and washed to remove any contaminants and stored in an airtight container for further processing.

ii. Sorghum

Sorghum is the fifth widely cultivated cereal crop worldwide which is known for its climatic resilience. It is widely cultivated for grain, sweet syrup, forage, and biomass. Sorghum is one of the most nutritious millets as compared to rice and wheat. It has evolved into five major species (*bicolor, guinea, caudatum, kafir, and durra*) and 10 intermediate hybrids based on panicle and spikelet structures. Sorghum is cultivated globally for food, fodder, alcoholic beverages, and biofuel production (Bhatt *et al.,* 2022; Li *et al.,* 2022b).

Sorghum K 11 variety was selected for formulation and standardization for millet tableware. White variety sorghum is highly available and consumed more widely than red or yellow-colored sorghum. During the study period, good-quality, dehusked sorghum grains were purchased from a supermarket in Coimbatore, Tamil Nadu. The procured sorghum was cleaned to remove any contaminants and stored in an airtight container for future research.

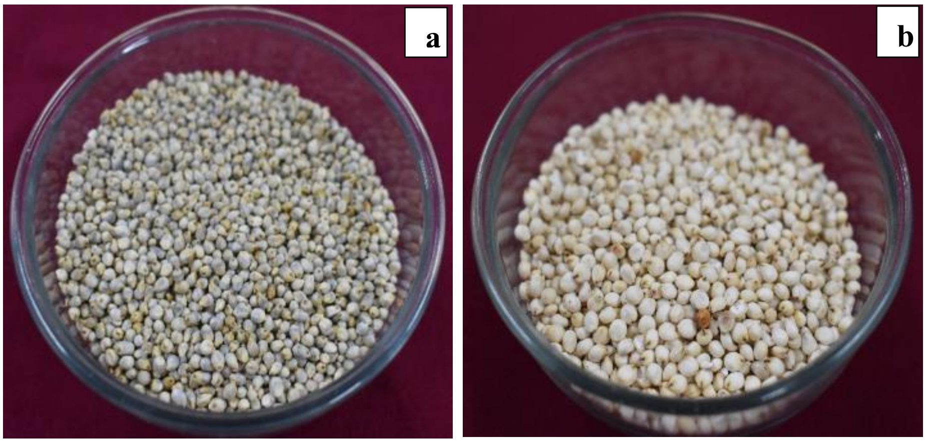


Plate – 1
Selected Unprocessed Millet, a. Pearl millet (*Cenchrus americanus* (L.) Morrone), b. Sorghum (*Sorghum bicolor* (L.) Moench)

B. Processing of Selected Major Millet

Nutrient bioavailability and absorption can be improved by minimizing the effects of antinutrients using various processing methods such as soaking, germination, fermentation, and application of heat and mechanical processing (Sunil *et al.,* 2024).

Milling, dehulling, fermentation and roasting of millet was employed to improve digestibility, sensory properties, nutritional value, mineral bioavailability and decreased antinutritional factors (Meena *et al.,* 2024).

Roasting and germination of pearl millet and sorghum led to modification of grain composition, reduced anti-nutritional factors and enhanced digestibility, and also improved the functional and antioxidant properties. It was due to the enzyme-driven macronutrient breakdown during germination and deactivation of heat-sensitive antinutritional factors during roasting (Li *et al.,* 2022b).

i. Pearl millet

In this study, pearl millet was used in three forms, such as unprocessed, germinated and roasted to formulate and standardise the edible tableware. Standard preliminary conventional methods, such as soaking, germination and roasting were done to enhance the physical, technological and functional properties of the grain (Sunil *et al*., 2024; Olamiti *et al*., 2020).

The procured pearl millet was washed and sorted to remove husk or other impurities. The washed pearl millet was sun dried at 38ºC in the month of April-May, 2022 for seven hours. The dried pearl millet was ground in commercial milling machine and sieved through 0.3 mm mesh. Then, the unprocessed pearl millet flour was stored in an airtight container at room temperature.

Germination of the pearl millet was done by soaking it for eight hours, then the water was drained and the grains were spread on a muslin cloth to remove excess water. Then, the soaked and drained pearl millet was wrapped in a muslin cloth for 35 hours, and water was sprinkled once in five hours to maintain the appropriate humidity. An optimum temperature of 30 - 32ºC at 60 per cent humidity throughout the process was maintained. After this, the grains were sun dried for ten hours until the moisture content reduced to 12 per cent. Then, it was ground using a commercial milling machine and sieved through a 3 mm mesh. The powdered germinated flour was stored in an airtight container for further edible tableware formulation and standardisation (Sunil *et al*., 2024).

Cleaned, dried, whole pearl millet was roasted in an iron pan for 12 minutes at 90ºC until popping of few grains. The roasted grains were cooled down to 25ºC to ensure ease in grounding in commercial milling machine. The milled and ground roasted pearl millet flour was sieved with 3 mm mesh and stored in an airtight container to maximize its shelf life (Olamiti *et al*., 2020).

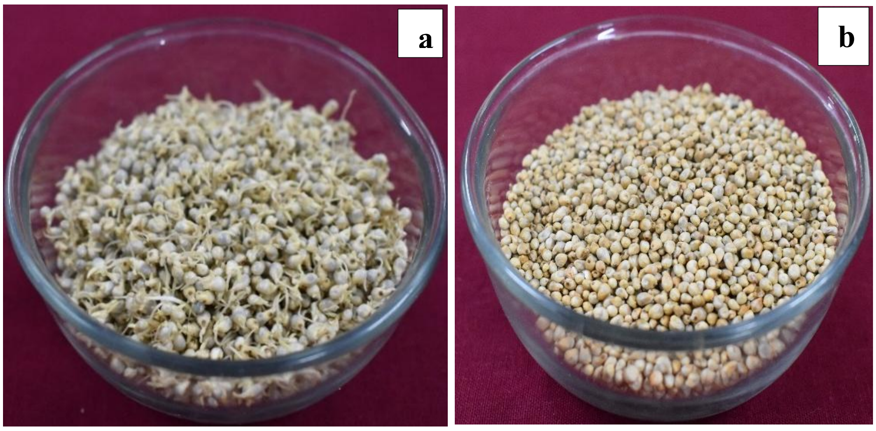


Plate – 2
Pearl millet, a. Germinated Pearl millet, b. Roasted Pearl millet

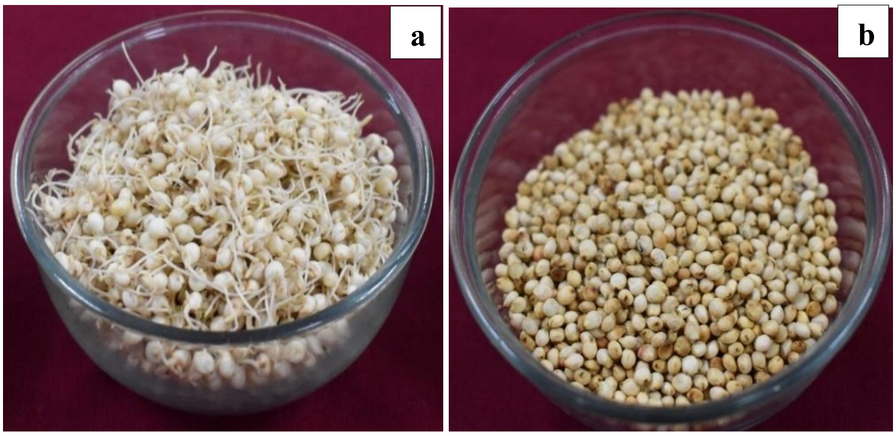


Plate – 3
Sorghum, a. Germinated Sorghum, b. Roasted Sorghum

ii. Sorghum

In this study, sorghum was processed to ensure consistency in the edible tableware formulation and standardisation. Whole sorghum grains were thoroughly washed, cleaned, and sorted to remove impurities. Then, it was sun dried at a temperature of 38ºC (average) for eight hours. Conventional preliminary processing, such as soaking, germination, and roasting, was conducted to enrich the properties of grains (Olamiti *et al.,* 2020).

Sorted sorghum grains were soaked for eight hours as the initial step of germination. The excess water was drained and the moisture was reduced by spreading the soaked grain on muslin cloth. Then, the grains were wrapped in a white muslin cloth and germinated for 35 hours at 30 - 32ºC with 60 per cent of humidity, by periodic sprinkling of water for every five hours. The grains were then, sun-dried for 10 hours until moisture content reached to 12 per cent. Then it was ground into fine flour in a commercial milling machine, and sieved through a 0.3 mm mesh. The germinated sorghum flour after sieving was stored in an airtight container for further analysis (Sunil *et al.,* 2024).

Dried sorghum grains were roasted in an iron pan for 12 - 14 minutes at 90°C until popping of a few grains. The roasted grains were cooled at 25°C, facilitating easier grinding in the commercial milling machine. Ground roasted sorghum flour was sieved through a 0.3 mm mesh and stored in an airtight container to maintain quality (Olamiti *et al.,* 2020).

3.1.2 Physical Properties of Millet

Grain yield and physical properties of the unprocessed and processed pearl millet and sorghum were analyzed to measure its quality. Thickness (mm), length (mm), breadth (mm), length/breadth ratio, thousand grain weight (g), and thousand grain volume (ml) were the physical properties analyzed. The dimensions like thickness, length, and breadth were measured by selecting 10 grains randomly. The length/breadth ratio was measured by dividing the length by breadth. Thousand grain weight was calculated by weighing the randomly selected hundred grains from different slots and multiplied by ten. Thousand grain volume was measured by using a graduated cylinder and 100 grains were counted and filled in it and the obtained volume was multiplied by 10 (Khatoniar & Das, 2020).

3.1.3 Physicochemical Properties of Millet Flour

Unprocessed and processed pearl millet and sorghum flour were used to analyse technological properties. Bulk density (g/ml), swelling capacity (%), water absorption capacity (ml/g), and oil absorption capacity (ml/g) were determined (Sunil *et al.,* 2024; Khatoniar & Das., 2020) (Appendix III).

3.1.4 Total Phenolic Content of Millet Flour

Total phenolic content of the unprocessed and processed pearl millet and sorghum flour was determined by Folin-Ciocalteu reagent method and the procedure is given in Appendix VI (Sunil *et al.,* 2024; Sadasivam & Manickam, 2023)

3.1.5 Antinutritional Factors of Millet Flour

Antinutritional factors such as phytic acid, saponin, and tannin in unprocessed and roasted pearl millet and sorghum flour were measured using standard procedures. Tannin content was determined by the Folin-Denis reagent as tannic acid as standard, similarly, saponin and phytic acid were determined as saponin and phytic acid as standards through spectrophotometry (Sunil *et al.,* 2024; Sadasivam & Manickam, 2023) (Appendix V).

3.1.6 Functional Properties of Millet Flour

i. Fourier Transform Infrared Spectroscopy of Millet Flour (FTIR)

Fourier Transform Infrared (FTIR) spectroscopy was used to identify the functional groups for unprocessed and roasted pearl millet and sorghum flour, providing insights into their molecular composition and chemical modifications due to conventional processing. The analysis was conducted using Shimadzu MIRacle10 FTIR spectrophotometer. Approximately, 0.5 g of the unprocessed and processed millet flour were scanned from a range of 4000 cm^{-1} to 450 cm^{-1} wavenumber at 16 runs per scan (Olamiti *et al.,* 2020).

ii. X-Ray Diffraction (XRD) of Millet Flour

The crystalline or amorphous nature of unprocessed and roasted pearl millet and sorghum flour were determined using patterns from X-Pert Pro, PANalytical model X-Ray Diffraction (XRD). The 5 g of fine millet flour was loaded and operated at 30 mA and 45 kV between the scanning zones of 10° to 79° 2θ with a continuous step size of 0.01 for 5.71 seconds. The Debye-Scherrer formula, $D = K \lambda / \beta \cos \theta$, had been applied to estimate the average crystalline size of sorghum and pearl millet flour, where D represented the crystalline size, λ denoted the X-ray wavelength of Cu, β was the full-width at its half maximum, and k represented a dimensionless shape factor with a fixed value of 0.94 (Olamiti *et al.,* 2020).

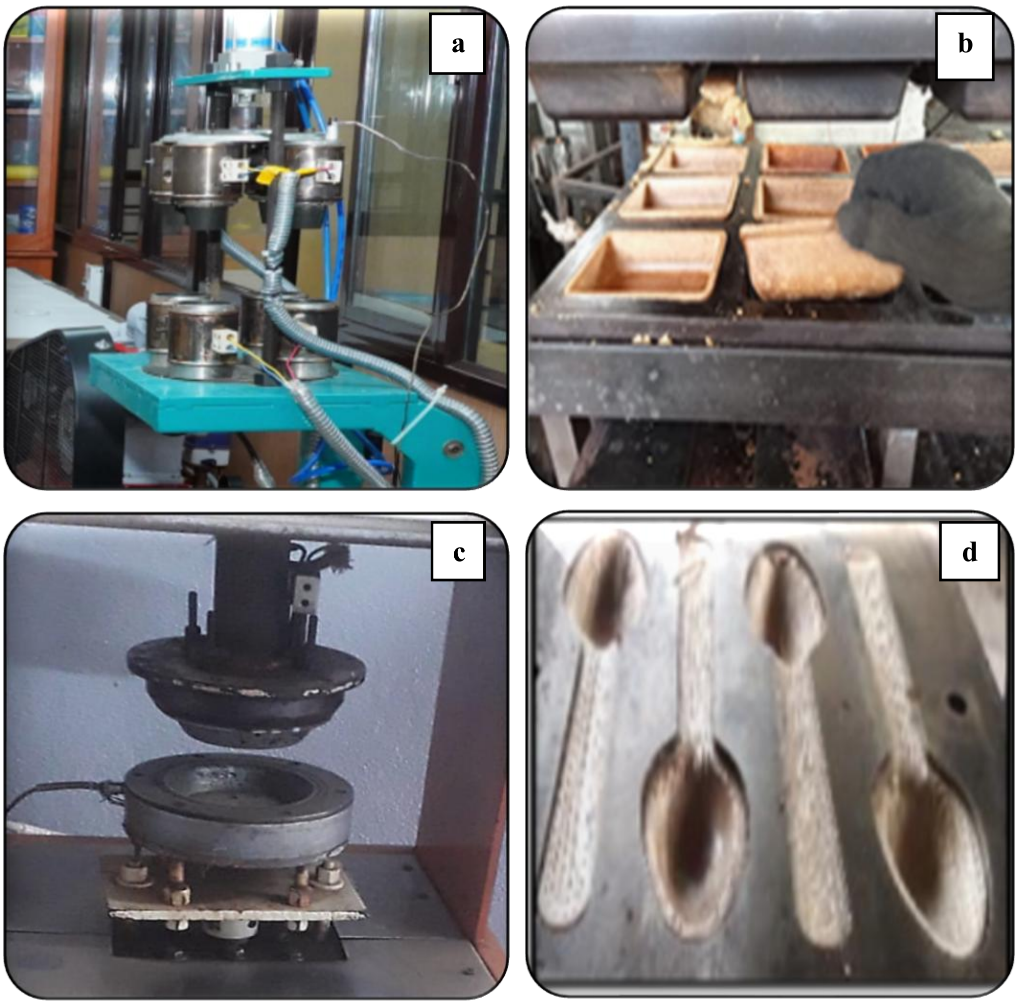
Unprocessed, germinated and roasted pearl millet and sorghum grain were characterised based on their physical, optical, technological and functional properties. Anti-nutritional factors were also assessed to facilitate in the formulation and standardisation of millet tableware.

PHASE - II

3.2 FORMULATION, STANDARDISATION, AND CHARACTERISATION OF MILLET TABLEWARE

In Phase II, the study focused on the formulation, standardisation, and characterisation of edible tableware such as, cup, bowl, katori, spoon, and plate from pearl millet and sorghum. Tableware was formulated using specific closed molds to ensure repetition and the cup was formulated in frustum-shaped cup mold with an average radius of 2.3 inches and 1.65 inches height, with a 45 ml holding capacity. Bowl was formulated in a 4-inch rectangular-shaped mold with curved edges. Katori in a four-inch circular-shaped mold, and the quarter plate in a six-inch circular-shaped mold with a depth of 0.8 inch. The spoon was formulated with 5.11 inches length, a head breadth of 1.25 inches, and a 0.47-inch handle mold. The formulation and standardisation were done by pneumatic and hydraulic pressing followed by baking, with fixed temperature and timing based on the unprocessed and processed flour, shape and thickness of the tableware. The temperature involved for the process was between 70°C to 90°C for 8 to 18 minutes under 1500 psi pressure. Germination and roasting of the millet were done to enhance the nutritional content, sensory parameters, and functional properties when compared with its unprocessed counterparts.

Different permutations and combinations were tried with unprocessed and processed pearl millet and sorghum flour with and without binders. Without binders, the tableware was highly porous, hence, the proportion were trailed by adding binders from one gram. Six variations with varying proportions of millet flour and binders were finalised for the formulation of cup, bowl, katori, spoon and plate, as discussed in Phase II. Subsequently, the variation that exhibit optimal texture and prolonged water-holding capacity was selected for further characterisation and enhancement.



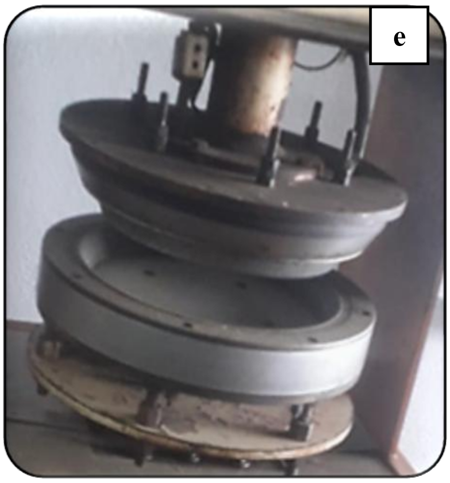


Plate – 4
Machine and Molds used for Millet Tableware Standardisation, a. Cup mold, b. Bowl mold, c. Katori mold, d. Spoon mold, e. Plate mold.

3.2.1 Formulation and Standardisation of Millet Cup

The composition of millet cup was trailed with different permutations and combinations of pearl millet and sorghum flour in unprocessed, germinated, and roasted forms. Each formulation included millet flour, binder, water, 0.5 ml of oil and a pinch of salt with the total weight standardised to 19 g based on the capacity of cup mold. The proportion was formulated by altering the quantity of millet flour and binder as mentioned in Table I.

Table I
Formulation of Millet Cup

Variations	Ingredients (g)	Pearl millet (PM)			Sorghum (S)		
		PMUC	PMGC	PMRC	SUC	SGC	SRC
I	Millet flour	16	16	16	16	16	16
	Binder	3	3	3	3	3	3
	Total	**19**	**19**	**19**	**19**	**19**	**19**
	Water (ml)*	10	9	12	12	10	12
II	Millet flour	14	14	14	14	14	14
	Binder	5	5	5	5	5	5
	Total	**19**	**19**	**19**	**19**	**19**	**19**
	Water (ml)*	11	10.5	14	13	11	13
III	Millet flour	12	12	12	12	12	12
	Binder	7	7	7	7	7	7

	Total	**19**	**19**	**19**	**19**	**19**	**19**
	Water (ml)*	12	11.5	14	14	12	14
IV	Millet flour	10	10	10	10	10	10
	Binder	9	9	9	9	9	9
	Total	**19**	**19**	**19**	**19**	**19**	**19**
	Water (ml)*	14	12	16	15	13	15
V	Millet flour	8	8	8	8	8	8
	Binder	11	11	11	11	11	11
	Total	**19**	**19**	**19**	**19**	**19**	**19**
	Water (ml)*	16	13	18	15	13	16
VI	Millet flour	6	6	6	6	6	6
	Binder	13	13	13	13	13	13
	Total	**19**	**19**	**19**	**19**	**19**	**19**
	Water (ml)*	18	14	20	16	14	16

*The quantity of water was added based on the type of millet subjected to unprocessed or processed form. *PMUC-Unprocessed Pearl millet Cup, PMGC – Germinated Pearl millet Cup, PMRC – Roasted Pearl millet Cup, SUC – Unprocessed Sorghum Cup, SGC- Germinated Sorghum Cup, SRC- Roasted Sorghum Cup

In the first variation of pearl millet and sorghum cup, 16 g of millet flour was used with 9 - 12 ml of water and 3 g of binder. Variation II contained 14 g of millet flour and 5 g of binder, requiring 10.5–14 ml of water for a thick batter. In subsequent variations III to VI, millet flour quantity was gradually reduced (12, 10, 8, and 6 g), and the amount of binder was increased (7, 9, 11, and 13 g), with water being adjusted to maintain thick consistency, 11.5 - 14 ml for Variation III, 12 - 16 ml for Variation IV, 13 - 18 ml for Variation V, and 14 - 20 ml for Variation VI. Less water was required for making germinated millet cups compared to unprocessed or roasted cups, aiding batter consistency.

The batter was thoroughly mixed to a thick, smooth consistency, then poured into cup-shaped mold and baking was done. Pearl millet cup had shorter baking time, 12 minutes for unprocessed, 10 minutes for germinated, and 9 minutes for roasted cups at 70°C where temperature being the same. Unprocessed sorghum cups were baked at 70°C for 15 minutes, with germinated and roasted sorghum cups requiring shorter time of 12 and 10 minutes, respectively. The formulated pearl millet and sorghum cups were validated for the structural integrity, porous nature, and appearance, and the best proportions were optimized for further enhancement and characterisation.

3.2.2 Formulation and Standardisation of Millet Bowl

Unprocessed, germinated, and roasted pearl millet and sorghum have been subjected to many permutations and combinations to formulate and standardise millet bowl as given in Table II. A pinch of salt and 1 ml of oil were added to improve the taste, flavour and texture, ensuring the sensory qualities and structural integrity of millet bowl.

Table II
Formulation of Millet Bowl

Variations	Ingredients (g)	Pearl millet			Sorghum		
		PMUB	PMGB	PMRB	SUB	SGB	SRB
I	Millet flour	22	22	22	22	22	22
	Binder	4	4	4	4	4	4
	Total	**26**	**26**	**26**	**26**	**26**	**26**
II	Millet flour	20	20	20	20	20	20
	Binder	6	6	6	6	6	6
	Total	**26**	**26**	**26**	**26**	**26**	**26**
III	Millet flour	18	18	18	18	18	18
	Binder	8	8	8	8	8	8
	Total	**26**	**26**	**26**	**26**	**26**	**26**
IV	Millet flour	16	16	16	16	16	16
	Binder	10	10	10	10	10	10
	Total	**26**	**26**	**26**	**26**	**26**	**26**
V	Millet flour	14	14	14	14	14	14
	Binder	12	12	12	12	12	12
	Total	**26**	**26**	**26**	**26**	**26**	**26**
VI	Millet flour	12	12	12	12	12	12
	Binder	14	14	14	14	14	14
	Total	**26**	**26**	**26**	**26**	**26**	**26**

*PMUB - Unprocessed Pearl millet Bowl, PMGB – Germinated Pearl millet Bowl, PMRB – Roasted Pearl millet Bowl, SUB – Unprocessed Sorghum Bowl, SGB- Germinated Sorghum Bowl, SRB - Roasted Sorghum Bowl

In Variation I, the bowls were prepared using 22 g of millet flour with 4 g of binder. From, Variation II to VI, the amount of millet flour gradually decreased while binders were increased. In, Variation II, 6 g of binder was added, and the millet flour was reduced to 20

g. Similarly, millet flour was reduced to 12 g in Variation VI while binder was increased to 14 g. For all variations, the ingredients were mixed thoroughly to form a thick batter. Addition of 18 to 25 ml of water was adjusted accordingly to maintain consistency. The addition of water was similar to the developed millet cup, where germinated variation required less water and roasted counterparts required more water than unprocessed millet bowl to form a thick consistent batter.

The thick batter was poured into a four-inch square-shaped bowl mold and baked at 90°C. The pearl millet bowl (unprocessed, germinated, and roasted) was baked for 8 minutes whereas for the sorghum, unprocessed bowl was baked for 12 minutes, germinated bowl for 10 minutes, and roasted bowl for 8 minutes. Each formulated pearl millet and sorghum bowl underwent validation for structural integrity, porosity, and visual appeal, and the optimal proportions were selected for further enhancement and characterisation.

3.2.3 Formulation and Standardisation of Millet Katori

Edible katori was developed utilizing pearl millet and sorghum flour in six different variations. The formulations of unprocessed, germinated and roasted pearl millet and sorghum katori are given in Table III.

Table III
Formulation of Millet Katori

Variations	Ingredients (g)	Pearl millet			Sorghum		
		PMUK	**PMGK**	**PMRK**	**SUK**	**SGK**	**SRK**
I	Millet flour	19	19	19	19	19	19
	Binder	4	4	4	4	4	4
	Total	**23**	**23**	**23**	**23**	**23**	**23**
II	Millet flour	17	17	17	17	17	17
	Binder	6	6	6	6	6	6
	Total	**23**	**23**	**23**	**23**	**23**	**23**
III	Millet flour	15	15	15	15	15	15
	Binder	8	8	8	8	8	8
	Total	**23**	**23**	**23**	**23**	**23**	**23**
IV	Millet flour	13	13	13	13	13	13
	Binder	10	4	4	4	4	4
	Total	**23**	**23**	**23**	**23**	**23**	**23**

V	Millet flour	11	11	11	11	11	11
	Binder	12	12	12	12	12	12
	Total	**23**	**23**	**23**	**23**	**23**	**23**
VI	Millet flour	9	9	9	9	9	9
	Binder	14	14	14	14	14	14
	Total	**23**	**23**	**23**	**23**	**23**	**23**
*PMUK - Unprocessed Pearl millet Katori, PMGK – Germinated Pearl millet Katori, PMRK – Roasted Pearl millet Katori, SUK – Unprocessed Sorghum Katori, SGK - Germinated Sorghum Katori, SRK - Roasted Sorghum Katori							

The pliability of the batter was enhanced by adding 1 ml of oil and a pinch of salt was added as taste enhancer. Variation I of millet katori was formulated with 19 g of millet flour, and 4 g of binder. From Variation II to VI, the amount of millet flour was gradually lowered, and the amount of binder was increased. In Variation II, 17 g of millet flour were mixed with 6 g of binder. Subsequently, in Variation VI, 9 g of millet flour and 14 g of binder were formulated. All six formulations were done and the consistency and structural integrity of the developed millet katori were analysed. 15 to 24 ml of water was adjusted accordingly to form a thick batter suitable for molding. The amount of water added was similar to that of the formulated pearl millet and sorghum cup and bowl. The germinated katori required less water, while roasted katori required more water as compared to unprocessed katori.

The batter was blended thoroughly and poured into a closed four-inch circular shaped katori mold and baked at 90ºC. Pearl millet katori (unprocessed, germinated, and roasted) were baked for 10 minutes, whereas the sorghum katori (unprocessed, germinated, and roasted) were baked for 12 minutes, 10 minutes, and 8 minutes respectively. The structural strength, porosity, and appearance of the formulated pearl millet and sorghum katori were assessed and the effective formulation was chosen for further enhancement and characterisation.

3.2.4 Formulation and Standardisation of Millet Spoon

Six variations of edible spoons were prepared at different ratios of unprocessed, germinated and roasted millet flour with binder. The millet spoon was formulated with 3 to 8 g of the millet flour while the quantity of binder was increased from 1 to 6 g. In all six variations, a pinch of salt and 0.5 ml of oil were added to improve the pliability of batter. The formulations used in this study are outlined below in Table IV.

Table IV
Formulation of Millet Spoon

Variations	Ingredients (g)	Pearl millet			Sorghum		
		PMUS	PMGS	PMRS	SUS	SGS	SRS
I	Millet flour	8	8	8	8	8	8
	Binder	1	1	1	1	1	1
	Total	**9**	**9**	**9**	**9**	**9**	**9**
II	Millet flour	7	7	7	7	7	7
	Binder	2	2	2	2	2	2
	Total	**9**	**9**	**9**	**9**	**9**	**9**
III	Millet flour	6	6	6	6	6	6
	Binder	3	3	3	3	3	3
	Total	**9**	**9**	**9**	**9**	**9**	**9**
IV	Millet flour	5	5	5	5	5	5
	Binder	4	4	4	4	4	4
	Total	**9**	**9**	**9**	**9**	**9**	**9**
V	Millet flour	4	4	4	4	4	4
	Binder	5	5	5	5	5	5
	Total	**9**	**9**	**9**	**9**	**9**	**9**
VI	Millet flour	3	3	3	3	3	3
	Binder	6	6	6	6	6	6
	Total	**9**	**9**	**9**	**9**	**9**	**9**

*PMUS - Unprocessed Pearl millet Spoon, PMGS – Germinated Pearl millet Spoon, PMRS – Roasted Pearl millet Spoon, SUS – Unprocessed Sorghum Spoon, SGS - Germinated Sorghum Spoon, SRS - Roasted Sorghum Spoon

In Variation I, 8 g of millet flour with 1 g of binder was trailed. In Variation II, 7 g of millet flour and 2 g of binder, and in Variation III, 6 g of millet flour and 3 g of binder were added allowing for a preliminary evaluation of texture changes. In Variations IV, V, and VI, the millet flour was progressively reduced from 5 to 3 g, while the binder was increased from 3 to 5 g. The addition of quantity of water ranged from 5 ml to 12 ml, which was adjusted to maintain a smooth, and thick consistency batter. The addition of water was consistent with the pattern for cups, bowls, and katori, where germinated flour required less water and roasted flour required more water than unprocessed flour to achieve the batter thickness.

The spoon was formulated by pouring the prepared thick batter into a spoon-shaped mold and baked at 70°C. Pearl millet spoons (unprocessed, germinated, and roasted) were baked for 8 minutes, while sorghum spoons baked for, 10 minutes for unprocessed, and 8 minutes for both germinated and roasted variations. The structural integrity, and porosity of all the formulated spoon from pearl millet and sorghum were assessed. Then, the best formulation was selected for further characterisation and enhancement.

3.2.5 Formulation and Standardisation of Millet Plate

Six different proportions of millet flour and binder were formulated to standardise the edible plate from pearl millet and sorghum in unprocessed, germinated and roasted forms. The pliability of batter was enhanced by adding 1.5 ml of oil and a pinch of salt was added to improve the flavour in all the six variations of pearl millet and sorghum plate. Table V depicts the millet plate formulations.

Table V
Formulation of Millet Plate

Variations	Ingredients (g)	Pearl millet			Sorghum		
		PMUP	**PMGP**	**PMRP**	**SUP**	**SGP**	**SRP**
I	Millet flour	46	46	46	46	46	46
	Binder	8	8	8	8	8	8
	Total	**54**	**54**	**54**	**54**	**54**	**54**
II	Millet flour	42	42	42	42	42	42
	Binder	12	12	12	12	12	12
	Total	**54**	**54**	**54**	**54**	**54**	**54**
III	Millet flour	38	38	38	38	38	38
	Binder	16	16	16	16	16	16
	Total	**54**	**54**	**54**	**54**	**54**	**54**
IV	Millet flour	34	34	34	34	34	34
	Binder	20	20	20	20	20	20
	Total	**54**	**54**	**54**	**54**	**54**	**54**
V	Millet flour	30	30	30	30	30	30
	Binder	24	24	24	24	24	24
	Total	**54**	**54**	**54**	**54**	**54**	**54**

VI	Millet flour	26	26	26	26	26	26
	Binder	28	28	28	28	28	28
	Total	**54**	**54**	**54**	**54**	**54**	**54**

*PMUP - Unprocessed Pearl millet Plate, PMGP – Germinated Pearl millet Plate, PMRP – Roasted Pearl millet Plate, SUP – Unprocessed Sorghum Plate, SGP - Germinated Sorghum Plate, SRP - Roasted Sorghum Plate

In Variation I, 46 g of millet flour was taken with 8 g of binder. In Variation II, 42 g of millet flour and 12 g of binder were mixed thoroughly without any lumps to make a thick and smooth consistency batter. Variation III was the combination of, 16 g binder and 38 g millet flour, increasing the gluten content to improve the structural integrity. In Variations IV, V, and VI, the quantity of millet flour was reduced to 34 g, 30 g, and 26 g, respectively, while the binder was progressively increased to 20 g, 24 g, and 28 g. Water content ranged from 45 to 48 ml depending on the flour ratio to form a thick consistency batter. The plates from unprocessed and processed pearl millet were baked at 90°C for 16 minutes whereas, the sorghum plates were baked for, 18, 15, and 12 minutes for unprocessed, germinated, and roasted variations, respectively. The textural and sensory properties of the formulated plate was evaluated and the best variation was taken for further enhancement and characterisation.

3.2.6 Selection of Standardised Proportion of Millet Tableware

The variation of tableware with a higher quantity of millet flour than the quantity of binder, and with the better structural integrity, minimized porosity were selected for further analysis. Specifically, Variation IV for both unprocessed and roasted pearl millet and sorghum tableware, as well as Variation V for germinated pearl millet and sorghum tableware, were identified as the best formulation for cup, bowl, katori, spoon, and plate. The selected proportions were subjected to a standardised baking process, cup and spoon baked at 70°C, and bowl, katori, and plate baked at 90°C. The baking times vary depending on the process (unprocessed, germinated, or roasted), millet (sorghum or pearl millet), and the tableware (cup, bowl, katori, spoon, and plate). The selected proportions with better structural integrity and without porosity are depicted in Table VI. The standardised formulations were subjected to nutrient analysis, sensory evaluation, physical, optical, functional and textural properties along with shelf life and toxicity analysis.

Variations I, II, and III of unprocessed and roasted cups, as well as the first four variations of germinated cups, exhibited high porosity that affects the ability to hold liquids for longer durations. Variation VI of unprocessed and roasted pearl millet and sorghum and Variation VI of germinated pearl millet and sorghum was not taken as it contains more binder than millet flour. Variation IV in unprocessed and roasted pearl millet and sorghum cups and Variation V in germinated pearl millet and sorghum cups were thick, stable, and non-porous and selected for further analysis. The optimized proportion of unprocessed, germinated and roasted pearl millet and sorghum cups were coded as PMUC, PMGC, PMRC, SUC, SGC, and SRC respectively, and given in Plate 5.

The first four variations of the germinated pearl millet and sorghum bowl, as well as variations I, II, and III of the unprocessed and roasted pearl millet and sorghum bowl, were highly porous and could not hold liquids for an extended period. Variation VI was excluded, as binder content was more than the millet flour. The thick, stable, and non-porous Variations IV in the unprocessed and roasted pearl millet and sorghum, whereas, Variations V in germinated pearl millet and sorghum bowls were chosen for further characterisation. Unprocessed, germinated and roasted pearl millet bowls were coded as PMUB, PMGB, and PMRB, while unprocessed, germinated and roasted sorghum bowls were coded as SUB, SGB, and SRB and the standardised bowl was displayed in Plate 6.

Table VI
Selection of Standardised Proportion of Millet Tableware

S. No	Millet	Process	Standardised Proportion (g)	Cup (C)	Bowl (B)	Katori (K)	Spoon (S)	Plate (P)
1	Pearl millet	Unprocessed (PMU)	Millet Flour	10	16	13	5	34
			Binder	9	10	10	4	20
			Total	**19**	**26**	**23**	**9**	**54**
			Water*	14	18	15	7	40
		Germinated (PMG)	Millet Flour	8	14	11	4	30
			Binder	11	12	12	5	24
			Total	**19**	**26**	**23**	**9**	**54**
			Water*	13	20	18	8	43
		Roasted (PMR)	Millet Flour	10	16	13	5	34
			Binder	9	10	10	4	20
			Total	**19**	**26**	**23**	**9**	**54**
			Water*	16	20	18	8	45
2	Sorghum	Unprocessed (SU)	Millet Flour	10	16	13	5	30
			Binder	9	10	10	4	24
			Total	**19**	**26**	**23**	**9**	**54**
			Water*	15	20	17	6	43

		Germinated (SG)	Millet Flour	8	14	11	4	30
			Binder	11	12	12	5	28
			Total	**19**	**26**	**23**	**9**	**54**
			Water*	13	18	15	5.5	40
		Roasted (SR)	Millet Flour	10	16	13	5	34
			Binder	9	10	10	4	20
			Total	**19**	**26**	**23**	**9**	**54**
			Water*	15	22	19	8	45

*The quantity of water (ml) was added based on the type of millet subjected to unprocessed or processed form.

Variations I, II, and III of the unprocessed pearl millet and sorghum katori, as well as the first four variations of the germinated pearl millet and sorghum katori, were highly permeable and were unable to hold liquids for more than 15 minutes. Variation V in the germinated pearl millet and sorghum katori and Variation IV in the unprocessed and roasted pearl millet and sorghum were non-porous, thick, with optimal structural integrity, were the finalized composition for further value addition and characterisation. The unprocessed, germinated and roasted pearl millet katori were coded as PMUK, PMGK, and PMRK, whereas, unprocessed, germinated and roasted sorghum katori were coded as SUK, SGK, and SRK and depicted in Plate 7**.**

Variation IV in unprocessed and roasted pearl millet and sorghum spoon and Variation V in germinated pearl millet and sorghum spoon were suited as the best variation and taken for further analysis and the remaining variations were excluded due to the lack of structural integrity and hardness. The spoons were coded as PMUS, PMGS, and PMRS for unprocessed, germinated, and roasted pearl millet spoon, respectively, and as SUS, SGS, and SRS for the unprocessed, germinated, and roasted sorghum spoon, as illustrated in the Plate 8.

Variation IV in unprocessed and roasted pearl millet and sorghum plate, and Variation V in germinated pearl millet and sorghum plate was the selected proportion for further characterisation. The selected variations were non-porous with optimal structural integrity. Unprocessed, germinated and roasted pearl millet plate were coded as PMUP, PMGP, and PMRP. Similarly, Unprocessed, germinated and roasted sorghum plate were coded as SUP, SGP, and SRP and given in Plate 9.

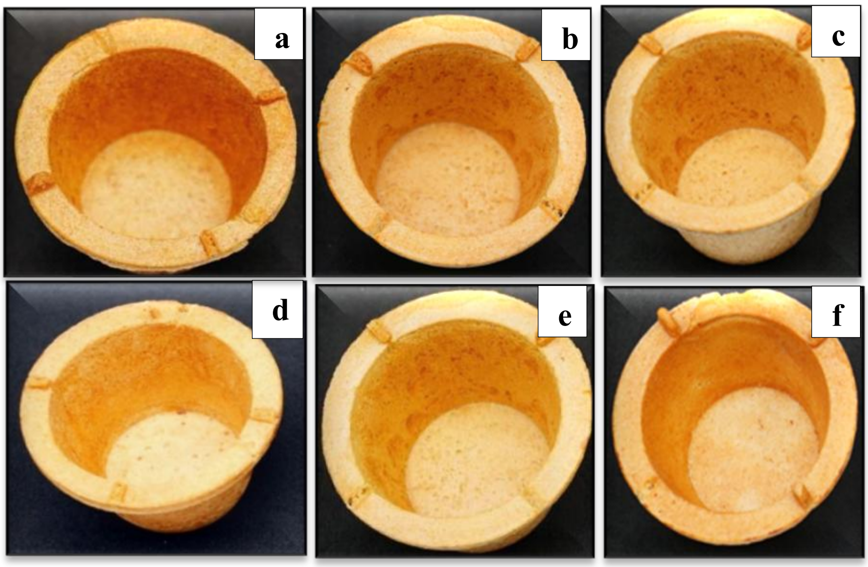


Plate – 5
Millet Cup, a. PMUC, b. PMGC, c. PMRC, d. SUC, e. SGC, f. SRC

(PMUC-Unprocessed Pearl millet Cup, PMGC – Germinated Pearl millet Cup, PMRC – Roasted Pearl millet Cup, SUC – Unprocessed Sorghum Cup, SGC- Germinated Sorghum Cup, SRC- Roasted Sorghum Cup)

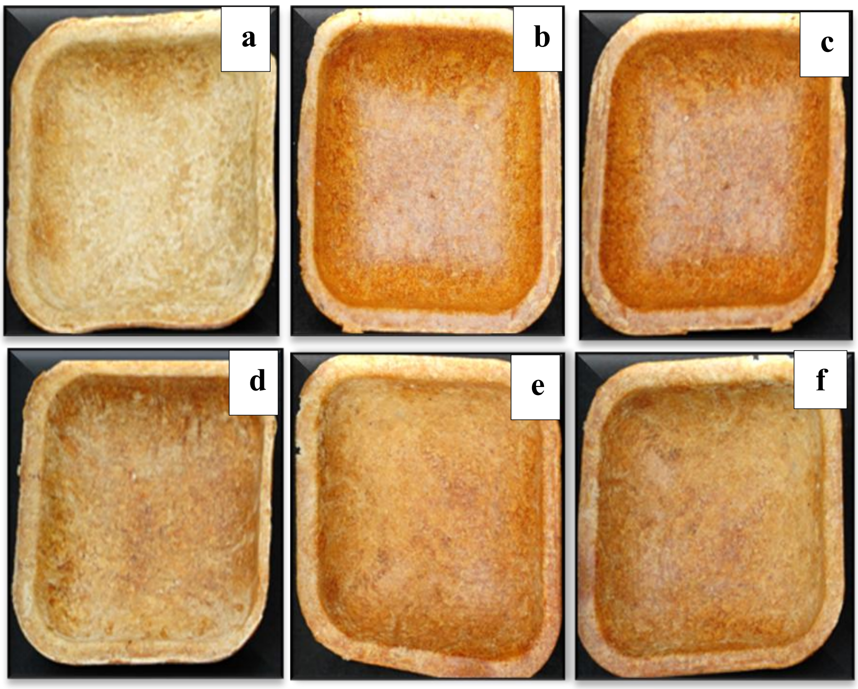


Plate – 6
Millet Bowl, a. PMUB, b. PMGB, c. PMRB, d. SUB, e. SGB, f. SRB

(PMUB - Unprocessed Pearl millet Bowl, PMGB – Germinated Pearl millet Bowl, PMRB – Roasted Pearl millet Bowl, SUB – Unprocessed Sorghum Bowl, SGB- Germinated Sorghum Bowl, SRB - Roasted Sorghum Bowl)

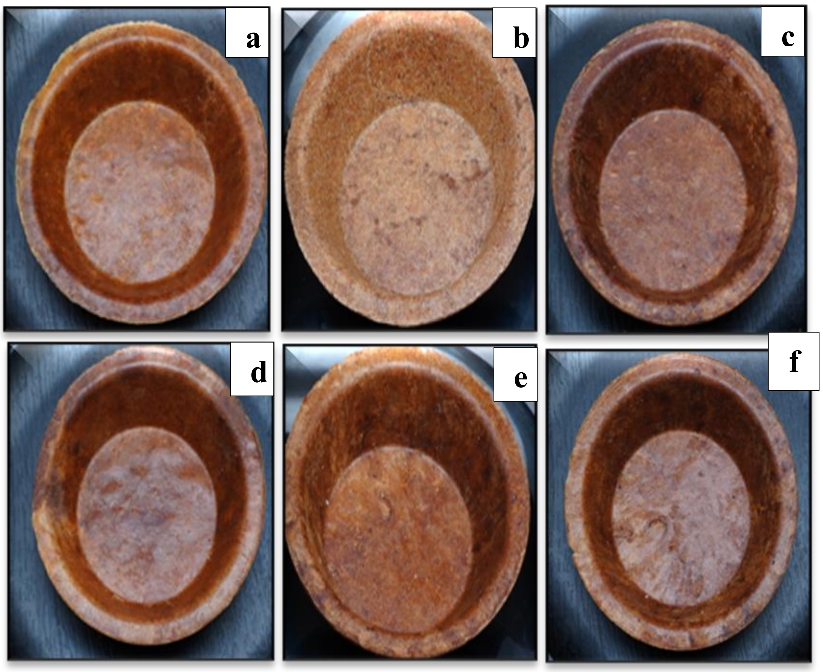


Plate – 7
Millet Katori, a. PMUK, b. PMGK, c. PMRK, d. SUK, e. SGK, f. SRK

(PMUK - Unprocessed Pearl millet Katori, PMGK – Germinated Pearl millet Katori, PMRK – Roasted Pearl millet Katori, SUK – Unprocessed Sorghum Katori, SGK - Germinated Sorghum Katori, SRK - Roasted Sorghum Katori)

Plate – 8
Millet Spoon, a. PMUS, b. PMGS, c. PMRS, d. SUS, e. SGS, f. SRS

(PMUS - Unprocessed Pearl millet Spoon, PMGS – Germinated Pearl millet Spoon, PMRS – Roasted Pearl millet Spoon, SUS – Unprocessed Sorghum Spoon, SGS - Germinated Sorghum Spoon, SRS - Roasted Sorghum Spoon)

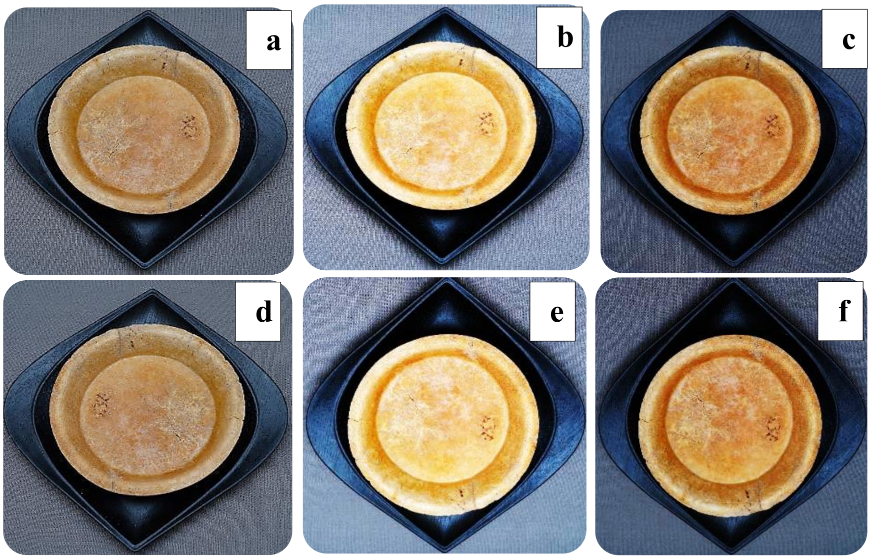


Plate – 9

Millet Plate, a. PMUP, b. PMGP, c. PMRP, d. SUP, e. SGP, f. SRP

(PMUP - Unprocessed Pearl millet Plate, PMGP – Germinated Pearl millet Plate, PMRP – Roasted Pearl millet Plate, SUP – Unprocessed Sorghum Plate, SGP - Germinated Sorghum Plate, SRP - Roasted Sorghum Plate)

3.2.7 Characterisation of Standardised Millet Tableware

3.2.7.1 Proximate and Nutrient Analysis of Millet Tableware

Proximate and Nutrient analysis for the standardised unprocessed, germinated and roasted pearl millet and sorghum tableware was done using standard procedures. Moisture, ash, protein, fat, and crude fiber were determined by AOAC standards and carbohydrates by Anthrone method. Vitamin C, iron, calcium, and phosphorus were quantified using the ascorbic acid volumetric method, Folin-Ciocalteu reagent method, and titration with $KMnO_4$ (AOAC standards; Sadasivam & Manickam, 2023) and the procedure is given in Appendix VII.

3.2.7.2 Sensory Evaluation of Millet Tableware

The sensory evaluation of the standardised unprocessed, germinated and roasted pearl millet and sorghum tableware was assessed using a nine-point hedonic scale by 30 semi-trained panel members. Panel members evaluated the pearl millet and sorghum tableware with six sensory parameters, including shape or appearance, colour, taste, flavour, texture or crispiness, and overall acceptability. Panel members were instructed to rate each parameter on a nine-point hedonic scale, with 1 being ranked "dislike extremely" and 9 representing "like extremely". The findings of sensory characterisation were the key indicator in formulations and optimization of pearl millet and sorghum tableware. It provides a valuable insight on sensory attributes and overall acceptability to meet consumer preferences and expectations (Hnin *et al.,* 2021) and the nine-point hedonic scale ratings is given in Appendix VIII. The semi-trained panel members were female students and research scholars between the age of 19 and 26. Semi-trained panel members are individuals who have the basic sensory evaluation knowledge and training and not fully trained experts.

Plate – 10
Sensory Evaluation of Millet Tableware

3.2.7.3 Functional Properties of Millet Tableware

i. Fourier Transform Infrared Spectroscopy (FTIR)

The peaks from the Fourier Transform Infrared spectrophotometer (Shimadzu MIRacle10) were used to identify the functional groups for the standardised unprocessed, germinated, and roasted pearl millet and sorghum tableware. The spectra of 0.5 g of millet tableware powder were obtained and run at 16 runs per scan, and the peaks were identified between 4000 cm^{-1} and 450 cm^{-1} wavenumbers (Guine, 2022; Sharanagat *et al.,* 2019).

ii. Thermo Gravimetric Analysis (TGA)

Thermo Gravimetric Analyser (EXSTAR/C300) was used to identify the thermal properties and to calculate the percentage of thermal degradation of the standardised unprocessed, germinated and roasted pearl millet and sorghum tableware. It exhibits the physiochemical changes during controlled rise in temperature. The powder from pearl millet or sorghum tableware was heated in an alumina pan from 20ºC to 1000ºC at 20ºC increase per minute (Guine, 2022).

iii. Water Absorption Rate

The water absorption rate of the standardised unprocessed, germinated, and roasted pearl millet and sorghum tableware was assessed by measuring the amount of water absorbed during a 40-minute exposure to liquids at different temperature, ambient (32°C), hot (80°C), and cold (4°C). For cup, 45 ml of water at ambient and hot temperature and ice cubes were poured for 30 minutes and change in weight was monitored (Nehra *et al.,* 2024). In case of bowl, katori, spoon and plate, a known weight of respective tableware was taken and immersed in ambient, hot, and cold temperature (Rajendran *et al*., 2020). The initial weight of the tableware (W_1) was recorded, and it was exposed in the ambient, hot and cold liquid for 40 minutes or until the first leakage appeared. After exposure, surface water was carefully removed using tissue paper, and the final weight (W_2) was measured. This method ensured accurate evaluation of water absorption under realistic serving conditions which was a important factor in analysing its functional properties (Nehra *et al.,* 2024: Habla *et al.,* 2023) The percentage of water absorption was calculated using the formula:

$$\text{Percentage of Water Absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100$$

Where W_1 is the initial weight, and W_2 is the final weight after water absorption of the millet tableware.

3.2.7.4 Texture Analysis of Millet Tableware

i. Texture Analysis

Mechanical properties like hardness force and elastic force were measured by Shimadzu EZ-XS texture analyser. The standardised unprocessed, germinated, and roasted pearl millet and sorghum tableware was measured at a speed of 1 mm per second until the threshold force or the deformation distance was reached. The texture analyser creates a force-displacement curve by recording force (N) against displacement (mm) during the compression test. Hardness force was the maximum force required to compress the millet tableware. Elastic force reflects its ability to deform and recover under applied pressure and the higher elastic force indicates greater elasticity or resilience (Guine, 2022).

ii. Drop Test

Drop test of the standardised unprocessed, germinated, and roasted pearl millet and sorghum tableware was evaluated to analyse the durability and resistance to force impact till certain fixed hights. The millet tableware without any cracks or deformations was dropped onto a flat, hard surface at different heights between 10 and 150 cm paving way to measure the stimulated accidental drops or falls that may occur during handling or serving (Grzelczyk *et al.,* 2022; Buxoo *et al.,* 2020).

Phase II dealt with the formulation, standardisation and characterisation of the millet tableware in unprocessed, germinated and roasted forms. The standardised millet tableware was characterised in respect to its nutrient analysis, sensory evaluation, functional properties and textural analysis. It showed that unprocessed and roasted tableware exhibited better properties whereas, germinated millet tableware showed the least properties which was excluded for further analysis. The best variation and proportion were selected for further edible flower enrichment and characterisation.

PHASE - III

3.3 SELECTION AND PROPERTY ANALYSIS OF NATIVE EDIBLE FLOWER

3.3.1 Selection and Processing of Native Edible Flower

Edible flower, spanning 97 families, 100 genera, and 180 species, were valued for their therapeutic properties and culinary applications and enhancing the aesthetic appeal, taste, and flavour of dishes. It was rich in vitamins, minerals, and antioxidants, that hold potential in the functional food industry. The high phenolic content and antioxidant capability may protect against oxidative stress-related illness (Rivas-García *et al.,* 2021; Purohit *et al.,* 2021; Skrajda-Brdak *et al.,* 2020). Edible flower was low in protein, and rich in carbohydrates that can be incorporated in carbohydrate-restricted diets in small quantities and their abundance of antioxidants aids in minimizing lifestyle disorders (Takahashi *et al.,* 2020). Drying methods including solar and shade drying have been found to preserve and enhance their nutritional content (Rivas-García *et al.,* 2021; Purohit *et al.,* 2021; Skrajda-Brdak *et al.,* 2020). Nowadays, the food industries were increasingly incorporating the novel ingredients such as fruits, vegetables, and edible flower in different forms into product formulations, to meet consumer demand for nutritious and functional options. The edible flower was gaining popularity not only for its ornamental appeal but also for their significant nutritional and medicinal properties (Teixeira *et al.,* 2023; Alves *et al.,* 2021; Hnin *et al.,* 2021; Rashwan *et al.,* 2021; Tun *et al.,* 2021; Takahashi *et al.,* 2020).

Hence, in the present study, four edible flower such as Moringa (*Moringa oleifera* Lam.), Hibiscus (*Hibiscus rosa-sinensis* L.), Rose (*Rosa damascena* Herrm.) and Agathi (*Sesbania grandiflora* (L.) Poir.), were selected due to its well-documented antioxidant properties, cost-effectiveness, and local availability. The authentication of the selected plants was provided by The Director, Rapinat Herbarium and Centre for Molecular Systematics (RHT), St. Joseph College, Tiruchirappalli, Tamil Nadu. The authentication numbers were D.S.M 001 (Moringa), D.S.M 002 (Hibiscus), D.S.M 003 (Rose), and D.S.M 004 (Agathi) (Appendix II c, d, e and f). The flower was collected during its peak blooming season (January to March) from the farms in Karur district of Tamil Nadu, India. Harvesting was done early in the morning, between 8 a.m. and 9 a.m to ensure its freshness.

The fully bloomed, white agathi flower, red five-petal hibiscus flower, whitish moringa flower, and pink damask rose was the selected flower varieties. After harvesting, the flower was cleaned, washed, and the petals were separated for analysis. The petals were shade-dried for 32 to 72 hours to retain their natural nutrients and phytochemical properties. Then, the shade dried petals were ground into a fine powder using household mixer-grinder and stored in an airtight container with a moisture content of less than 9 per cent for further use and subsequent tests.

Plate – 11
Selected Edible Flower, a. Moringa (*Moringa oleifera* Lam.), b. Hibiscus (*Hibiscus rosa-sinensis* L.), c. Rose (*Rosa damascena* Herrm.), and d. Agathi (*Sesbania grandiflora* (L.) Poir.)

i. Moringa (*Moringa oleifera* Lam.)

Moringa flower, a rich source of bioactive pigments, including chlorophyll, anthocyanins, carotenoids, and lycopene, derived from fats and flavonoids. They also contain key compounds such as alkaloids, flavonoids, flavanols, phenols, polyphenols, and anthocyanins, known for its strong antioxidant properties and play a vital role in reducing the risk of chronic diseases (Patil *et al.,* 2022; Hodas *et al.,* 2021; Milla *et al.,* 2021).

Fresh moringa flowers, free from insect damage and other impurities, were collected for processing. It has five small petals, one to two centimetres long, and white to creamy in colour. The calyx was greenish, has five lobes, and curves back to protect the flower bud before it blooms. The collected flowers were thoroughly washed several times using a colander to remove all external contaminants. The entire flowers, including the petals, were shade-dried for 42 hours, ensuring that the moisture content dropped below 5 per cent. After drying, the flowers were finely ground into powder and stored in airtight container at 4ºC in refrigerator for further characterisation.

ii. Hibiscus (*Hibiscus rosa-sinensis* L.)

Hibiscus was known for its vibrant colour and tangy flavour, provides therapeutic benefits, including antioxidant, antibacterial, lipid-modulating, and insulin resistance-reducing effects. It contains phenolic acids, flavonoids, organic acids, lutein, tannins, and various anthocyanins. These compounds enhance the antioxidant, anti-inflammatory, anti-cancer, anti-aging, antimicrobial, hepatoprotective, and neurogenic properties (Dos Santos Silva *et al.,* 2023; Vasic *et al.,* 2023; Shelke *et al.,* 2021).

Red five-petal hibiscus flowers were harvested at peak bloom. It has five petals, six to eight centimetres length and four to six centimetres width. The calyx was green, cup-like, has lobes, with an additional outer layer of 5–10 narrow bracts (epicalyx). The stamens were joined together to form a long column with yellow tips. The selected flower was trumpet-shaped, brightly coloured, and have a prominent central style.

The flowers were washed under running water to remove surface impurities, and the petals were manually separated from stamens and calyces. The cleaned petals were shade-dried for 36 hours until they became brittle. The dried petals were ground into a fine powder, and stored in an airtight container at 4°C in a refrigerator.

iii. Rose (*Rosa damascena* Herrm.)

Rose was widely recognized in traditional and modern medicine for its essential oils, with an antioxidant, antibacterial, antimicrobial, and anti-inflammatory benefits, and aids in menstrual bleeding, inflammatory bowel disease (IBD), and gastroesophageal reflux. Rose exhibited flavonoids (quercetin, kaempferol, apigenin), catechin, anthocyanins, proanthocyanidins (procyanidin), phenolic acids (gallic and ellagic acid), and stilbenes like resveratrol (Trendafilova *et al.,* 2023; Hegde *et al.,* 2022; Akram *et al.,* 2020).

The selected pink damask rose petals were broad and oval or reverse-oval in shape, typically three to five centimetres length and two to four centimetres wide. The flower has five green, lance-shaped sepals that curve backward, forming a persistent calyx. The stamens are numerous and arranged in a circle. The petals were soft, thin, and fragrant, commonly used in cooking and traditional medicines.

The petals were separated from the calyx, stamens, and other non-edible parts. The separated petals were washed in running water to eliminate any dirt or debris. Then, it was shade-dried for 32 hours, reducing the moisture content to five to seven per cent and ground into a fine powder (sieved using 3 mm mesh). It was stored in airtight containers at 4ºC in refrigerator, ensuring their stability for future characterisation and enhancement in edible tableware production.

Plate – 12
Selected Edible Flower Powder, a. Moringa (*Moringa oleifera* Lam.), b. Hibiscus (*Hibiscus rosa-sinensis* L.), c. Rose (*Rosa damascena* Herrm.), and d. Agathi (*Sesbania grandiflora* (L.) Poir.)

iv. Agathi (*Sesbania grandiflora* (L.) Poir.)

Agathi flower contain flavonoids and phenolic compounds that reduces oedema and exhibited antibacterial properties against pathogens such as *Staphylococcus aureus, Shigella flexneri, Salmonella Typhi, E. coli,* and *Vibrio cholera*. Additionally, phenolic acids (syringic, salicylic, and chlorogenic acids) inhibit AChE and BuChE enzymes, that supports nerve health by preventing acetylcholine degradation. The flower also contains bioactive compounds namely oleanolic acid and kaempferol-3-rutinoside (Prabawati *et al.,* 2021; Tun *et al.,* 2021).

Fully matured, insect-free agathi flowers were harvested to ensure optimal quality. The flowers were butterfly shaped and the petals were seven to ten centimetres long. The calyx was small, green, and bell-shaped, with five short fused lobes with 10 stamens. The petals of the selected flower were white, soft, and slightly curved, making them ideal for edible use. The flowers were washed under running water to remove any dust or impurities. After cleaning, the petals were separated from non-edible components such as stamens, calyces, and stems. The isolated petals were shade-dried for approximately 72 hours until they became brittle due to moisture loss. The dried petals were then ground into a fine powder using a mixer grinder. This powder was stored in air-tight containers at 4°C in a refrigerator to maintain its freshness and prevent moisture absorption for future analyses and potential application in millet tableware.

3.3.2 Nutrient Analysis of Selected Flower Powder

The nutrient analysis of edible flower powder was determined by AOAC standard. Moisture, ash, protein, fat, and crude fiber content of the powder was analysed by AOAC standard. Carbohydrate content was determined using anthrone method. Micronutrients like ascorbic acid was measured by volumetric method, the Folin-Ciocalteu reagent method for iron, and titration with $KMnO_4$ for calcium and phosphorus, respectively (Sadasivam & Manickam, 2023) (Appendix VII).

3.3.3 Phytochemical Screening of Selected Flower Powder

The screening of bioactive phytochemicals in the edible flower powder was performed to identify the presence of phenolic compounds associated with antioxidant activity. Alkaloids, amino acids, anthocyanins, flavonoids, glycosides, phenols, phytic acid, saponin, tannin and terpenoids were analysed and the screening procedures are included (Appendix IV).

3.3.4 Antioxidant Activity of Selected Flower Powder

The antioxidant activity of the dried flower powder was determined using the DPPH (1,1-diphenyl-2-picrylhydrazyl) scavenging assay, with ascorbic acid as a standard. IC_{50} values, representing the concentration required to inhibit 50 per cent of free radicals and calculated through linear regression analysis. A value ranging between 10 and 50 mg/mL indicated strong antioxidant activity, 50 to 100 mg/mL indicated moderate activity, and values above 100 mg/mL showed weak antioxidant capacity (Appendix IX).

3.3.5 Optical Property of Selected Flower Powder

Optical property was measured by using Laboratory Scale Food Colourimeter. The varying values of L*, a*, b*, and Δ E indicate the optical properties of selected shade-dried edible flower. L* values, ranging from zero to hundred, represent lighter to darker shades of the selected edible flowers. Positive values of a* indicate redness and negative values indicate the presence of greenness. While positive and negative values of b* indicate yellowness and blueness. The Δ E indicates the total difference between chroma and hue (Sunil *et al.,* 2024).

In Phase III, the four selected native edible flowers were subjected to nutrient analysis, qualitative phytochemical screening, quantitative antioxidant activity, and optical property. In that, hibiscus and rose flower powder exhibited better properties and selected for further enrichment, in varied proportions into the standardised formulation from Phase II.

PHASE - IV

3.4. FORMULATION, STANDARDISATION AND CHARACTERISATION OF FLOWER-ENRICHED MILLET TABLEWARE

3.4.1 Formulation and Standardisation of Flower-enriched Millet Tableware

The Table VII, presents the formulation and standardisation of edible tableware (cup, bowl, katori, spoon, and plate) from unprocessed and roasted pearl millet and sorghum and functionally enriched with selected edible flower. Hence, incorporation of shade-dried flower powder enhances the antioxidant activity, optical characteristics, functional properties, and sensory evaluation of the developed unprocessed and roasted pearl millet and sorghum tableware.

The millet tableware was functionally enhanced by adding 1 to 10 g of hibiscus or rose flower powder with millet flour, binder and water in specific ratios to optimize an edible, eco-friendly and economically viable alternative to conventional plastic cutlery. The taste of the millet tableware was further enhanced by adding a pinch of salt and the pliability of batter was enhanced by adding 2 to 7 ml of refined sunflower oil.

From the finalized proportion of millet tableware in Phase II, the selected edible flower from Phase III were incorporated by replacing two parts of millet flour and one part of binder. Incorporation of selected flower powder beyond the finalized proportion reduced the structural integrity, and increased the porous nature of the tableware.

Table VII

Standardisation of Edible Flower-enriched Millet Tableware

Millet	Process	Standardised Proportion (g)	Cup	Bowl	Katori	Spoon	Plate
Pearl millet	Unprocessed	Millet Flour	8	13	10	4	28
		Rose powder/ Hibiscus powder	3	4	4	1.5	8
		Binder	8	9	9	3.5	18
		Total	**19**	**26**	**23**	**9**	**54**
		Water*	14	21	17	8	45
	Roasted	Millet Flour	8	13	10	4	28
		Rose powder / Hibiscus powder	3	4	4	1.5	8
		Binder	8	9	9	3.5	18
		Total	**19**	**26**	**23**	**9**	**54**
		Water*	18	24	22	10	50
Sorghum	Unprocessed	Millet Flour	8	13	10	4	28
		Rose powder / Hibiscus powder	3	4	4	1.5	8
		Binder	8	9	9	3.5	18
		Total	**19**	**26**	**23**	**9**	**54**
		Water*	17	24	20	9	50
	Roasted	Millet Flour	8	13	10	4	28
		Rose powder/ Hibiscus powder	3	4	4	1.5	8
		Binder	8	9	9	3.5	18
		Total	**19**	**26**	**23**	**9**	**54**
		Water*	19	26	22	10	53

*The quantity of water (ml) was added based on the type of millet subjected to unprocessed or processed form.

The selected proportions were baked at 70°C for cup and spoon, while the bowl, katori, and plate were baked at 90°C. The baking duration were ranging from 8 to 20 minutes, depending on the unprocessed or roasted pearl millet and sorghum flour. The addition of shade-dried edible flower powder had not affected the required baking time or temperature for millet tableware. The tableware without any deformities and with good structural integrity were selected for further characterisation.

Flower-enriched unprocessed and roasted pearl millet and sorghum cup were standardised by mixing 8 g of millet flour, 8 g of binder, 3 g of shade-dried rose or hibiscus flower powder along with 0.5 ml of refined sunflower oil. 14 to 19 ml of water was added to make a thick batter poured into a unique closed cup-shaped mold and baked at 70°C for 9 to 15 minutes similar to standardised pearl millet and sorghum cup in Phase II. The finalized rose and hibiscus flower-enriched unprocessed and roasted pearl millet and sorghum cup were named PMURC, PMUHC, PMRRC, PMRHC, SURC, SUHC, SRRC, and SRHC respectively, and as given in Plate 13 and 14.

Flower-enriched unprocessed and roasted pearl millet and sorghum bowl were standardised using 13 g of millet flour, 9 g of binder, 4 g of rose or hibiscus flower powder, and 1 ml of refined sunflower oil. Water (21–26 ml) was added to form a thick batter, which was poured into a four-inch closed bowl-shaped mold and baked at 90°C for 8 – 12 minutes. Finalized bowl variants of the flower-enriched unprocessed and roasted pearl millet and sorghum bowl were named PMURB, PMUHB, PMRRB, PMRHB, and SURB, SUHB, SRRB, SRHB, as depicted in Plate 15 and 16.

Flower-enriched unprocessed and roasted pearl millet and sorghum katori were standardised by mixing 10 g of millet flour, four grams of binder, three grams of shade-dried rose or hibiscus flower powder along with 1 ml of refined sunflower oil. 17 to 22 ml of water was added to make a thick batter and poured into a unique closed four-inch circular-shaped mold and baked at 90°C for 9 to 15 minutes similar to standardised pearl millet and sorghum katori in Phase II. The finalized rose and hibiscus flower-enriched unprocessed and roasted pearl millet and sorghum katori were named PMURK, PMUHK, PMRRK, PMRHK, SURK, SUHK, SRRK, and SRHK respectively, and as shown in Plate 17 and 18.

Flower-enriched unprocessed and roasted pearl millet and sorghum spoon, the thick batter consists of 4 g of millet flour, 3.5 g of binder, 1.5 g of rose or hibiscus flower powder, and 0.5 ml of sunflower oil. Water (8 to 10 ml) was added, and the batter was poured into a 13.5 cm spoon-shaped mold and baked at 70°C for 8–12 minutes. Finalized spoon variants were named PMURS, PMUHS, PMRRS, PMRHS for pearl millet, SURS, SUHS, SRRS, and SRHS for sorghum counterparts, depicted in Plate 19 and 20.

Flower-enriched unprocessed and roasted pearl millet and sorghum plate formulation included 28 g of millet flour, 18 g of binder, 8 g of rose or hibiscus flower powder, and 1.5 ml of sunflower oil. 45–53 ml of water was used to prepare a thick batter, which was poured into a six-inch circular-shaped mold and baked at 90°C for 12–18 minutes. Finalized plate products were named PMURP, PMUHP, PMRRP, PMRHP, SURP, SUHP, SRRP, and SRHP, shown in Plate 21 and 22.

The inclusion of the selected flower powder was done to enhance the nutritional and functional properties of the tableware and also to improve the structural integrity in cup, bowl, katori, spoon, and plate that was standardised from unprocessed and roasted pearl millet and sorghum.

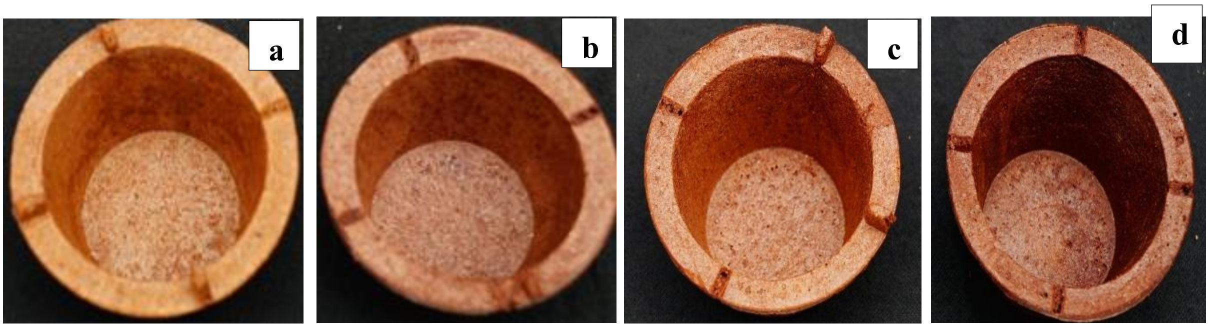


Plate – 13

Flower-Enriched Pearl millet Cup, a. PMURC, b. PMUHC, c. PMRRC, d. PMRHC

(PMURC-Unprocessed Pearl millet Rose-enriched Cup, PMUHC-Unprocessed Pearl millet Hibiscus-enriched Cup, PMRRC-Roasted Pearl millet Rose-enriched Cup, PMRHC-Roasted Pearl millet Hibiscus-enriched Cup)

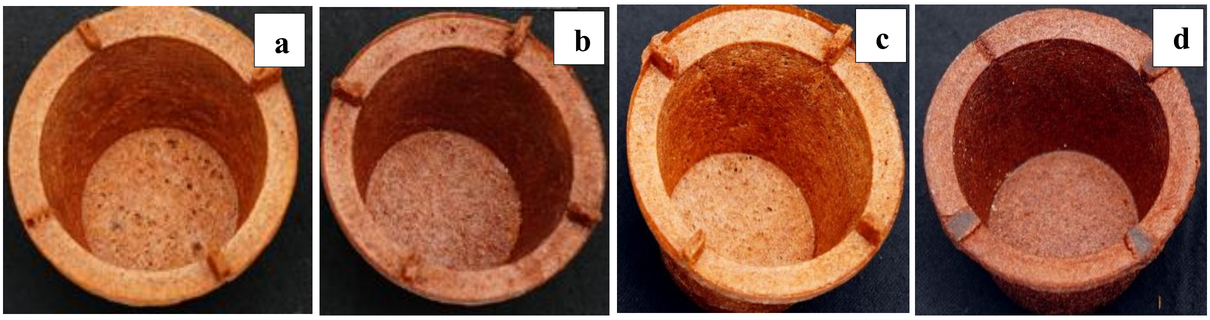


Plate – 14

Flower-Enriched Sorghum Cup, a. SURC, b. SUHC, c. SRRC, d. SRHC

(SURC-Unprocessed Sorghum Rose-enriched Cup, SUHC-Unprocessed Sorghum Hibiscus-enriched Cup, SRRC-Roasted Sorghum Rose-enriched Cup, SRHC-Roasted Sorghum Hibiscus-enriched Cup)

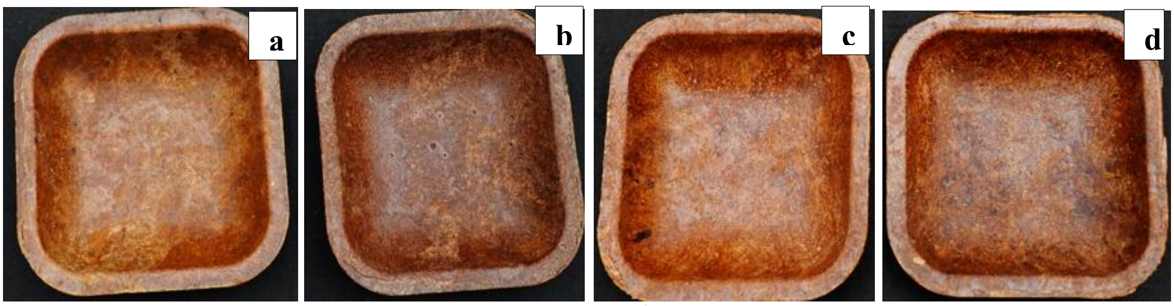


Plate – 15

Flower-Enriched Pearl millet Bowl, a. PMURB, b. PMUHB, c. PMRRB, d. PMRHB

(PMURB-Unprocessed Pearl millet Rose-enriched Bowl, PMUHB-Unprocessed Pearl millet Hibiscus-enriched Bowl, PMRRB-Roasted Pearl millet Rose-enriched Bowl, PMRHB-Roasted Pearl millet Hibiscus-enriched Bowl)

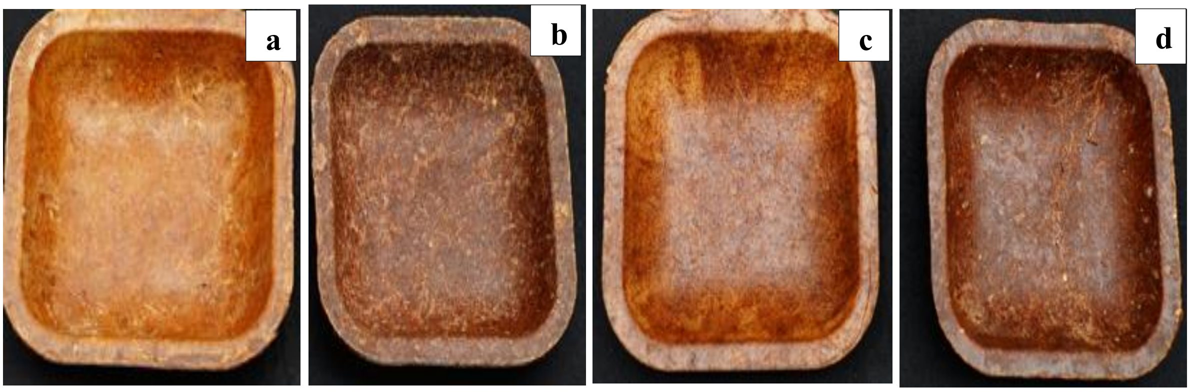


Plate – 16

Flower-Enriched Sorghum Bowl, a. SURB, b. SUHB, c. SRRB, d. SRHB

(SURB-Unprocessed Sorghum Rose-enriched Bowl, SUHB-Unprocessed Sorghum Hibiscus enriched Bowl, SRRB-Roasted Sorghum Rose-enriched Bowl, SRHB-Roasted Sorghum Hibiscus-enriched Bowl)

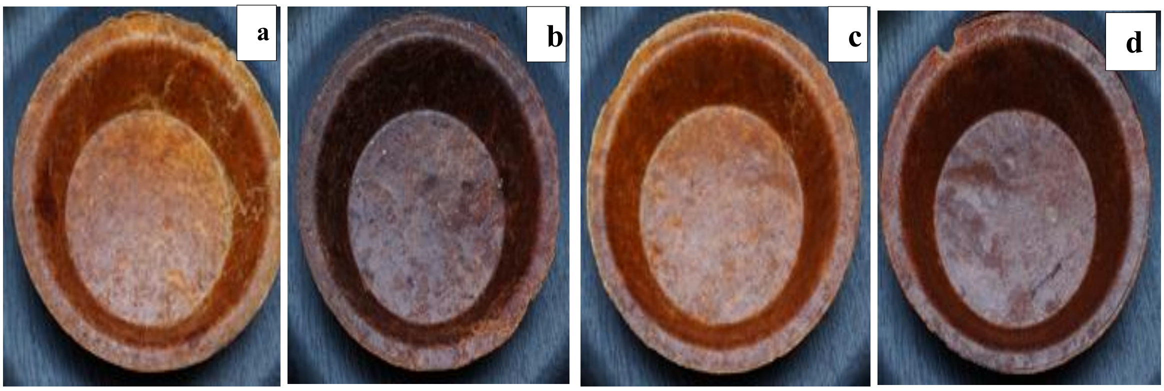


Plate – 17

Flower-Enriched Pearl millet Katori, a. PMURK, b. PMUHK, c. PMRRK, d. PMRHK

(PMURK-Unprocessed Pearl millet Rose-enriched Katori, PMUHK-Unprocessed Pearl millet Hibiscus-enriched Katori, PMRRK-Roasted Pearl millet Rose-enriched Katori, PMRHK-Roasted Pearl millet Hibiscus-enriched Katori)

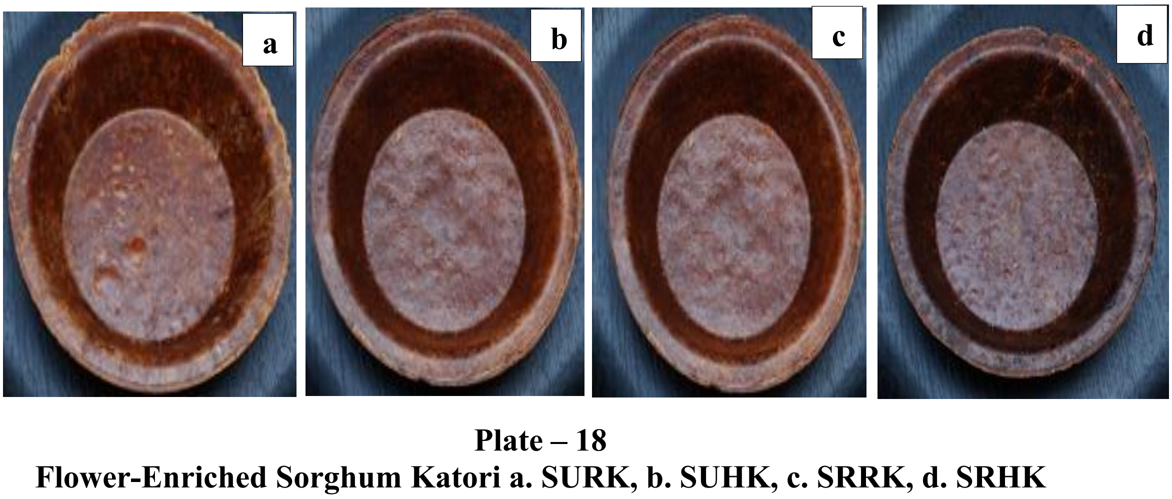


Plate – 18

Flower-Enriched Sorghum Katori a. SURK, b. SUHK, c. SRRK, d. SRHK

(SURK-Unprocessed Sorghum Rose-enriched Katori, SUHK-Unprocessed Sorghum Hibiscus enriched Katori, SRRK-Roasted Sorghum Rose-enriched Katori, SRHK-Roasted Sorghum Hibiscus-enriched Katori)

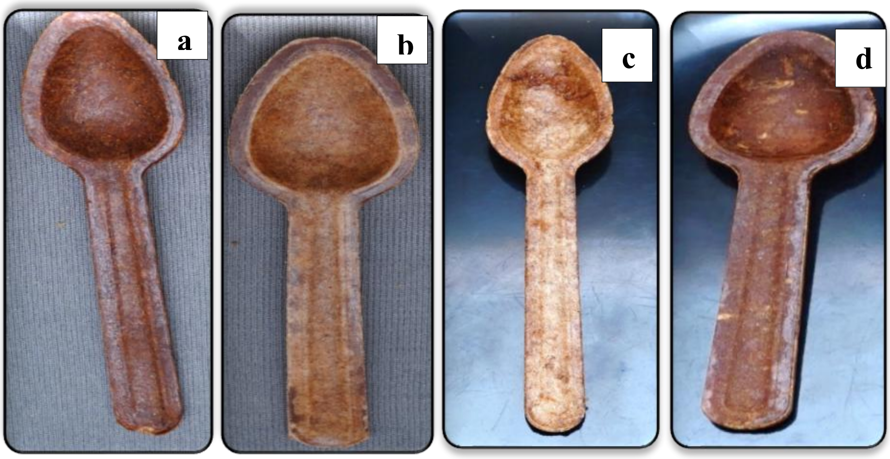


Plate – 19

Flower-Enriched Pearl millet Spoon, a. PMURS, b. PMUHS, c. PMRRS, d. PMRHS

(PMURS-Unprocessed Pearl millet Rose-enriched Spoon, PMUHS-Unprocessed Pearl millet Hibiscus-enriched Spoon, PMRRS-Roasted Pearl millet Rose-enriched Spoon, PMRHS-Roasted Pearl millet Hibiscus-enriched Spoon)

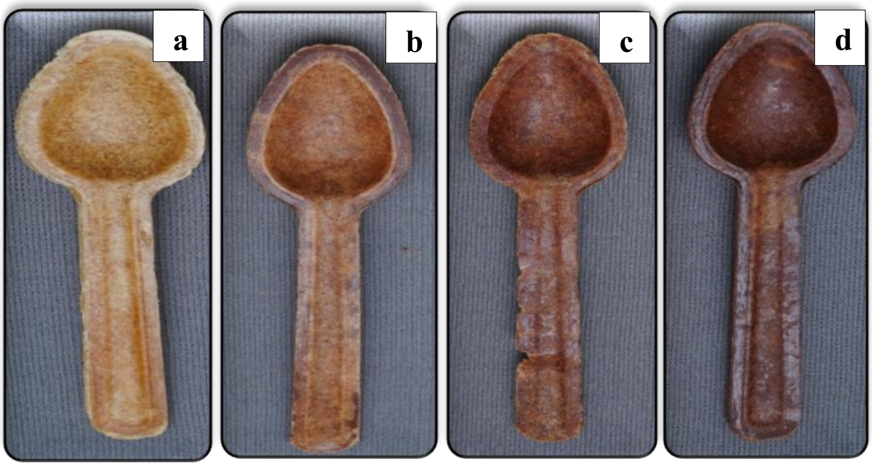


Plate – 20

Flower-Enriched Sorghum Spoon, a. SURS, b. SUHS, c. SRRS, d. SRHS

SURS-Unprocessed Sorghum Rose-enriched Spoon, SUHS-Unprocessed Sorghum Hibiscus-enriched Spoon, SRRS-Roasted Sorghum Rose-enriched Spoon, SRHS-Roasted Sorghum Hibiscus-enriched Spoon)

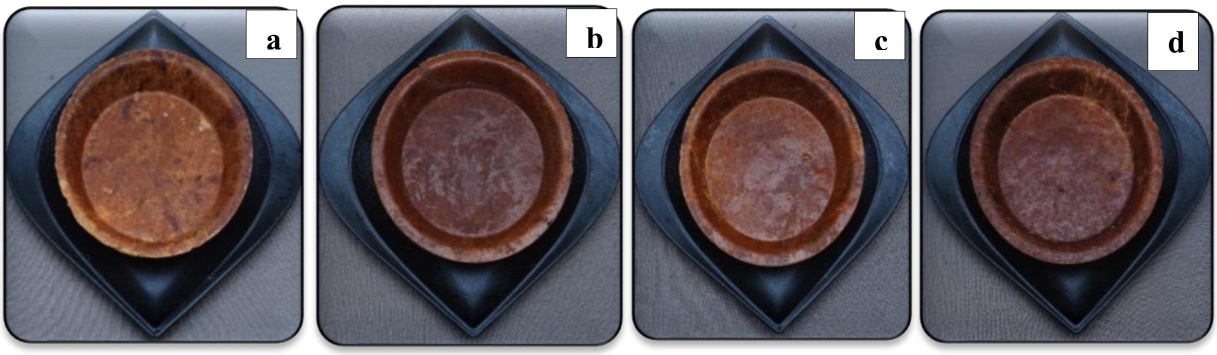


Plate – 21

Flower-Enriched Pearl millet Plate, a. PMURP, b. PMUHP, c. PMRRP, d. PMRHP

(PMURP-Unprocessed Pearl millet Rose-enriched Plate, PMUHP-Unprocessed Pearl millet Hibiscus-enriched Plate, PMRRP-Roasted Pearl millet Rose-enriched Plate, PMRHP-Roasted Pearl millet Hibiscus-enriched Plate)

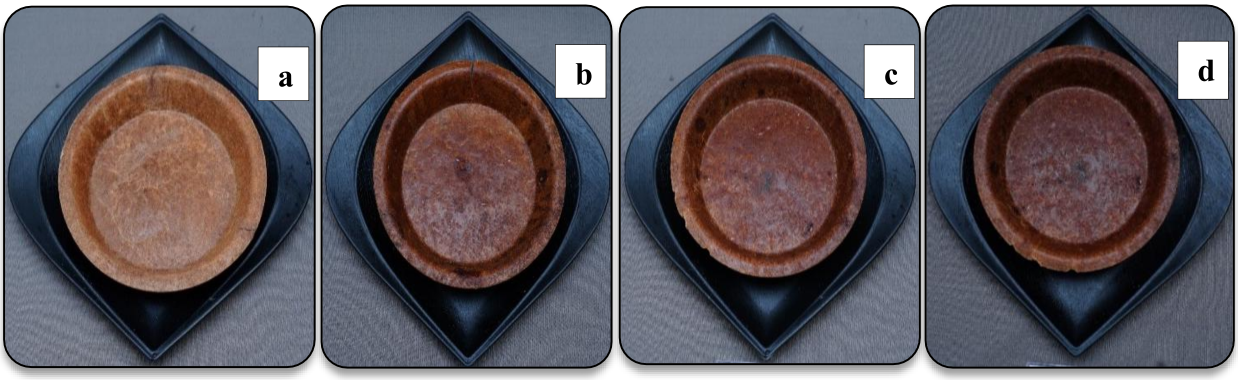


Plate – 22
Flower-Enriched Sorghum Plate, a. SURP, b. SUHP, c. SRRP, d. SRHP
SURP-Unprocessed Sorghum Rose-enriched Plate, SUHP-Unprocessed Sorghum Hibiscus-enriched Plate, SRRP-Roasted Sorghum Rose-enriched Plate, SRHP-Roasted Sorghum Hibiscus-enriched Plate)

3.4.2 Characterisation of Flower-Enriched Millet Tableware

3.4.2.1 Proximate and Nutrient Analysis of Flower-Enriched Millet Tableware

Moisture, ash, protein, fat, and crude fibre were quantified using standard AOAC procedures. Carbohydrates were quantified using the anthrone method whereas the vitamin C was measured using the ascorbic acid volumetric method, whereas, iron, calcium, and phosphorus were determined using the Folin-Ciocalteu reagent method and titration against $KMnO_4$ (AOAC standards; Sadasivam & Manickam, 2023) (Appendix VII).

3.4.2.2 Antioxidant activity of Flower-Enriched Millet Tableware

The antioxidant activity of the flower-enriched millet tableware was assessed using the DPPH (1,1-diphenyl-2-picrylhydrazyl) free radical scavenging assay, with ascorbic acid as the standard. The IC_{50} value, which represents the concentration needed to inhibit 50 per cent of free radicals, that was determined through linear regression. Antioxidant activity was classified based on IC_{50} values, the strong activity for values were between 10 and 50 mg/mL, moderate activity for 50 to 100 mg/mL, and weak activity for values exceeding 100 mg/mL (Appendix X).

3.4.2.3 Optical Property of Flower-Enriched Millet Tableware

The optical property of the standardised flower powder-enriched millet tableware was analysed using a Laboratory Scale Food Colourimeter by measuring L* (lightness, 0 denotes black and 100 denotes white), a* (red-green scale), and b* (yellow-blue scale) values. It assessed the visual appeal of the tableware, which was a crucial factor for consumer acceptance. ΔE values were the measure of overall colour differences, indicating the chromatic shift due to the incorporation of edible flower (Sunil *et al.,* 2024).

3.4.2.4 Sensory Evaluation of Flower-Enriched Millet Tableware

Sensory evaluation was conducted to analyse the acceptability and consumer preference for the standardised flower powder-enriched millet tableware. A panel of 30 semi-trained members evaluated the sensory qualities of the flower-enriched millet tableware, including shape or appearance, colour, taste, flavour, texture (crispiness), and overall acceptance using a nine-point hedonic scale. Each attribute was rated from 1 (dislike extremely) to 9 (like extremely). The sensory evaluation provided critical insights into the consumer perception of the product, helping to refine the formulations for improved sensory quality (Hnin *et al.,* 2021) and the nine-point rating scale is given in Appendix VIII.

3.4.2.5 Functional Properties of Flower-Enriched Millet Tableware

i. Fourier Transform Infrared Spectroscopy (FTIR)

The structural composition of standardised flower-enriched millet tableware was determined using FTIR analysis and peaks were recorded between 4000 cm^{-1} and 450 cm^{-1} wavenumbers. It identifies the key changes in functional groups, molecular structure and chemical bonds after combining the millet, binder, and flower powders in the Flower-Enriched pearl millet and sorghum tableware (Guine, 2022; Sharanagat *et al.,* 2019).

ii. Thermo Gravimetric Analysis (TGA)

Thermo Gravimetric Analysis (TGA) was used to assess the thermal stability of standardised flower powder-enriched millet tableware. Upto 4 to 12 mg of Flower-Enriched pearl millet and sorghum tableware was taken and heated from 20°C to 1000°C, with a temperature increase of 20°C per minute. It helps in understanding the temperature responds to high temperatures, providing insights into the degradation behaviour and thermal resistance of the tableware under various conditions (Guine, 2022).

iii. Exposure Test

The standardised flower-enriched millet tableware was subjected to three different temperature conditions such as ambient temperature (about 29°C), hot temperature (about 80°C), and cold temperature (4°C). The temperatures were selected depending on typical serving conditions, such as serving cold sweets or hot food and it was kept in the fixed temperature setting for an hour (Nehra *et al*., 2024).

iv. Water Absorption Rate

The water absorption rate of the standardised flower-enriched pearl millet and sorghum tableware was assessed to determine the quantity of water absorbed by the tableware at ambient, hot and cold foods and beverages. The amount of water absorbed during a 60 minutes exposure to liquids was measured at, ambient (30°C), hot (80°C), and cold (4°C) temperatures. For cup, 45 ml of water at ambient, hot temperature and ice cubes were poured for 60 minutes and change in weight was measured (Nehra *et al.,* 2024). For bowl, katori, spoon and plate, a known weight of respective tableware was taken and immersed in ambient, hot, and cold temperature for 60 minutes. The quantity of water absorbed was measured by weighting at 10 minutes interval (Rajendran *et al*., 2020). The initial weight of the flower tableware (W_1) was recorded, and it was then exposed to the respective liquid for 60 minutes or until the first leakage appeared. After exposure, surface water was carefully removed using tissue paper, and the final weight (W_2) was measured to ensure the accurate evaluation of water absorption at different serving conditions (Nehra *et al.,* 2024; Habla *et al.,* 2023). The percentage of water absorption of the Flower-Enriched pearl millet and sorghum tableware was calculated using the formula:

$$\text{Percentage of Water Absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100$$

Where W_1 is the initial weight, and W_2 is the final weight after absorption.

3.4.2.6 Texture Analysis of Flower-Enriched Millet Tableware

The texture analysis of the developed flower-enriched millet tableware was analysed to assess its durability and resilience under various conditions.

i. Texture Analysis

A Shimadzu EZ-XS texture analyzer was used to measure the hardness and elasticity of the standardised flower-enriched millet tableware. The flower-enriched millet tableware was compressed at 1 mm per second until a predefined force or deformation was reached. The hardness force referred to the maximum force needed to compress the flower-enriched millet tableware, while elastic force measures its ability to recover its original shape after deformation. It provides crucial data on the strength and resilience of the tableware, indicating its suitability for practical use (Guine, 2022).

ii. Drop Test

The drop test of the standardised flower-enriched millet tableware was measured by dropping it from heights ranging from 10 cm to 150 cm onto a uniform hard surface. Tableware without any cracks or deformations was taken for the analysis. This test simulates accidental drops during handling or serving, providing data on the product's durability and resistance to breaking or cracking (Grzelczyk *et al.,* 2022; Buxoo & Jeetah, 2020).

The best variation from unprocessed and roasted millet tableware was selected from Phase II. In Phase III, the four edible flowers were selected and characterised to enrich the millet tableware. In Phase IV, the standardised millet tableware variation from Phase II and best edible flower from Phase III was selected to formulate flower-enriched millet tableware. Then, the characterisation of edible flower-enriched pearl millet and sorghum tableware (unprocessed and roasted) were done by, analysing the nutrient content, antioxidant property, optical property, functional properties and texture analysis to replace single use cutleries in food service sector. The characterisation including shelf life, toxicity and cost of the millet tableware was analysed further.

PHASE - V

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

3.5.1 Shelf-life Analysis of Millet Tableware

Total plate or colony count, change in weight, and moisture content of the millet tableware was measured for 120 days in 30 days interval.

i. Microbial Load of Millet Tableware

The microbial load of the standardised sorghum and pearl millet tableware was monitored on the 30th, 60th, 90th and 120th day using a modified procedure described by Makawi *et al.* (2019). One gram of flower-enriched millet tableware was mixed with 9 ml sterile peptone water (0.1%), followed by serial dilutions (10^{-1} to 10^{-5}). Then the homogenate was plated on count agar and incubated at 35°C for 48 hours. Colonies were counted to assess microbial safety (Appendix VI).

ii. Change in weight of Millet Tableware

Weight change was conducted on standardised pearl millet and sorghum tableware over a 120 days period in the interval of 40 days (on 0th, 40th, 80th and 120th days) that was stored in air-tight containers. Weight fluctuations serve as key indicators to measure the atmospheric moisture absorption of the standardised pearl millet and sorghum tableware, offering valuable data on its stability. It also helps to evaluate the shelf life and overall performance of the edible tableware.

3.5.2 Toxicity Evaluation of Millet Tableware

In-vivo Brine Shrimp Lethality Assay cytotoxicity studies for the standardised edible pearl millet and sorghum tableware were done for the toxicity study.

i. Brine Shrimp Lethality Assay of Millet Tableware

Brine shrimp lethality assay of standardised pearl millet and sorghum tableware was done at five different concentrations (100, 250, 500, 1000, and 1500 mg/ml) against brine solution as blank and potassium dichromate as positive control for 24 hours and the lethality was observed at 1, 2, 4, 6, and 24 hours. 30 brine shrimps (after 24 hours of hatching) were introduced in a beaker containing, 25 ml of brine solution with millet tableware to observe the mortality and percentage of lethality calculated (Itam *et al.,* 2021) and the procedure in Appendix XI.

$$\text{Percentage of Mortality (\%)} = \frac{\text{Number of brine shrimp mortal}}{\text{Number of brine shrimp introduced}} \times 100$$

3.5.3 Biodegradability Analysis of Millet Tableware

i. Soil Burial Test of Millet Tableware

Wet top soil was collected and a piece of tableware weighing 2 g was buried in a beaker containing the soil at a depth of 10 cm and tested till complete degradation. The millet tableware was removed from the soil, brushed the excess soil particles, and dried in a hot air oven at 70˚C for 2 hours and the weight was measured. It was done to remove the excess moisture and dirt. The process was done on the third, sixth, and ninth day (Grzelczyk *et al.,* 2022). The weight change and percentage of degradation was measured as follows,

$$\text{Percentage of Degradation (\%)} = \frac{\text{Final weight of the millet tableware taken} - \text{Initial weight of the millet tableware taken}}{\text{Initial weight of the millet tableware taken}} \times 100$$

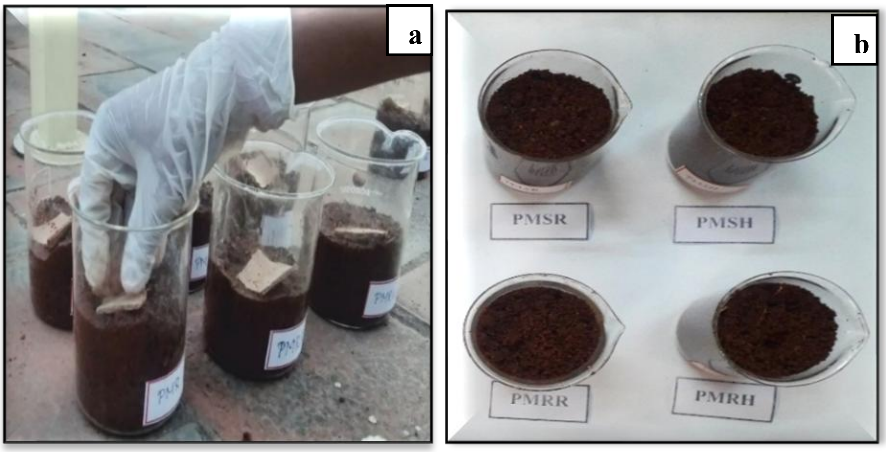


Plate – 23
Soil Burial Test of Millet Tableware, a. keeping sample for soil burial test, b. filling of soil in the beaker upto 10 cm

3.5.4 Feasibility Analysis of Millet Tableware

i. Cost Calculation of Millet Tableware

The estimated cost of the pearl millet and sorghum tableware was calculated based on the expenses made for direct materials. It includes, initial procurement of the millet, edible flower, and transportation, processing charges, manpower cost, and overhead cost including indirect labour, indirect material, and others. The cost of the product was calculated as follows,

Product Cost = Direct Labour + Direct Material + Overheads*

Product cost per unit = Total product cost / Number of units produced

*Indirect labour + Indirect material + Others

3.6 STATISTICAL ANALYSIS OF MILLET TABLEWARE

One-way ANOVA was done in IBM SPSS statistics software version 25 for the present study to statistically assess differences among unprocessed, germinated, roasted, and functionally enhanced pearl millet and sorghum tableware for various parameters, including optical properties, nutrient profile, and other functional attributes. By using one-way ANOVA, the study could effectively examine the impact of germination and roasting that altered the qualities and properties of sorghum and pearl millet, ultimately influencing its suitability and performance as sustainable, functional tableware materials as well as the significance of millet tableware after processing and flower powder enrichment at significant level of $p>0.05$ with 95 per cent confidence level. The graphs and figures in the present study were plotted using Origin software, version 2024 (Origin Pro Learning Edition) and Microsoft Excel.