Development of Millet-Based Edible Cutlery Fortified with Basella alba (Malabar Spinach) Fruit Powder

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Abstract- The objective of this study is to formulate millet-based edible cutlery enriched with Basella alba (Malabar spinach) fruit powder, utilizing Response Surface Methodology (RSM) to assess and optimize the formulation parameters. Different ingredient ratios were trialed to develop a product with enhanced nutritional and functional properties. Among six experimental formulations, Trial 3 exhibited superior results with a carbohydrate content of 66.26 g/100 g, protein content of 8.42 g/100 g, total sugar content of 1.35%, and dietary fiber of 12.06%. Texture profile analysis revealed favorable mechanical attributes, including springiness (0.65), gumminess (143.15), resilience (0.068), cohesiveness (0.199) and fracturability (1513.29). The moisture content was recorded at 2.26%, supporting the product's structural stability. Water absorption tests showed the cutlery maintained integrity for 25–40 minutes across different liquid foods. Microbial analysis confirmed the hygienic quality with a total plate count of <10 CFU/g. Sensory evaluation and accelerated shelf-life analysis indicated product stability and acceptability for up to 15 days. These findings demonstrate the feasibility of developing nutrient-rich, structurally robust edible cutlery through strategic ingredient optimization and incorporation of functional plant-based fortificants.

Keywords: Malabar spinach fruit, Response Surface Methodology, Product stability, Nutrient-rich, Mechanical attributes

I. INTRODUCTION

With increasing awareness of the detrimental effects of plastic pollution, there has been a global push toward developing alternatives to traditional plastic products. Single-use plastic items, particularly disposable cutlery, contribute heavily to the growing burden of environmental degradation, affecting both terrestrial and marine ecosystems. This urgent environmental concern has motivated industries, researchers, and policymakers to explore sustainable materials and innovative product designs that offer viable substitutes for plastic[1].

One such innovation is edible cutlery, which serves the dual purpose of utility and environmental stewardship[22]. These consumable cutlery are not only capable of reducing plastic waste but also add nutritional and aesthetic value to the food experience when made from natural ingredients.

Among the promising ingredients for edible cutlery are millets—a group of small-seeded grains known for their high nutritional value and resilience to harsh agricultural conditions. These grains, including varieties such as finger millet, pearl millet, sorghum and foxtail millet, are rich in fiber, essential micronutrients and bioactive compounds. Their gluten-free nature and functional versatility make them ideal candidates for incorporation into food-grade materials like edible utensils. This approach not only contributes to environmental conservation but also addresses consumer health through enhanced dietary benefits[2].

Additionally, Malabar spinach (*Basella alba*), particularly its fruit, presents an innovative way to boost both the nutritional and sensory qualities of edible products. Although traditionally underutilized, the fruit is packed with valuable phytochemicals, including antioxidants and natural pigments such as betalains. These compounds deliver health benefits such as improved immunity and reduced oxidative stress[3].

A. Edible Packaging and Environmental Sustainability

The concept of edible packaging has emerged as a sustainable solution to the environmental problems caused by conventional food packaging waste[24]. This field focuses on utilizing natural, biodegradable resources such as starches, proteins, lipids and polysaccharides to create packaging materials that are safe for consumption and friendly to the environment. As an alternative to synthetic polymers, these edible materials can degrade naturally without leaving behind harmful residues.

Recent advancements in edible packaging technologies have demonstrated that utensils made from cereals and plant-based biopolymers can closely mimic and sometimes even outperform, conventional plastic cutlery in terms of durability, water resistance and heat tolerance. Moreover, edible packaging eliminates post-consumer waste, aligns with zero-waste goals and promotes circular economy principles by integrating food and packaging systems into a single consumable product[4].

B. Nutritional and Functional Benefits of Millets

Millets are rapidly gaining popularity as a key ingredient in health-oriented food innovations due to their exceptional nutritional profile and environmental adaptability. These ancient grains are naturally gluten-free, making them suitable for individuals with gluten intolerance or celiac disease. They are abundant in dietary fiber, protein, essential amino acids, vitamins (such as B-complex) , minerals including magnesium, calcium and iron.

Functionally, millets contribute to improved texture, binding properties and shelf life when used in food processing applications. They have been successfully utilized in the formulation of bakery goods, snacks, weaning foods and now, edible packaging solutions[23]. In the context of edible cutlery, their high gelatinization and water absorption capacity provide structural integrity, while their nutritional density enhances the overall value of the product. Incorporating different millet varieties enables customization based on the desired taste, appearance and nutritional content of the final product[5].

C. Functional Properties of Malabar Spinach Fruit

The fruit of Malabar spinach (*Basella alba*), though often discarded or ignored, offers significant potential as a natural functional ingredient in food applications. These compounds are known for their potent antioxidant properties, which help combat oxidative stress and may contribute to the prevention of chronic diseases.

In addition to its nutritional properties, the deep violet-red pigmentation of Malabar spinach fruit can be used as a natural food colorant, reducing reliance on synthetic dyes[25]. Its incorporation into food products not only enhances their visual appeal but also supports the functional food movement, which aims to deliver health benefits through everyday consumption.

Utilizing this underexploited plant component in edible cutlery production serves multiple purposes: it minimizes agricultural waste, improves the nutritive content of the final product, and promotes the use of natural additives in food processing[6].

D. Use of Response Surface Methodology (RSM) in Food Product Development

Response Surface Methodology (RSM) is a powerful statistical and experimental tool widely applied in the optimization of food formulations. It allows researchers to analyze the relationships between multiple independent variables and target responses, such as texture, taste, shelf life, or structural integrity in edible products.

In the development of edible cutlery, RSM plays a critical role in fine-tuning the ingredient ratios, such as the proportion of millet flour, binding agents, water and color additives, to achieve desired product characteristics[26]. This technique helps identify the optimal conditions for processing parameters like baking temperature, drying time and moisture content, thereby reducing the reliance on costly and time-consuming trial-and-error methods.

By applying RSM, food technologists can efficiently evaluate interactions between ingredients, assess the statistical significance of each factor and determine the best combination that meets functional, sensory and nutritional goals. Its application enhances the scientific rigor and commercial viability of sustainable food product innovations[7].

II. MATERIALS AND METHODS

A. Materials

The ingredients used in the formulation of millet-based edible cutlery—wheat flour, sorghum flour, maida (refined wheat flour), Malabar spinach fruit powder, sugar, and water—each contribute distinct functional and nutritional benefits. Wheat flour provides elasticity and strength due to its gluten content, while sorghum flour enhances the product's nutritional value with dietary fiber, antioxidants, and minerals like iron and magnesium[16]. Maida plays a key role in providing a smooth texture and improving firmness, making it easier to mold and bake the dough. Malabar spinach fruit powder, rich in antioxidants and essential vitamins, boosts the cutlery's nutritional profile and offers potential antimicrobial properties. Sugar not only enhances flavor and texture but also improves firmness during baking, contributing to the product's durability[18]. Together, these ingredients support the creation of a functional, nutritious, and eco-friendly alternative to traditional plastic cutlery[13].

B. Analytical Methods

1) Nutritional Analysis:

A. Total Carbohydrate Test:

The carbohydrate test on edible cutlery, sample, was collected. The material should be ground or homogenized into a fine powder to ensure consistent analysis. Next, using an appropriate solvent, like water or ethanol, to remove the sample's carbohydrates. Using enzymes or acid hydrolysis to hydrolyze the carbs into simple sugars after extraction. Techniques like gas chromatography (GC) and high-performance liquid chromatography (HPLC) can be used to quantify the resultant sugars[22].

B. Protein Test :

The Kjeldahl method is typically employed to analyze the protein content in edible cutlery by determining the nitrogen concentration in the sample and calculating the protein content using a standard conversion factor.. For this analysis, around 0.5 to 1 g of the powdered sample is accurately weighed and digested with concentrated sulfuric acid in the presence of a catalyst to convert nitrogen into ammonium sulfate[23]. To ascertain the nitrogen content, the digest is subsequently neutralized, distilled and titrated. The formula used to calculate protein is:

$$\%Protein = \%\ Nitrogen \times Conversion\ factor\ (\text{usually } 6.25)$$

C. Total Sugar Test:

Its ease and sensitivity, the phenol-sulfuric acid method is frequently used to estimate the total sugars in edible cutlery. In this method, approximately 100 mg (0.1 g) of the finely ground edible cutlery sample is taken and hydrolyzed using distilled water or dilute acid to release the sugars. An aliquot of the extract (typically 1 mL) is then reacted with 5% phenol and concentrated sulfuric acid, producing a colored complex measurable at 490 nm using a spectrophotometer[24]. A glucose standard curve is prepared and the sugar content in the sample is calculated using the following formula:

$$\text{Total Sugar (\%)} = \frac{\text{(Absorbance of sample / Absorbance of standard)} \times \text{Concentration of standard} \times \text{Dilution Factor} \times 100}{\text{Weight of sample (mg)}}$$

D. Dietary Fiber:

The AOAC 991.43 enzymatic-gravimetric method, which mimics human digestion, can be used to measure the amount of dietary fiber in edible cutlery. About 1 gram of the dried, pulverized sample is used in this procedure. Heat-stable α-amylase, protease and amyloglucosidase are used in succession to break down the sample's protein and starch in order to simulate gastrointestinal digestion. .The actual fiber content is calculated by subtracting the residue's ash and protein contents[25]. The formula is as follows:

$$\text{\% Dietary Fiber} = \frac{\text{(Residue Weight} - \text{Protein} - \text{Ash)}}{\text{Sample Weight}} \times 100$$

2) Texture Analysis

A. Springiness

The capacity of edible cutlery to regain its original shape after being crushed is measured by a textural metric called springiness. A texture analyzer and the Texture Profile Analysis (TPA) approach are used to test it. In order to simulate biting, a probe is used to squeeze the cutlery sample twice. The distance that the sample returns between the first and second compressions is known as springiness [28]. In order to preserve structure prior to ingestion, edible cutlery with a greater springiness rating is more elastic and less crumbly.

B. Gumminess

Gumminess is a texture parameter used to describe the energy required to disintegrate a semi-solid food product and it is particularly relevant when testing edible cutlery made from dough-based ingredients. It is measured using a Texture Profile Analyzer (TPA) through a double compression test, which mimics the action of chewing. For edible cutlery, this helps determine whether the product is too tough or just firm enough to be functional yet chewable. A balanced gumminess ensures the cutlery maintains shape during use but can still be consumed without excessive effort[30].

C. Resilience

Resilience in edible cutlery is a texture parameter that measures the product's ability to recover its original shape quickly after a compressive force is removed. To assess its robustness, the cutlery sample undergoes a controlled compression cycle during Texture Profile Analysis (TPA) using a texture analyzer [29].

D. Cohesiveness

Cohesiveness in edible cutlery refers to the internal strength of its structure how well it holds together during chewing or compression. It is measured using a Texture Profile Analysis (TPA) test on a texture analyzer, which compresses the sample twice to simulate biting . A higher cohesiveness value indicates a more uniform and resilient structure, while a lower value suggests the cutlery is more likely to crumble or break apart. This parameter helps assess the integrity and quality of the edible cutlery during handling and consumption[29].

E. Fracturability

Fracturability, also known as brittleness or break force, is a key texture attribute tested in edible cutlery to assess how easily it breaks under pressure. It is measured using a Texture Analyzer fitted with a blade or three-point bend rig. A sample of the cutlery is placed on the testing platform and force is applied until it fractures. The peak force at the texturing curve's first significant break is the fracturability value. This test helps determine the strength and crispness of the edible cutlery, ensuring it is sturdy enough for use yet easy to bite or chew when consumed[32].

3) Moisture Content Test

The moisture content test in edible cutlery is crucial for maintaining its quality, texture and shelf life. Generally, a process is used for determining the quantity of water in a substance, usually a solid material. For this, take an edible cutlery sample, weigh it. Placed it in a hot air oven and set the temperature to 105 ◦C, then check its weight until the sample's weight stays constant[34].

4) Water Absorption Test

To perform the water absorption test on millet-based edible cutlery, begin by accurately weighing the initial dry sample of the cutlery. Immerse the sample completely in a beaker containing a known volume of distilled water at room temperature. Allow it to soak for a specific duration, typically ranging from 30 minutes to 2 hours, depending on the study parameters. After the designated time, remove the cutlery, gently blot the surface with filter paper to eliminate excess water and immediately weigh the sample[36]. This test helps in determining the product's resistance to moisture and its structural integrity when in contact with liquids, which is crucial for assessing the usability of millet-based edible cutlery in real-life applications.

5) Total Plate Count

The Total Plate Count (TPC) test is conducted to assess the microbial load in edible cutlery, indicating its safety and hygiene. Serial dilutions are then prepared, and 1 mL of each dilution is poured onto Plate Count Agar (PCA) in sterile Petri dishes. After incubating at 35–37°C for 24–48 hours, plates showing 30 to 300 colonies are selected for counting. The total plate count is subsequently determined using the following formula

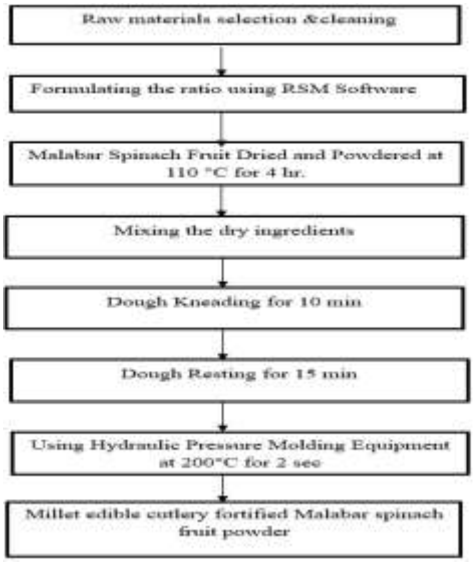
$$\text{TPC (CFU/g)} = \frac{\text{Number of Colonies} \times \text{Dilution Factor}}{\text{Volume Plated (in mL)}}$$

This test helps ensure that the edible cutlery meets microbiological safety standards[39].

6) Shelf Life Test

Shelf-life testing of edible cutlery involves monitoring its physical, microbial and sensory stability over time under controlled storage conditions[40]. Samples are stored at room temperature or accelerated conditions (e.g., 35–40°C and 75% relative humidity) and regularly observed for changes in texture, color, odor, moisture content, and microbial growth. The cutlery is also checked for signs of spoilage like mold, cracking, or softening. Testing is typically done at intervals such as 0, 3,5,11 and 15 days to assess durability and safety. This helps determine how long the edible cutlery remains safe and usable without compromising quality[38].

C. Flowchart: Development Process of Millet-Based Edible Cutlery Fortified with Malabar Spinach Fruit Powder



1) Raw Material Selection & Cleaning:

The selected components that are used in making the edible cutlery are wheat flour, Sorghum flour , Maida flour , Malabar spinach fruit powder and sugar was selectively produced from the markets. For wheat , maida and sorghum flour, cleaning involves removing impurities like dust, stones by sieves. Malabar spinach fruit is manually cleaned by washing to remove dirt and sorted by ripeness to ensure quality and uniformity before use [14] .

Fig 1: Raw Materials

2) Formulating Using RSM Software:

Each ingredient was meticulously measured with the help of RSM to maintain consistency and reproducibility. Accurate measurement was essential to ensure the uniformity of the mixture and the structural integrity of the edible cutlery[15]. The formulation includes wheat flour ranging from 50 to 100 grams and similar range with the sorghum flour. Malabar spinach fruit powder is incorporated between 10 to 25 grams. Sugar is added in the range of 15 to 25 grams, while maida is included between 20 to 30 grams. Water is required in quantities ranging from 50 to 70 grams.

Table 1: Different ratios using the RSM software

SI NO	**WHEAT FLOUR (g) Upper limit – 100 Lower limit – 50**	**SORGHUM FLOUR(g) Upper limit – 100 Lower limit – 50**	**MALABAR SPINACH SEEDS POWDER(g) Upper limit – 25 Lower limit – 10**	**SUGAR Upper limit –25 Lower limit – 15**	**MAIDA Upper limit – 30 Lower limit –20**	**WATER Upper limit – 70 Lower limit – 50**
1	50	75	15	20	25	65
2	50	50	20	18	30	60
3	75	60	23	21	20	50
4	60	75	10	19	25	55
5	75	55	18	20	30	60
6	70	85	18	23	20	55

3) Malabar Spinach Fruit Dried And Powdered :

To get rid of any dirt or adulterants, thoroughly wash the fruits under running water. Arrange the fruits in a single layer on a drying rack to guarantee that they are exposed to heat. At 110 °C, let it dry for four hours. At this time and temperature, grease is effective moisture without nutritional decline. To avoid burning or overheating, check periodically. When grinding, cooling helps prevent moisture condensation. Pulverize them until they have the consistency of fine cream. To produce a harmonious cream, coarser patches are separated using a fine fiber screen. The finished cream should be kept in an airtight, dry and clean vessel. To save quality and shelf life, store it in a cool, dark position. It's a healthy way to use Malabar spinach fruits[16].

Fig 2 : Before And After Drying Of Malabar Spinach Fruit

4*)* Mixing The Dry Ingredients :

First, precisely measure the necessary quantities of each component for making the dry blend. Combine the wheat flour, maida and sorghum. These factors give structure, agreeableness, and nutritive value, and they constitute the foundation of the expression, also combining the dry admixture with the powdered Malabar spinach fruit. In addition to perfecting the nutritive profile, natural greasepaint gives the admixture a distinct, subtle, earthy flavor. Make sure the greasepaint is inversely distributed throughout the flour admixture. This dry admixture can serve as a foundation for a variety of fashions, including baked products or traditional This process improves the quality of the finished product and aids in effective blending. Malabar spinach greasepaint is added for its natural value and aesthetic appeal[17].

Fig 3: Mixing The Dry Ingredients

5) Dough Making :

The ingredients that were combined kneaded into a smooth and elastic dough. Appropriate kneading was necessary to ensure uniformity in texture and component distribution which took 10min . The structure of the edible utensils was established by portioning and pressing the prepared dough into moulds that were sculpted to make the proper cutlery patterns[18].

Fig .4 :Dough Making

6) Dough Resting :

Resting the dough for 15 minutes after mixing flours like maida, wheat, sorghum and Malabar spinach fruit powder allows the gluten and starches to fully hydrate, improving the dough's smoothness and elasticity. In maida and wheat flour, this rest period helps relax the gluten network, making the dough smoother and easier to shape. For sorghum flour, which is gluten-free, resting helps soften the dough and improve binding. When Malabar spinach fruit powder is added, the resting time allows the nutrients to blend uniformly into the dough, enhancing its appearance and nutritional profile[19].

7) Using Hydraulic Pressure Moulding Equipment:

The shaped dough was subjected to a hydraulic moulding press, set to 200°C for a duration of 2 seconds. This high-temperature treatment ensured rapid cooking, solidifying the dough into a durable and structurally stable form. The process also enhanced the cutlery’s resistance to moisture and improved its functional properties for practical use [20].

Fig 5: Hydraulic Pressure Moulding Equipment

8) Millet Edible Cutlery With Malabar Spinach Fruit Powder:

The final product is eco-friendly, nutritious edible cutlery crafted from a mixture of Malabar spinach fruit powder, sorghum flour, maida and wheat flour. This combination ensures a balanced texture, maida and wheat provide elasticity and structure, while sorghum adds fiber and a slightly earthy flavor. The inclusion of Malabar spinach fruit powder not only gives a natural, attractive purple tint but also boosts the antioxidant and nutrient content. The cutlery is a sustainable substitute for plastic with additional health advantages and aesthetic appeal because it is hard, sharp, and able to withstand both hot and cold foods[21].

Fig. 6: Final Product

III. RESULTS AND DISCUSSIONS

1) Product Development Outcomes

The experimental trials conducted using Response Surface Methodology (RSM) led to the successful development of millet-based edible cutlery fortified with Malabar spinach fruit powder. The combination of wheat flour, sorghum flour and maida provided a sturdy base, while the incorporation of Malabar spinach fruit powder enriched the formulation with natural antioxidants, minerals and pigments. The optimized dough exhibited desirable physical characteristics, including elasticity, smoothness and moldability, which were essential for producing well-shaped, durable edible cutlery. Numerous trials and errors were conducted, with the third trial emerging as the most successful compared with the two suitable ones, which are trial 1 and trial 6. This trial exhibited favorable characteristics that contributed to obtaining effective responses. The values are given below table 2

Table 2: Different parameter values of trials

PARAMETER	TRIAL 1	TRIAL 3	TRIAL 6
CARBOHYDRTAE(g/100g)	65.8	66.26	64.3
PROTEIN (g/100g)	7.2	8.42	8.1
DIETARY FIBRE (%)	1.5	1.35	2

Given below are the different millet edible cutlery trials with varying ratios of ingredients based on the RSM software trials

Trial 1

Trial 2

Trial 3

Trial 4

Trial 5

Trial 6

Among all the trials, the third one shows good strength and various positive feedback from other parameters

2) Nutritional Analysis Properties

The nutritional composition analysis was conducted on the third trial sample to evaluate its key nutrient content. The assessment focused on essential parameters including carbohydrates, protein, total sugars, dietary fiber and fat. These components play a vital role in determining the nutritional value and health benefits of the product. A portion of the sample was used for the analysis and the results are summarized in the table below, providing a comprehensive overview of its nutritional profile. The values are given below table 3

Table 3: Nutritional analysis values of trial 3

SI NO	**PARAMETER**	**VALUES**
1	CARBOHYDRATE(g/100g)	66.26
2	PROTEIN (g/100g)	8.42
3	TOTAL SUGAR (%)	1.35

4	DIETARY FIBRE (%)	12.06

3) Texture Analysis with Product Testing

The texture of the developed millet-based edible cutlery fortified with Malabar spinach fruit powder was evaluated using a Texture Profile Analyzer (TPA). This helped determine the product's mechanical integrity. The third trial product was observed to be firm, compact, and retained its shape without cracking or warping. Additionally, it demonstrated a good surface finish and acceptable thickness, suitable for handling semi-solid and liquid food items. This confirms that the optimized formulation was effective in achieving mechanical strength comparable to traditional disposable cutlery. During different trials, there were lots of differences in the strength of cups. The variation in the ratio of different ingredients will affect the overall physical and functional properties. The final tested values of various texture properties are listed below table 4

Table 4: Texture Analysis values of trial 3

SI NO	PARAMETER	VALUES
1	SPRINGNESS	0.65
2	GUMIMINESS	143.152
3	RESILIENCE	0.068
4	COHESIVENESS	0.199
5	FRACTURABILITY	1513.287

4) Moisture Content Test

The moisture content analysis was performed on the third trial edible cup, and the resulting data, which offers a comprehensive assessment of the moisture level. The moisture content of the product is recorded at 2.26%, indicating a low level of water present. This low moisture content contributes to improved shelf stability by minimizing the risk of microbial growth, spoilage, and quality deterioration over time. Maintaining such a low moisture level is particularly important for enhancing the product's storage life and ensuring consistent texture and safety.

5) Water Absorption Test

The functional performance of the third trial edible cutlery was tested across various food substances to assess water absorption and structural breakdown over time. The findings indicated that the product preserved its shape for different food substances for a certain period. The values of the test are given in Table 5

Table 5 : Water absorption test in different substances and temperatures

SI NO	SUBSTANCE	TEMPERATURE	WATER ABSORPTION TIME
1	NORMAL WATER	25	40
2	HOT WATER	80	25
3	MILK	35	33
4	TEA	40	30

5	COFFEE	45	28

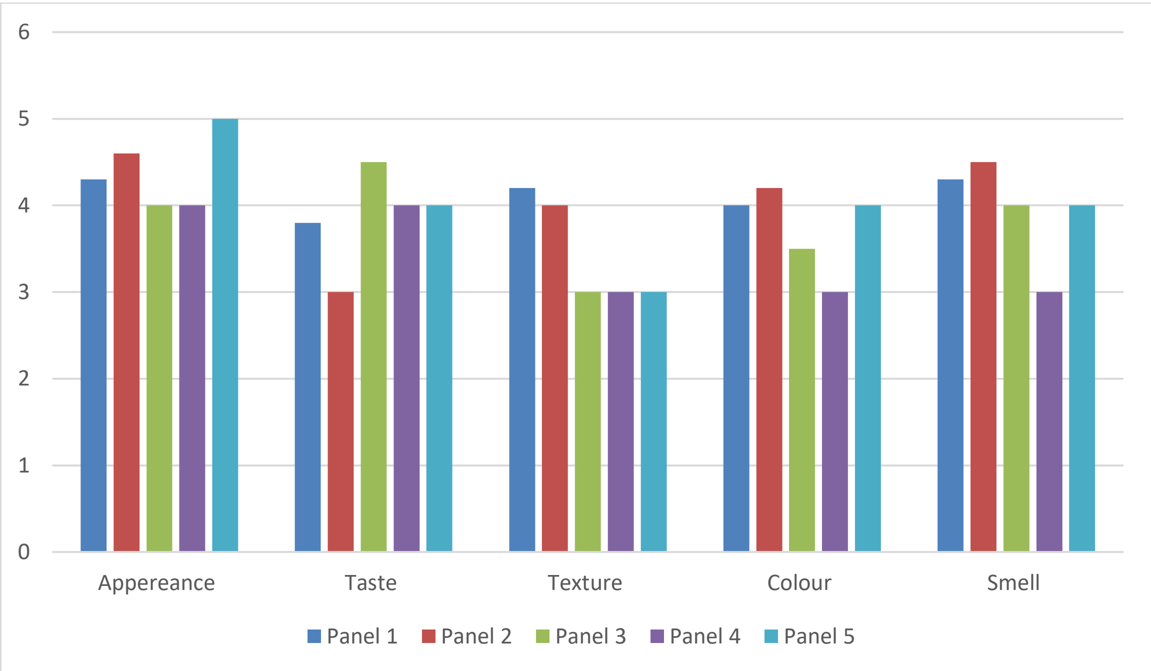
These findings suggest that the cutlery is suitable for short-term consumption alongside beverages and soft foods.

7) Microbial Content Properties

A microbial content test was carried out on the third trial edible cup, and the findings have been summarized and are now presented in the table below, providing a detailed overview of the results obtained from the analysis. The total plate count of the product was found to be less than 10, indicating excellent microbiological quality. A low total plate count reflects good hygienic practices during production and suggests minimal microbial contamination, contributing to the product's safety and extended shelf life.

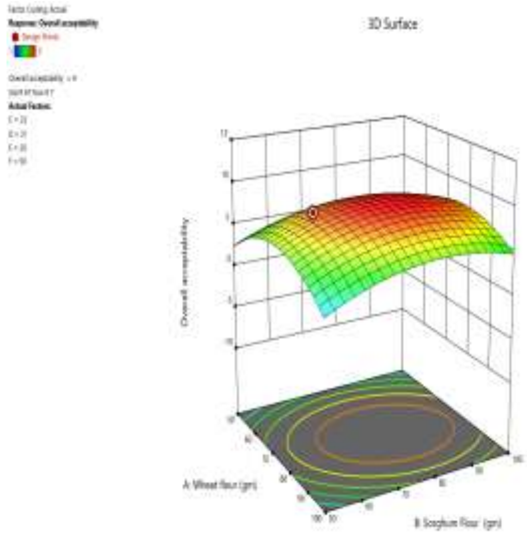
8) Sensory and Shelf-Life Considerations

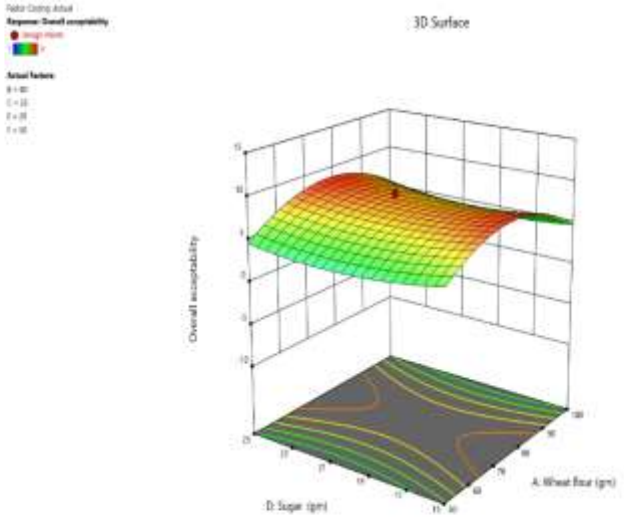
Sensory characteristics affect consumer acceptance, while shelf-life impacts the product's commercial feasibility. Together, these evaluations ensure that the food stays safe, attractive and nutritionally stable throughout its expected duration. Below are the determined values from the sensory and shelf-life tests. The desired shelf life of the product, determined through accelerated shelf life testing with an aging factor of 10, is estimated to be 15 days. This indicates that under normal storage conditions, the product is expected to maintain its quality, safety, and acceptability for up to 15 days.

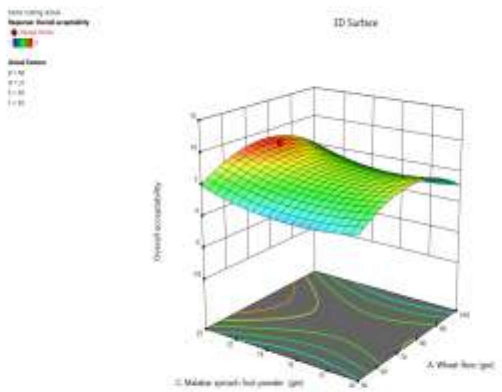


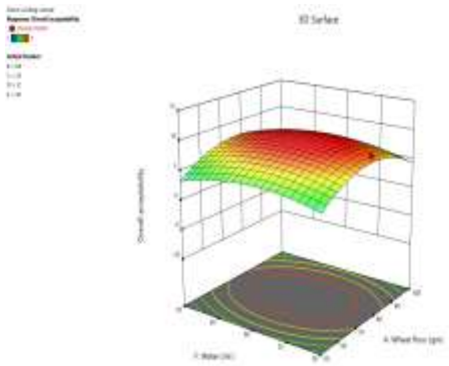
9) RSM Trial Optimization

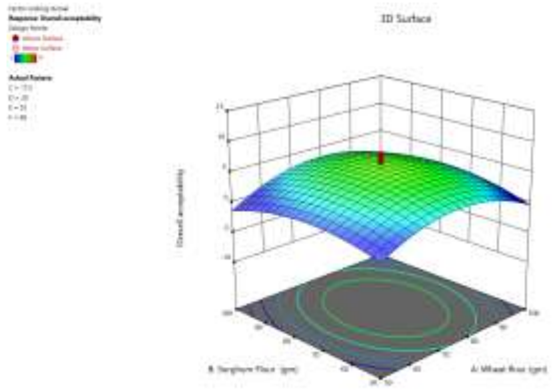
The following set of graphical representations has been systematically generated using Response Surface Methodology (RSM) software, offering valuable insights into the interactive effects of various formulation parameters and their influence on the developed edible cutlery.

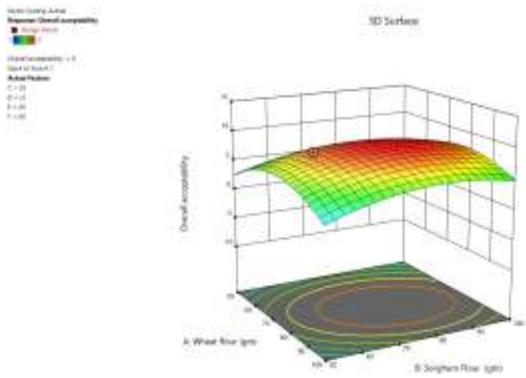












These are some of the response graphs which are created with the help of the RSM software. The parameter that is used for the creation of these graphs is mainly the overall acceptability of the product. The graphs that are shown above are in correlation with different trials

IV.CONCLUSION

The study successfully developed functional edible cutlery using a combination of millet-based flours and Malabar spinach fruit powder, aiming to provide a healthier and nutritionally beneficial alternative to traditional single-use cutlery. Various formulations were evaluated through multiple trials, among which trial 3 demonstrated the best performance, showing mechanical strength, moisture resistance and overall sensory acceptability. The incorporation of millet flours and Malabar spinach fruit powder significantly improved the product's overall quality and nutritional value, marking it as a promising option for food service applications with a focus on health-conscious consumption. The optimized formulation provided sufficient mechanical strength, moisture resistance and sensory appeal for practical use in food service applications. Overall, this innovative approach supports sustainability goals and nutritional advancement, making it a promising solution in the field of food industry.

V. REFERENCES

[1] Ahuja, I., & Bhaskar, N. (2021). Edible cutlery: An alternative to plastic utensils. Journal of Food Science and Technology, 58(5), 1625–1633. https://doi.org/10.1007/s13197-020-04619-2

[2] Arora, A., & Damle, N. (2019). Development of edible spoons using sorghum and wheat flour. International Journal of Home Science, 5(2), 250–254.

[3] Atwell, W. A., & Finnie, S. (2016). *Wheat flour*. Elsevier.

[4] Awika JM , Lloyd W. Rooney. (2004). Sorghum phytochemicals and their potential impact on human health. Phytochemistry. 65: 1199-1221.

[5] Aydin A, Paulsen P, Sulders FJ. (2009). The physiochemical and microbial properties of wheat in Thrace. Turk Journal of Agriculture. 33: 445-454

[6] Bari, M. L., & Molla, M. M. (2020). Development of biodegradable edible film from Basella alba mucilage. Journal of Food Packaging and Shelf Life, 3(1), 12–18.

[7] Chavan, J. K., & Kadam, S. S. (1989). Nutritional improvement of cereals by fermentation. CriticalReviews in Food Science and Nutrition, 28(5), 349–400. https://doi.org/10.1080/10408398909527507

[8] Dordevic, D., Necasova, L., Antonic, B., Jancikova, S., & Tremlová, B. (2021). Plastic cutlery alternative: Case study with biodegradable spoons. *Foods*, *10*(7), 1612.

[9] Ghosh, S., & Chatterjee, S. (2020). Biodegradable edible utensils: A sustainable alternative. Environmental Science and Pollution Research, 27(28), 34750–34760. https://doi.org/10.1007/s11356-020-09668-3

[10] Gómez, M., Gutkoski, L. C., & Bravo-Núñez, Á. (2020). Understanding whole-wheat flour and its effect in breads: A review. *Comprehensive Reviews in Food Science and Food Safety*, *19*(6), 3241-3265.

[11] Gupta, S., & Bawa, A. S. (2017). Development and shelf-life evaluation of edible spoons from composite flour. International Journal of Food Science and Nutrition, 2(4), 132–137.

[12] Handa, A., & Mishra, V. (2020). Development of sorghum-wheat flour-based edible cutlery: An eco-friendly approach. International Journal of Innovative Research in Science, Engineering and Technology, 9(7), 6734–6739.

[13] Ingle, A. P., & Rai, M. (2021). Sustainable food packaging materials: Edible films and cutlery. Green Sustainable Process for Chemical and Environmental Engineering and Science, 245–270. https://doi.org/10.1016/B978-0-12-821007-7.00006-6

[14] Iqbal, B., Raza, R., Khan, N., & Siddiqui, K. A. (2022). Bio-friendly edible cutlery-an effective alternative to plastic disposable cutlery. J Res (Science), 33(1), 30-36.

[15] Joshi, S., & Mahapatra, A. (2018). Edible cutlery as a sustainable option: Consumer perception study. Food Research International, 106, 611–618. https://doi.org/10.1016/j.foodres.2018.01.01

[16] Kabir, M. H., Hamidon, N., Awang, M., Rahman, M. A. A., & Adnan, S. H. (2021). An edible cutleries using green materials: sorghum flour. In Green Infrastructure: Materials and Applications (pp. 305-317). Singapore: Springer Singapore.

[17] Katiyar, R., & Kumar, N. (2021). An updated review on Malabar spinach (Basella alba and Basella rubra) and their importance. *Journal of Pharmacognosy and Phytochemistry*, *10*(2), 1201-1207.

[18] Kumar, D., & Sinha, S. (2020). Mucilage extracted from Basella alba as a natural binder in edible formulations. International Journal of Food Studies, 9(1), 88–95. https://doi.org/10.7455/ijfs.v9i1.810

[19] Kumar, R., & Singh, S. (2022). Utilization of millets for development of eco-friendly tableware. Journal of Environmental Management, 301, 113933. https://doi.org/10.1016/j.jenvman.2021.113933

[20]Kumar, S. S., Manoj, P., Nimisha, G., & Giridhar, P. (2016). Phytoconstituents and stability of betalains in fruit extracts of Malabar spinach (Basella rubra L.). *Journal of Food Science and Technology*, *53*, 4014-4022.

[21] Mahapatra, A., Kumar, P., Behera, A. K., Sen, A., & Pradhan, B. (2023). Comparative study of natural dye-sensitized solar cells using inedible extracts from kumkum, kamala and malabar spinach fruits. *Journal of Photochemistry and Photobiology A: Chemistry*, *436*, 114385

[22] Manivel, D., & Paramasivam, R. (2024). Sorghum spoons enriched with selected edible flowers: A sustainable alternative to conventional cutlery in the food and tourism sectors. *Biomass Conversion and Biorefinery*, 1-14.

[23] Mehta, R., & Sharma, N. (2019). Formulation of edible spoon using sorghum flour. Asian Journal of Dairy and Food Research, 38(2), 119–123. https://doi.org/10.18805/ajdfr.DR-1635

[24] Mohd Hafizalrisman Kabir, Nuramidah Hamidon. (2021). A Study of Edible Cutleries by Using Sorghum Flour. Progress in Engineering Application and Technology. 2(1):292-300.

[25] Mukherjee, K., & Raju, A. (2023). Edible cutlery-A prototype to combat malnutrition and plastic waste management. Asian Journal of Biological and Life Sciences, 12(1), 92-102.

[26] Munir S. Edible cutlery: the future of eco-friendly utensils. 2017.

[27] Natarajan N, Vasudevan M, Vivekk Velusamy V, et al. Eco-friendly and edible waste cutlery for sustainable environment. Int J Eng Adv Technol. 2019; 9(1s4).

[28] Nur, M. A., Khan, M., Satter, M. A., Rahman, M. M., & Amin, M. Z. (2023). Assessment of physicochemical properties, nutrient contents and colorant stability of the two varieties of Malabar spinach (Basella alba L.) fruits. *Biocatalysis and Agricultural Biotechnology*, *51*, 102746.

[29] Patil, R., & Jadhav, S. (2021). Edible spoons made of millet and wheat: A review. International Journal of Engineering Research & Technology, 10(3), 565–570.

[30] Rana, M. K., Mulge, R., & Evoor, S. (2017). Malabar Spinach. In *Vegetable Crop Science* (pp. 191-196). CRC Press.

[31] Singh, A., & Kaur, G. (2022). Biodegradable edible cutlery: Innovation in sustainable food service. Journal of Cleaner Production, 336, 130394. https://doi.org/10.1016/j.jclepro.2022.130394

[32] Singh, A., Mal, D., Swain, A. R., & Mohapatra, A. (2024). Exploring the Nutritional and Medicinal Potential of Indian Spinach (Basella rubra L.): A Comprehensive Review. Journal of Advances in Biology & Biotechnology, 27(7), 437-446.

[33] Sorna Prema Rajendran, Abirami Saravanan, Ganesh Kumar Namachivayam, Jayasree Jambunathan, and Ganeshwari Ramachandran. (2020). Optimization of composition for preparation of edible cutlery using response surface methodology (RSM). AIP Conference Proceedings. 2240:050001(1-8).

[34] Srinath, S., Prabha, D. D., & Mathipurani, V. B. (2020). Plastic waste management for economic growth–a study on emerging opportunities for ecopreneurs. International Journal on Global Business Management & Research, 9(1), 77-87.

[35] Taylor, J. R., & Anyango, J. O. (2011). Sorghum flour and flour products: Production, nutritional quality, and fortification. In *Flour and breads and their fortification in health and disease prevention* (pp. 127-139). Academic Press.

[36] Thakur, R., & Kumar, V. (2022). Development of sustainable edible packaging from plant mucilage: A case study with Basella alba. Journal of Environmental Chemical Engineering, 10(1), 106842. https://doi.org/10.1016/j.jece.2021.106842

[37] Vijayendra, S. V. N., & Sreedhar, R. (2023). Production of buns, the bakery-based snack food, with reduced refined wheat flour content: Recent developments. Journal of Food Science and Technology, 60(12), 2907-2915.

[38] Villarino, C. B. J., Jayasena, V., Coorey, R., Chakrabarti-Bell, S., & Johnson, S. K. (2016). Nutritional, health, and technological functionality of lupin flour addition to bread and other baked products: Benefits and challenges. *Critical reviews in food science and nutrition*, *56*(5), 835-857.

[39] Yadav, P., & Mathur, R. Development of Gluten Free Flour & Gluten Free Cookies and their Sensory evaluation.

[40] Yadav, R. B., Yadav, B. S., & Dhull, N. (2011). Effect of fermentation on physicochemical properties and in vitro starch and protein digestibility of selected cereals. Food Research International, 44(1), 308–315. https://doi.org/10.1016/j.foodres.2010.10.01