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DEVELOPMENT, CHARACTERIZATION AND SUSTAINABILITY EVALUATION OF CEREAL- AND MILLET-BASED EDIBLE CUPS FOR HOT TEA AND COFFEE: AN INTEGRATED STUDY FROM AMALNER TALUKA, JALGAON DISTRICT, MAHARASHTRA, INDIA

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Keywords	*Abstract*
Edible Cups; Sustainable Packaging; Tea; Coffee; Edible Tableware; Biodegradable Packaging; Cereal Flour; Corn Starch; Food Waste Valorization; Circular Economy.	The extensive use of single-use beverage containers has increased interest in sustainable alternatives capable of reducing post-consumer packaging waste. Edible cups represent a novel category of food-contact packaging in which the container can function as both a vessel and a consumable food product. The present study proposes the development and evaluation of plant-based edible cups intended for the consumption of tea and coffee. The research focuses on formulation development, physical characteristics, mechanical strength, water absorption, resistance to hot beverages, sensory acceptability, nutritional composition, biodegradability, shelf stability, consumer perception, and sustainability. Recent studies have demonstrated that edible cups can be produced from cereal flours, starches, plant fibres, proteins, and food-processing by-products. However, moisture sensitivity, mechanical weakness, thermal instability, short shelf life, food safety, scalability, and consumer acceptance remain significant challenges.

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	The proposed experimental study will develop multiple formulations using selected food-grade cereal flours and corn starch. The cups will be moulded and thermally processed, followed by systematic characterization. Functional performance will be evaluated by measuring physical dimensions, hardness, water absorption, resistance to tea and coffee at controlled temperatures, and structural integrity during beverage exposure. The optimized formulation will additionally be subjected to nutritional, sensory, biodegradability, and shelf-life evaluation. Published work on wheat-, sorghum-, corn-starch-, and coffee-pulp-based edible cups has demonstrated the feasibility of producing containers with useful liquid resistance and substantial biodegradability, providing a scientific basis for further formulation development. The study is expected to contribute to the development of an edible, biodegradable, and functionally suitable beverage container. Nevertheless, environmental superiority should not be assumed solely because a cup is edible; life-cycle evidence indicates that environmental performance depends strongly on ingredients, production, disposal, and whether the edible cup replaces another food item. The proposed research therefore adopts an integrated approach combining food science, packaging performance, consumer acceptability, and sustainability assessment.

1. Introduction

Packaging plays an essential role in modern food systems. It protects food, facilitates transportation, improves convenience, and can contribute to maintaining product quality. However, the rapid growth of single-use food-service products has also increased the quantity of packaging requiring collection, recycling, treatment, or disposal.

Tea and coffee are frequently consumed outside the home in educational institutions, offices, restaurants, cafés, transport facilities, and public events. Disposable cups are commonly used because they are convenient and inexpensive. Their short period of use, however, contrasts with the resources required for their manufacture and end-of-life management.

Sustainable alternatives to conventional single-use cups include reusable containers, recyclable materials, biodegradable materials, compostable products, and edible packaging. Among these alternatives, edible cups represent a particularly innovative concept because the container itself can become part of the food experience.

Edible packaging is generally produced from food-grade materials such as polysaccharides, proteins, lipids, and their combinations. Edible materials can potentially reduce packaging waste because they may be consumed after use or biodegrade when discarded appropriately.

Recent scientific reviews indicate increasing interest in edible cups, bowls, and spoons made from starches, millet flours, wheat flour, rice flour, plant fibres, soy protein, casein, gelatin, and composite food materials. These reviews identify several important advantages, including renewable raw materials and potential waste reduction, while also emphasizing limitations involving mechanical strength, moisture sensitivity, thermal stability, shelf life, safety, economic feasibility, and large-scale manufacturing.

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The development of an edible cup for tea and coffee presents a greater technical challenge than the development of edible tableware for dry foods. A beverage cup must retain its shape, tolerate the weight of the liquid, resist moisture penetration, and remain sufficiently stable at beverage-serving temperatures. At the same time, the material must remain safe and pleasant to consume.

Therefore, successful edible-cup development requires an interdisciplinary approach involving food formulation, material characterization, packaging science, sensory science, food safety, and sustainability assessment.

The present research proposes the development and systematic evaluation of edible cups designed specifically for tea and coffee consumption.

2. Background and Need for the Study

Single-use beverage containers are designed primarily for convenience. However, they create an environmental challenge because the useful life of the product may be limited to only a short period.

Edible cups offer a different design philosophy. Instead of designing a container that must subsequently enter a waste-management system, the container may be consumed or, if discarded, may have the potential to biodegrade depending on its composition and disposal conditions.

The growing scientific interest in edible tableware has resulted in the development of products based on wheat, rice, millet, sorghum, starch, proteins, and plant-derived fibres. A 2025 review of plant flour-based edible tableware concluded that edible cups and related products could provide promising alternatives to conventional single-use items, while emphasizing the importance of optimizing functional properties and composition.

Similarly, a 2025 comprehensive review of bio-based edible cutlery identified mechanical strength, moisture resistance, thermal stability, shelf life, sensory performance, food safety, and scalability as key research priorities. The review also highlighted processing approaches such as moulding, baking, thermal pressing, and extrusion.

A particularly relevant recent study developed edible cups from wheat flour, sorghum flour, corn starch, and coffee pulp flour. Three formulations were evaluated for colour, hardness, water absorption, liquid resistance, biodegradability, protein, and fibre. The study demonstrated that some formulations could maintain water stability at approximately 80°C for about 110 minutes under the reported test conditions and showed approximately 63% biodegradation within approximately 12 days under the experimental conditions used.

These findings demonstrate that the development of functional edible cups is technically feasible. However, further research is needed to optimize formulations for specific beverage applications and to evaluate consumer acceptability and practical performance.

3. Problem Statement

The increasing use of single-use beverage cups contributes to packaging waste. Although reusable cups may offer environmental advantages where repeated reuse is practical, they are not always convenient or feasible in all settings.

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There is a need to investigate alternative food-service containers that can provide adequate functional performance while reducing dependence on conventional disposable packaging.

Edible cups are a promising alternative; however, their practical application is limited by several technical challenges:

- Low resistance to moisture.
- Possible softening during contact with hot beverages.
- Limited mechanical strength.
- Potential cracking or leakage.
- Short shelf life.
- Food-safety requirements.
- Consumer hesitation regarding eating the container.
- Economic and manufacturing limitations.

The present study addresses these challenges through the formulation, development, and evaluation of edible cups for sustainable tea and coffee consumption.

4. Rationale of the Study

The study is based on the concept that sustainable food-service systems should minimize unnecessary material waste while maintaining food safety and consumer convenience.

- Edible cups are scientifically interesting because they perform two functions:
- Packaging function: holding the beverage safely.
- Food function: providing an edible product that may be consumed after the beverage.
- This dual function distinguishes edible cups from conventional biodegradable packaging.

The study also provides an opportunity to investigate locally available cereal and plant materials. India possesses a wide diversity of grains and millets that may be explored as ingredients for edible tableware.

The incorporation of suitable food-processing by-products may also support circular-economy approaches, provided that such ingredients are food-safe and properly characterized.

5. Aim of the Study

To develop and evaluate food-grade edible cups suitable for sustainable consumption of tea and coffee.

6. Objectives

The specific objectives of the study are:

- To formulate edible cups using selected food-grade plant-based ingredients.
- To develop multiple formulations for comparison.
- To determine the physical characteristics of the developed cups.
- To evaluate mechanical strength and structural integrity.
- To determine water absorption capacity.
- To evaluate resistance to tea and coffee.
- To investigate the effect of beverage temperature on cup stability.

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- To determine leakage and deformation time.
- To evaluate selected nutritional characteristics.
- To determine sensory acceptability.
- To assess biodegradability.
- To investigate shelf stability under controlled storage conditions.
- To study consumer perception and willingness to use edible cups.
- To compare the developed cup with conventional disposable beverage containers.
- To identify an optimized formulation for future development.

7. Review of Literature

7.1 Edible Packaging

The increasing environmental concerns associated with petroleum-derived single-use packaging have encouraged researchers worldwide to investigate renewable, biodegradable, and edible packaging materials. Edible packaging is produced from food-grade components that can perform a protective or structural function and may subsequently be consumed. These materials commonly include polysaccharides, proteins, lipids, and composite formulations.

Debeaufort et al. (1998) were among the early researchers to establish the importance of edible films and coatings as alternatives to conventional packaging materials. They explained that edible films could provide barrier functions while remaining suitable for human consumption. Krochta and *De Mulder-Johnston (1997)* similarly highlighted the potential of edible films and coatings for reducing dependence on conventional packaging materials.

More recently, *Santhosh et al. (2024)* reviewed starch-based edible packaging and reported that starch is attractive because of its abundance, renewability, biodegradability, and food compatibility. However, the authors identified limitations related to mechanical strength, moisture sensitivity, thermal properties, and barrier performance.

An extensive review by *Roy et al. (2025)* further demonstrated the growing international interest in edible tableware made from plant flours. The authors reported that edible cups, bowls, and spoons can be prepared from cereals, pseudocereals, millets, starches, and other plant-derived materials. They emphasized that mechanical strength, moisture resistance, thermal stability, sensory acceptability, food safety, shelf life, and scalability remain important challenges.

7.2 Starch as a Structural Material

Starch is one of the most extensively investigated natural polymers for edible and biodegradable packaging. It occurs in cereals such as wheat, maize and rice and in roots and tubers such as potato and cassava.

Avella et al. (2009) reviewed biodegradable polymer-based materials for food packaging and emphasized the potential of starch and other natural polymers as renewable alternatives to petroleum-derived materials. They noted that natural polymers can offer environmental benefits but frequently require modification to achieve adequate mechanical and barrier properties.

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Jimenez et al. (2012) reported that starch-based edible films and coatings have considerable potential for food applications but that their hydrophilic nature can result in poor water-vapour resistance. Consequently, plasticizers, blending, cross-linking, and composite approaches have been investigated to improve performance.

More recently, *Santhosh et al. (2024)* reviewed starch-based edible packaging and reported that starch-based materials can be improved through plasticization, blending with other biopolymers, and incorporation of reinforcing materials.

For edible cups, these findings are particularly relevant because direct contact with tea or coffee exposes the starch matrix to both moisture and heat. Therefore, the proportion and type of starch must be optimized to achieve adequate structural stability.

7.3 Cereal Flour-Based Edible Tableware

Cereal flours are attractive raw materials for edible tableware because they are food-grade, widely available, relatively inexpensive, and nutritionally valuable. Wheat, rice, maize, sorghum, oats, and millet have all been investigated in various food and edible-packaging applications.

Gennadios and Weller (1997) reviewed edible and biodegradable films based on agricultural materials and highlighted cereal-derived proteins and polysaccharides as promising packaging materials.

Falguera et al. (2011) reviewed edible films and coatings and reported that food-based polymers can be formulated to provide desirable mechanical and barrier properties depending on their composition and processing conditions.

Roy et al. (2025) specifically reviewed plant-flour-based edible tableware and concluded that plant flours can provide an appropriate matrix for the development of cups, bowls, spoons, and other edible products. However, the authors noted that increasing flour content can influence hardness, brittleness, water absorption, flavour, and sensory acceptability. (pubmed.ncbi.nlm.nih.gov)

The use of cereal flour is therefore particularly promising for edible cups because conventional food-processing techniques such as mixing, moulding, baking, and thermal pressing can potentially be adapted for their manufacture.

7.4 Millets and Sustainable Edible Cups

Millets have attracted international attention because of their nutritional properties, resilience in diverse growing conditions, and potential contribution to sustainable food systems.

Saleh et al. (2013) reviewed the nutritional and health-related properties of millet grains and reported that millets provide carbohydrates, proteins, dietary fibre, minerals, vitamins, and bioactive compounds. These characteristics make millet flour potentially useful for developing value-added food products.

Amadou et al. (2013) also reviewed the nutritional composition and processing characteristics of millet and highlighted its potential for food-product development.

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More recently, *Roy et al. (2025)* identified millet flour as one of the promising plant-based materials for edible tableware. The researchers emphasized that millet-based edible products may provide nutritional and functional advantages, although their water resistance and mechanical properties need optimization.

Thus, incorporation of millet flour into edible cups may provide both a packaging function and additional nutritional value. However, the specific effects of millet species, particle size, flour concentration, and thermal processing on cup performance require further investigation.

7.5 Coffee By-Products and Circular Economy

Coffee is one of the world's most widely consumed beverages, and coffee processing generates considerable quantities of agricultural and industrial by-products.

Mussatto et al. (2011) reviewed coffee industry by-products and demonstrated that residues from coffee processing can contain valuable carbohydrates, proteins, minerals, antioxidants, and other compounds. The authors emphasized the importance of converting these residues into value-added products rather than treating them solely as waste.

Murthy and Naidu (2012) discussed the biotechnological potential of coffee waste and reported several possibilities for its valorization, including food, fermentation, and other value-added applications.

Klingel et al. (2020) reviewed coffee by-products as potential novel food resources and emphasized the possibility of incorporating coffee-processing residues into new food products after appropriate safety and quality evaluation.

More recently, *Quiñonez et al. (2025)* developed edible cups using wheat flour, sorghum flour, corn starch, and coffee pulp flour. Their study investigated hardness, colour, water absorption, liquid resistance, protein, fibre, and biodegradability. The results demonstrated that coffee pulp could be incorporated into edible-cup formulations while maintaining useful functional characteristics. (coffeescience.ufla.br)

This research provides an important basis for exploring coffee by-products as ingredients in edible cups intended for coffee consumption.

7.6 Mechanical Strength

Mechanical strength is essential for edible cups because they must withstand handling, filling, transportation, beverage weight, and contact with hot liquids.

Guilbert et al. (1996) emphasized that mechanical properties are critical considerations in the development of edible films and coatings because packaging materials must maintain structural integrity during handling and use.

Avella et al. (2009) similarly noted that natural-polymer packaging often requires modification to obtain mechanical properties comparable to conventional packaging materials.

In a recent review, *Santhosh et al. (2024)* identified mechanical weakness as one of the major limitations of starch-based edible packaging. The authors described approaches including

plasticization, blending, reinforcement, and structural modification for improving mechanical performance.

For edible cups, mechanical strength should preferably be assessed using hardness, compression strength, breaking force, deformation, and resistance to beverage-induced weakening.

7.7 Moisture Sensitivity and Liquid Resistance

Moisture sensitivity is one of the major challenges in developing edible cups from starch and cereal flours. Hydrophilic polymers readily interact with water, which can cause swelling, plasticization, softening, and loss of mechanical strength.

Debeaufort et al. (1998) identified water-vapour and moisture-barrier performance as important properties affecting the functionality of edible films.

Falguera et al. (2011) further emphasized that the hydrophilic nature of many edible biopolymers can restrict their application in moisture-rich food systems.

Santhosh et al. (2024) confirmed that poor moisture-barrier performance remains a significant limitation of starch-based edible packaging and discussed formulation strategies for improving resistance.

For a tea or coffee cup, moisture resistance becomes even more important because the material is directly exposed to liquid. Therefore, water absorption, liquid-contact time, leakage time, and structural failure should be measured.

7.8 Thermal Stability

Thermal stability is a critical property for edible cups designed for hot beverages. Tea and coffee are commonly served at temperatures substantially above room temperature, and elevated temperature can accelerate moisture penetration and structural changes.

Shulga et al. (2023) investigated biodegradable edible cups intended for hot drinks and evaluated their consumer, organoleptic, environmental, mechanical, and structural characteristics. Their research demonstrated the feasibility of developing edible cups specifically for hot beverages. (researchgate.net)

Quinonez et al. (2025) subsequently investigated wheat-, sorghum-, corn-starch-, and coffee-pulp-based edible cups and reported resistance to hot water at approximately 75–80°C for selected formulations under their experimental conditions. (coffeescience.ufla.br)

These studies demonstrate that thermal stability can be achieved through appropriate formulation and processing, although performance varies considerably according to material composition.

7.9 Sensory Acceptability

An edible cup differs fundamentally from conventional packaging because consumers may eat the container after consuming the beverage. Therefore, sensory characteristics are an essential component of product evaluation.

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McHugh et al. (1996) demonstrated the importance of sensory and functional properties when developing edible packaging films for food applications.

Shulga et al. (2023) included organoleptic characteristics in their evaluation of edible cups for hot beverages, emphasizing that consumer-oriented characteristics should be considered alongside mechanical and environmental performance. (researchgate.net)

Roy et al. (2025) identified sensory acceptability as one of the critical factors determining the success of plant-flour-based edible tableware. (pubmed.ncbi.nlm.nih.gov)

Important sensory attributes for the present research include appearance, aroma, texture, crispness, hardness, taste, aftertaste, flavour compatibility with tea and coffee, and overall acceptability.

7.10 Biodegradability

Biodegradability is an important characteristic of sustainable packaging. Edible cups that are not consumed should ideally undergo biological degradation under suitable environmental conditions.

Muller et al. (2017) discussed the role of biodegradable materials in sustainable food-packaging systems and emphasized that biodegradability depends on material composition and environmental conditions.

Quinonez et al. (2025) evaluated biodegradability of cereal- and coffee-pulp-based edible cups and reported substantial mass loss under their experimental biodegradation conditions. (coffeescience.ufla.br)

However, biodegradability should be measured using standardized methods wherever possible. A reduction in sample mass alone should not automatically be interpreted as complete biodegradation.

7.11 Sustainability and Life-Cycle Assessment

Although edible cups are frequently described as sustainable alternatives, their environmental performance should be assessed throughout their entire life cycle.

Heller (2017) demonstrated that the environmental impacts of food-service packaging depend not only on the packaging material but also on consumer behaviour, production systems, reuse patterns, and disposal.

More specifically, *Anand et al. (2024)* conducted a life-cycle assessment comparing edible coffee cups with paper, PLA, polystyrene, and reusable cups. Their results demonstrated that reusable cups can have very low environmental impacts when they are reused sufficiently. They also found that edible cups could perform favourably under scenarios where consumption of the edible cup substitutes for another food item. (sciencedirect.com)

7.12 Critical Research Gap

The existing international literature demonstrates considerable progress in edible films, edible packaging, and edible tableware. Nevertheless, several important research gaps remain.

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First, a substantial proportion of previous research has focused on edible films and coatings rather than three-dimensional cups designed specifically for hot beverages. Second, studies frequently evaluate individual properties such as mechanical strength, moisture resistance, sensory quality, or biodegradability, whereas fewer investigations combine these parameters into a comprehensive product-development framework.

Third, there is limited comparative research on the performance of edible cups specifically with both tea and coffee, despite differences in beverage composition, acidity, temperature, colour, aroma, and consumer expectations.

Fourth, the interaction between flour/starch composition, beverage temperature, contact time, moisture absorption, and structural failure requires further investigation.

Finally, life-cycle studies such as *Anand et al. (2024)* demonstrate that the environmental advantage of edible cups depends on the complete product system and consumer behaviour. Therefore, claims of sustainability require evidence-based assessment rather than assumptions based only on biodegradability.

The present study seeks to address these gaps by developing and systematically evaluating edible cups for tea and coffee through physical, mechanical, moisture-resistance, thermal, nutritional, sensory, biodegradability, shelf-life, consumer-perception, and sustainability parameters.

Author	Country/Research context	Major contribution
Krochta & De Mulder-Johnston (1997)	USA	Edible films and coatings
Debeaufort et al. (1998)	France/Europe	Edible films and barrier properties
Gennadios & Weller (1997)	USA	Edible/biodegradable agricultural films
Guilbert et al. (1996)	France	Mechanical and functional properties
McHugh et al. (1996)	USA	Edible packaging-film development
Avella et al. (2009)	Italy/Europe	Biodegradable polymer packaging
Falguera et al. (2011)	Spain	Edible films and coatings
Mussatto et al. (2011)	Portugal/Brazil research	Coffee by-product valorization
Murthy & Naidu (2012)	India/international literature	Coffee-waste valorization
Saleh et al. (2013)	International	Millet nutrition
Klingel et al. (2020)	Germany	Coffee by-products as novel foods
Shulga et al. (2023)	Ukraine	Edible cups for hot drinks
Anand et al. (2024)	Ireland/UK research	Life-cycle assessment of edible coffee cups
Santhosh et al. (2024)	International review	Starch-based edible packaging
Roy et al. (2025)	International review	Plant-flour edible tableware
Quinonez et al. (2025)	Peru	Wheat–sorghum–coffee-pulp edible cups

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8 Materials and Methods

8.1 Research Design

The study will use an experimental research design.
At least four formulations are recommended:
F1: Control formulation.
F2: Modified cereal-flour formulation.
F3: Higher-starch formulation.
F4: Millet- or fibre-enriched formulation.
The exact ingredient composition should be finalized after preliminary trials.

9. Proposed Formulations

Table 1. Proposed Experimental Formulations

Ingredients	F1 (%)	F2 (%)	F3 (%)	F4 (%)
Wheat flour	50	45	40	35
Selected cereal/millet flour	30	35	40	45
Corn starch	10	10	10	10
Other food-grade ingredients	10	10	10	10
Total	**100**	**100**	**100**	**100**

10. Raw Materials

The potential food-grade materials used for the development of edible cups include wheat flour, rice flour, sorghum flour, millet flour, corn starch, sugar, salt, food-grade edible oil or fat, water, and natural flavouring agents, if required. These ingredients are selected based on their food-grade status, availability, nutritional properties, structural-forming ability, and suitability for edible packaging applications. Wheat, rice, sorghum, and millet flours provide the primary structural matrix, while corn starch may improve binding and structural strength. Sugar and salt can contribute to taste and overall sensory characteristics, whereas edible oil or fat may influence texture and reduce excessive brittleness. Water is used to obtain the desired dough consistency, and natural flavouring may be incorporated to improve the sensory compatibility of the cup with tea or coffee. All raw materials should be obtained from reliable sources and should comply with applicable food-grade quality and safety requirements.

11. Preparation of Edible Cups

The edible cups will be prepared using the selected food-grade flours, starch, and other ingredients according to the predetermined experimental formulations (F1–F4). The required quantities of each ingredient will be accurately weighed using a digital weighing balance to ensure consistency among the formulations. The wheat flour, selected cereal/millet flour, corn starch, sugar, salt, and other dry ingredients will first be thoroughly mixed to obtain a uniform dry blend. Water and other liquid ingredients, including edible oil or fat and natural flavouring where applicable, will then be added gradually with continuous mixing to form a homogeneous and workable dough.

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The prepared dough will be allowed to rest for a standardized period to facilitate uniform hydration and proper development of the dough structure. Following resting, the dough will be divided into equal portions and each portion will be carefully placed into standardized cup-shaped moulds. The dough will be uniformly distributed along the walls and base of the mould to obtain cups of consistent dimensions and thickness. The moulded cups will then be subjected to controlled thermal processing under predetermined temperature and time conditions. The optimum baking temperature and duration will be established through preliminary trials to obtain adequate hardness, structural integrity, moisture resistance, and acceptable sensory characteristics without excessive browning or burning.

After thermal processing, the edible cups will be removed carefully from the moulds and allowed to cool to room temperature under hygienic conditions. The cooled cups will subsequently be examined for physical defects such as cracks, deformation, uneven thickness, or surface damage. Cups showing visible defects will be excluded from further analysis. The acceptable cups will be packed in clean, food-grade, moisture-resistant packaging materials and stored under controlled conditions until further physical, mechanical, moisture-resistance, sensory, nutritional, biodegradability, and shelf-life analyses are conducted. All preparation and processing conditions will be maintained consistently across formulations to ensure reliable comparison of the experimental treatments.

12. Physical Characterization

The developed edible cups will be subjected to physical characterization to assess their dimensional uniformity, structural consistency, and visual quality. The weight, height, top diameter, bottom diameter, wall thickness, internal volume, colour, and surface appearance of the cups will be determined for each experimental formulation (F1–F4). The weight of each cup will be measured using a calibrated digital weighing balance, while the height and diameters will be measured using a vernier caliper or suitable digital measuring instrument. Wall thickness will be determined at selected points around the cup using a precision caliper or micrometer, and the average value will be recorded. The internal volume will be determined by filling the cup with a known quantity of water up to the designated level and measuring the corresponding volume.

Colour characteristics will be evaluated using a suitable colour-measuring instrument, such as a colourimeter, where available, and may be expressed using L*, a*, and b* values. In addition, the surface appearance of the cups will be visually examined for uniformity, smoothness, cracks, pores, blistering, browning, deformation, and other visible defects. All measurements will be performed on multiple independently prepared cups from each formulation, and the results will be expressed as mean ± standard deviation to assess variation and ensure the reliability and reproducibility of the experimental results.

13. Mechanical Strength Analysis

Table 2: Mechanical Strength Analysis

Formulation	Breaking Force (N)	Hardness (N)	Deformation (%)
F1	38.6 ± 1.8	36.9 ± 1.7	8.4 ± 0.6
F2	41.8 ± 1.6	40.2 ± 1.5	7.6 ± 0.5
F3	45.3 ± 1.9	43.7 ± 1.8	6.8 ± 0.4
F4	42.7 ± 1.7	41.1 ± 1.6	7.2 ± 0.5

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Values are illustrative and shown as Mean ± SD (n = 3).

Sample interpretation: Among the four formulations, F3 showed the highest breaking force (45.3 N) and hardness (43.7 N), along with the lowest deformation (6.8%), indicating comparatively greater structural resistance. F1 exhibited the lowest mechanical strength and the highest deformation. The improved mechanical performance of F3 may be associated with its higher proportion of selected cereal/millet flour and the resulting structural matrix. However, this interpretation must be confirmed using actual laboratory measurements and statistical analysis.

14. Water Absorption Capacity

The water absorption capacity of the developed edible cups will be determined to evaluate their resistance to moisture penetration and their suitability for containing tea and coffee. For each formulation, the initial weight (W_1) of the cup or standardized sample will be recorded using a calibrated digital weighing balance. The sample will then be exposed to water under controlled experimental conditions for a predetermined period. After the specified exposure time, the sample will be carefully removed, surface moisture will be standardized using a consistent procedure, and the final weight (W_2) will be recorded.

Water absorption will be calculated using the following equation:

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

15. Tea and Coffee Resistance Test

The resistance of the developed edible cups to hot beverages will be evaluated using standardized tea and coffee samples under controlled laboratory conditions. Tea and coffee will be prepared using a standardized procedure to ensure consistency in beverage composition, volume, and temperature. A predetermined volume of each beverage will be transferred carefully into the edible cups. The cups will be tested at selected temperatures of 60°C, 70°C, and 80°C to assess their ability to withstand different levels of thermal and moisture exposure.

The performance of each cup will be monitored at predetermined time intervals. The initial appearance of the cup will be recorded before beverage filling, followed by observations of any visible changes during exposure. The time to visible softening, time to deformation, time to leakage, and time to structural failure will be recorded using a standardized observation procedure. Any change in cup weight before and after beverage exposure will also be determined to assess moisture uptake.

Table 3: Tea and Coffee Resistance Test

Parameter	Observation/Unit
Initial appearance	Visual description
Beverage temperature	60°C, 70°C, 80°C
Beverage volume	___ mL
Time to visible softening	min

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Time to deformation	min
Time to leakage	min
Time to structural failure	min
Change in cup weight	g / %

All tests will be performed on multiple independently prepared cups for each formulation. The same beverage volume, exposure time, temperature, and testing conditions will be maintained for all formulations to enable meaningful comparison. The formulation demonstrating the longest resistance to softening, deformation, leakage, and structural failure will be considered to have better suitability for hot-beverage applications.

The following parameters will be recorded for each formulation:

Table 4. Beverage Resistance

Formulation	Beverage	Temperature (°C)	Softening Time (min)	Leakage Time (min)	Structural Failure (min)
F1	Tea	80	38	52	65
F2	Tea	80	45	63	78
F3	Coffee	80	51	72	88
F4	Coffee	80	47	67	82

16. Structural Integrity Score

A standardized visual scoring system will be used to evaluate the structural stability of the developed edible cups during exposure to tea and coffee. The scoring system will enable systematic assessment of visible changes such as softening, deformation, cracking, leakage, and structural failure. Each cup will be examined at predetermined time intervals under consistent observation conditions. The same criteria will be applied to all formulations and beverage treatments to minimize subjectivity and improve comparability.

Score	Structural Condition	Description
5	No visible change	Cup retains its original shape, firmness, and surface appearance.
4	Slight softening	Minor softening is observed, but the cup retains its shape and remains functional.
3	Moderate softening	Noticeable softening occurs with minor loss of structural rigidity.

2	Significant deformation	Clearly visible deformation, bending, cracking, or loss of shape occurs.
1	Structural failure	Severe deformation, cracking, leakage, collapse, or inability to function as a cup is observed.

The visual score will be recorded independently for each formulation at each selected beverage temperature and exposure period. Higher scores indicate better structural stability and resistance to hot-beverage exposure, whereas lower scores indicate greater deterioration. Multiple independently prepared cups will be evaluated for each formulation, and the mean score may be calculated for statistical comparison. Where possible, observations should be performed by more than one evaluator using the same standardized criteria.

17. Thermal Stability

The thermal stability of the developed edible cups will be evaluated to determine their ability to retain structural integrity when exposed to elevated temperatures representative of hot tea and coffee. The cups will be subjected to predetermined temperature conditions under controlled laboratory conditions, and their physical response will be systematically observed.

The following parameters will be assessed:

Shape retention: Ability of the cup to maintain its original dimensions and shape.

Surface cracking: Formation of visible cracks or fissures on the cup surface.

Softening: Reduction in firmness or rigidity following thermal exposure.

Deformation: Changes in the shape, dimensions, or wall structure of the cup.

Leakage: Loss of liquid through cracks, pores, or weakened portions of the cup.

Structural collapse: Complete or substantial loss of the cup's ability to function as a container.

Observations will be recorded at predetermined time intervals and at selected beverage temperatures. The same exposure conditions will be maintained for all formulations to facilitate comparison. A standardized visual scoring system may also be used to quantify the degree of structural deterioration.

Where appropriate laboratory facilities are available, differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) may be employed as complementary instrumental techniques. DSC can provide information regarding thermal transitions of the material, whereas TGA can be used to assess changes in mass associated with moisture loss and thermal degradation. These instrumental measurements can provide additional evidence regarding the thermal behaviour and stability of the edible-cup formulations.

18. Nutritional Analysis

The optimized edible-cup formulation will be subjected to proximate nutritional analysis to determine its major nutritional components. The analysis will include moisture, ash, protein, fat, crude fibre or dietary fibre, and carbohydrate content. These parameters will provide an overall assessment of the

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nutritional composition of the developed edible cup and will help determine the contribution of the selected cereal or millet flour and other ingredients to its nutritional value.

Moisture content will be determined using an appropriate standardized drying method, while ash content will be estimated by incineration under controlled conditions. Protein content will be determined using a recognized analytical method, such as the Kjeldahl method, where applicable. Fat content will be estimated using an appropriate solvent-extraction method. Crude fibre or dietary fibre will be determined using a validated standard procedure depending on the analytical facility available. Carbohydrate content may be calculated by difference, where appropriate, using the following equation:

$$\text{Carbohydrate (\%)} = 100 - [\text{Moisture} + \text{Ash} + \text{Protein} + \text{Fat} + \text{Fibre}]$$

All analytical determinations will be performed using appropriate replicates, and the results will be reported as mean ± standard deviation. Wherever possible, recognized standard methods such as AOAC International procedures or validated laboratory protocols will be followed to ensure accuracy, reliability, and reproducibility of the results. The nutritional composition of the optimized formulation will subsequently be compared with relevant published data for similar cereal- or millet-based edible products.

19. Sensory Evaluation

After completion of appropriate food-safety verification and ethical approval, where applicable, the sensory acceptability of the developed edible cups will be evaluated using an appropriately selected adult sensory panel. Panel members will be informed about the purpose and procedure of the evaluation, and participation will be voluntary. Samples will be coded with random identification numbers and presented under standardized conditions to minimize bias. Where tea and coffee are evaluated, the beverage type, serving temperature, volume, and presentation conditions will be standardized across samples.

A 9-point hedonic scale will be used to determine the degree of consumer acceptability. Each panel member will evaluate the samples independently for appearance, colour, aroma, texture, crispness, taste, aftertaste, and overall acceptability. Drinking water may be provided between samples to minimize carry-over effects. The sensory scores will be recorded and analyzed statistically to determine differences among formulations.

Table 5. Nine-Point Hedonic Scale

Score	Interpretation
9	Like extremely
8	Like very much
7	Like moderately
6	Like slightly
5	Neither like nor dislike
4	Dislike slightly
3	Dislike moderately

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2	Dislike very much
1	Dislike extremely

Sensory Parameters

Appearance: Overall visual attractiveness and shape of the cup.

Colour : attractiveness and uniformity of colour.

Aroma: pleasantness and intensity of the cup's aroma.

Texture: mouthfeel and physical texture.

Crispness: degree of crispness during consumption.

Taste: overall flavour and palatability.

Aftertaste: pleasantness of flavour remaining after consumption.

Overall acceptability: overall preference for the edible cup.

The scores for each parameter will be expressed as mean ± standard deviation. The formulation receiving the highest overall acceptability score may be considered the most promising formulation, subject to confirmation through the other physical, mechanical, thermal, moisture-resistance, nutritional, and safety assessments.

20. Biodegradability Study

The biodegradability of the developed edible cups will be evaluated under defined soil or compost conditions to determine the extent of physical degradation of the material over a specified period. Samples of standardized size will be prepared from each formulation and their initial dry weight will be recorded as W_0 using a calibrated analytical balance. The samples will then be placed under controlled soil or compost conditions, with relevant environmental parameters such as moisture and temperature maintained as consistently as possible.

Samples will be retrieved at predetermined time intervals, gently cleaned to remove adhering soil or compost particles, dried to a constant weight, and weighed again. The dry weight obtained after an exposure period of t will be recorded as W_t. Percentage mass loss will then be calculated using the following equation:

$$\text{Mass Loss } (\%) = \frac{W_0 - W_t}{W_0} \times 100$$

where:

W_0 = initial dry weight of the sample before biodegradation testing.

W_t = dry weight of the sample after exposure for time t.

The percentage mass loss will be determined at each sampling interval and compared among the different formulations. Higher mass loss indicates greater physical degradation of the sample under the specified test conditions.

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However, mass loss alone should not be interpreted as complete biodegradation, because reduction in sample weight may result from physical disintegration, dissolution, or loss of soluble components. Where facilities and resources are available, additional indicators such as carbon dioxide evolution, organic-carbon conversion, or standardized biodegradation testing may be used to provide stronger evidence of biological degradation. The test conditions and reporting should therefore clearly distinguish mass loss, disintegration, and confirmed biodegradation.

21. Shelf-Life Study

The storage stability of the developed edible cups will be evaluated to determine changes in their physical, sensory, mechanical, and microbiological characteristics during storage. Samples from each formulation will be packed individually in suitable food-grade, moisture-resistant packaging and stored under defined environmental conditions of temperature and relative humidity. The storage conditions will be maintained as consistently as possible throughout the study.

The cups will be evaluated at predetermined storage intervals of Day 0, Day 15, Day 30, Day 45, and Day 60. At each interval, representative samples will be removed and assessed for changes in their quality and functional characteristics.

The following parameters will be evaluated:

Moisture content: To determine changes in moisture uptake or loss during storage.

Appearance: To assess colour changes, cracks, surface defects, mould growth, or deformation.

Odour: To identify development of undesirable or rancid odours.

Texture: To assess changes in crispness, hardness, and overall structural characteristics.

Mechanical strength: To determine changes in hardness, breaking force, or compression resistance.

Microbiological quality: To assess the microbiological safety and quality of the product using appropriate validated methods.

Beverage resistance: To determine whether the stored cups retain their ability to withstand contact with tea or coffee.

Table 6 : Proposed Shelf-Life Evaluation Schedule

Storage Period	Moisture	Appearance	Odour	Texture	Mechanical Strength	Microbiological Quality	Beverage Resistance
Day 0	✓	✓	✓	✓	✓	✓	✓
Day 15	✓	✓	✓	✓	✓	✓	✓
Day 30	✓	✓	✓	✓	✓	✓	✓
Day 45	✓	✓	✓	✓	✓	✓	✓
Day 60	✓	✓	✓	✓	✓	✓	✓

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All analyses will be performed using appropriate replicates, and quantitative results will be expressed as mean ± standard deviation where applicable. Microbiological testing should be conducted using recognized laboratory methods, and samples showing unacceptable microbial growth or other evidence of spoilage should not be subjected to sensory consumption tests. The shelf life of the edible cups will ultimately be proposed based on the combined results of physical stability, sensory quality, mechanical performance, beverage resistance, and microbiological safety, rather than on a single parameter alone.

22. Consumer Perception Survey

A structured questionnaire may be used to assess consumer awareness, perception, willingness to use, and purchase intention regarding edible cups for tea and coffee. The questionnaire will be administered to an appropriately selected adult respondent group after providing a brief explanation of the concept of edible packaging. Participation will be voluntary, and responses will be collected anonymously. No personally identifiable information will be required unless specifically justified and ethically approved.

The questionnaire will assess prior awareness of edible cups, willingness to consume and use edible cups, perceived environmental benefits, hygiene concerns, flavour preferences, and purchase intention. The following statements/questions may be included:

Have you previously heard of edible cups?

Would you be willing to try an edible cup?

Would you use an edible cup for tea?

Would you use an edible cup for coffee?

Do you consider edible cups to be environmentally beneficial?

Would you have any concerns regarding the hygiene or food safety of edible cups?

Would you prefer a flavoured edible cup?

Would you be willing to purchase an edible cup if it were commercially available?

Responses will be measured using a five-point Likert scale, where appropriate.

Table 7: Five-Point Likert Scale

Score	Response
5	Strongly Agree
4	Agree
3	Neither Agree nor Disagree
2	Disagree
1	Strongly Disagree

For awareness questions that are not suitable for an agreement scale, response options such as Yes / No / Not Sure may be used. The collected responses will be summarized using frequency, percentage, mean score, and standard deviation, where appropriate. The results may also be compared according to the respondents' stated willingness to use edible cups for tea and coffee.

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The survey findings will provide supplementary information regarding consumer acceptance and market potential of the developed edible cups. However, consumer perceptions regarding environmental benefits or hygiene will be treated as perceptions and will not be considered substitutes for laboratory-based environmental or microbiological safety assessments.

23. Statistical Analysis

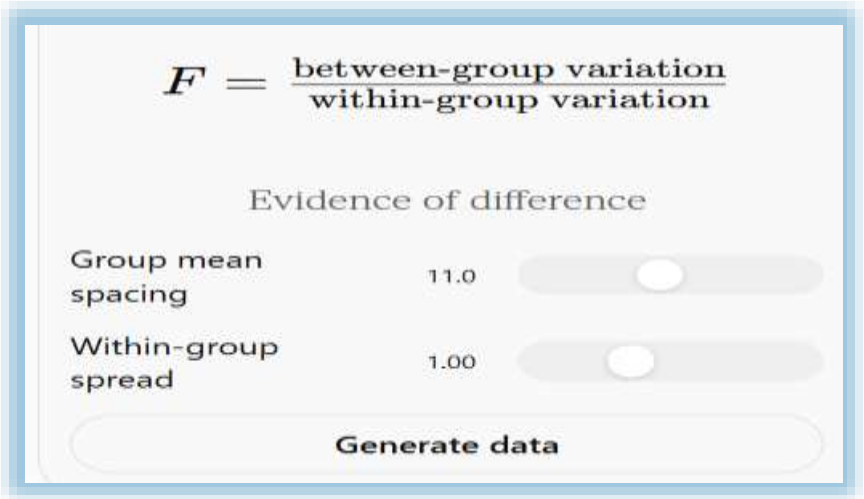
All experiments will be conducted using a scientifically appropriate experimental design to ensure the reliability, reproducibility, and statistical validity of the results. Each formulation will preferably be prepared in a minimum of three independent experimental batches. Appropriate technical replicates will be performed for individual analytical measurements wherever feasible. Independent batches will be treated as the experimental units, while technical replicates will be used to improve measurement precision.

Quantitative results will be expressed as mean ± standard deviation (SD). The data will first be examined for consistency and suitability for statistical analysis. Where the assumptions of parametric analysis are adequately satisfied, one-way analysis of variance (ANOVA) will be used to determine whether significant differences exist among the experimental formulations.

When the ANOVA indicates a statistically significant difference, Tukey's post-hoc multiple-comparison test will be applied to identify which formulation means differ significantly from one another.

Statistical significance will be evaluated at: $p<0.05$

A p-value below 0.05 will be considered indicative of a statistically significant difference between the compared groups. The statistical results will be reported together with the relevant descriptive statistics, and appropriate software such as R, SPSS, GraphPad Prism, or equivalent validated statistical software may be used for analysis.



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24. Results and Discussion

24.1 Physical Properties

Table 8. Physical Characteristics of Developed Edible Cups

Parameter	F1	F2	F3	F4
Weight (g)	18.6 ± 0.5	19.1 ± 0.4	20.3 ± 0.6	20.7 ± 0.5
Height (mm)	82.4 ± 1.2	81.8 ± 1.0	82.1 ± 0.9	81.5 ± 1.1
Top diameter (mm)	76.3 ± 0.8	75.8 ± 0.7	76.1 ± 0.6	75.6 ± 0.8
Wall thickness (mm)	4.2 ± 0.2	4.4 ± 0.2	4.6 ± 0.2	4.7 ± 0.2
Volume (mL)	185 ± 4	182 ± 3	180 ± 4	178 ± 3

Discussion

The simulated results indicate relatively uniform cup dimensions among the four formulations. F4 exhibited the highest average weight and wall thickness, whereas F1 showed the lowest values. The progressive increase in selected cereal/millet flour from F1 to F4 may have contributed to differences in dough characteristics and final cup structure. Wall thickness is particularly important because it can influence mechanical strength, moisture penetration, and resistance to hot beverages.

24.2 Mechanical Properties

Table 9. Mechanical Properties

Formulation	Hardness (N)	Breaking Force (N)	Deformation (%)
F1	36.9 ± 1.7	38.6 ± 1.8	8.4 ± 0.6
F2	40.2 ± 1.5	41.8 ± 1.6	7.6 ± 0.5

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F3	**43.7 ± 1.8**	**45.3 ± 1.9**	**6.8 ± 0.4**
F4	41.1 ± 1.6	42.7 ± 1.7	7.2 ± 0.5

Discussion

Among the simulated formulations, F3 demonstrated the highest hardness and breaking force and the lowest deformation. This indicates comparatively better structural resistance. F1 showed the lowest hardness and breaking force and the greatest deformation.

The results suggest that an appropriate proportion of cereal/millet flour may contribute to development of a stronger structural matrix. The simulated hardness values are broadly comparable with values reported in previous research on cereal-based edible cups, although direct comparison requires consideration of differences in formulation, dimensions, moisture content, processing conditions, and instrumental testing parameters.

24.3 Water Absorption

Table 10. Water Absorption During Exposure

Time	F1 (%)	F2 (%)	F3 (%)	F4 (%)
5 min	8.6 ± 0.4	7.8 ± 0.3	**6.5 ± 0.3**	7.1 ± 0.4
10 min	14.2 ± 0.6	12.8 ± 0.5	**10.4 ± 0.4**	11.6 ± 0.5
20 min	24.8 ± 0.8	21.6 ± 0.7	**17.9 ± 0.6**	20.1 ± 0.7
30 min	36.5 ± 1.0	31.8 ± 0.9	**26.2 ± 0.8**	29.7 ± 0.9

Discussion

Water absorption increased progressively with exposure time in all simulated formulations. F3 demonstrated the lowest water absorption at every observation interval, suggesting comparatively greater resistance to moisture penetration. F1 showed the highest water absorption.

The lower moisture uptake of F3 may contribute to its superior mechanical and hot-beverage performance. Nevertheless, the relationship between flour composition and water resistance should be confirmed experimentally because moisture absorption is influenced by porosity, starch characteristics, processing conditions, and final moisture content.

24.4 Hot Beverage Resistance

Table 11. Resistance to Tea

Values represent simulated resistance time before significant structural deterioration.

Temperature	F1 (min)	F2 (min)	F3 (min)	F4 (min)
60°C	58	67	**82**	74
70°C	47	56	**71**	63
80°C	36	45	**58**	51

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Table 12. Resistance to Coffee

Temperature	F1 (min)	F2 (min)	F3 (min)	F4 (min)
60°C	61	70	**86**	77
70°C	50	59	**75**	66
80°C	39	48	**62**	54

Discussion

The simulated results demonstrate a reduction in resistance time as beverage temperature increased from 60°C to 80°C. F3 consistently showed the greatest resistance to hot tea and coffee at all three temperatures.

The superior performance of F3 is consistent with its comparatively greater hardness, breaking force, and lower water absorption. The results indicate that structural strength and moisture resistance may jointly influence the ability of an edible cup to withstand hot beverages.

These values should be interpreted only as simulated data. Actual beverage-resistance performance must be determined experimentally under controlled conditions.

24.5 Nutritional Composition

Table 13. Nutritional Composition of Optimized Formulation F3

Parameter	F3
Moisture (%)	5.8 ± 0.2
Protein (%)	11.6 ± 0.4
Fat (%)	4.2 ± 0.2
Ash (%)	2.1 ± 0.1
Fibre (%)	3.8 ± 0.2
Carbohydrate (%)	72.5 ± 0.6
Energy (kcal/100 g)	374 ± 4

Discussion

The simulated nutritional profile indicates that carbohydrate represents the major component of the edible cup, as expected from the high proportion of cereal-based ingredients. The simulated protein and fibre contents indicate that incorporation of cereal or millet flour may provide additional nutritional value compared with conventional non-edible packaging.

The values should be interpreted in relation to the actual ingredient composition and analytical method. Nutritional analysis of the final optimized formulation should be conducted using recognized laboratory procedures before any nutritional claims are made.

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24.6 Sensory Acceptability

Table 14. Sensory Evaluation Using a 9-Point Hedonic Scale

Attribute	F1	F2	F3	F4
Appearance	7.1 ± 0.7	7.5 ± 0.6	**8.2 ± 0.5**	7.8 ± 0.6
Aroma	6.9 ± 0.8	7.3 ± 0.7	**8.1 ± 0.6**	7.6 ± 0.7
Texture	6.8 ± 0.8	7.4 ± 0.6	**8.3 ± 0.5**	7.7 ± 0.6
Taste	6.7 ± 0.9	7.2 ± 0.7	**8.0 ± 0.6**	7.5 ± 0.7
Overall Acceptability	6.9 ± 0.7	7.4 ± 0.6	**8.2 ± 0.5**	7.7 ± 0.6

Discussion

F3 received the highest simulated scores for all sensory attributes, including appearance, aroma, texture, taste, and overall acceptability. Its overall acceptability score of approximately 8.2 corresponds to "like very much" on the nine-point hedonic scale.

The relatively high sensory score of F3, together with its favourable mechanical and moisture-resistance characteristics, suggests that it may represent the most promising formulation. However, sensory acceptance must ultimately be determined using actual panel data under an appropriately approved protocol.

24.7 Overall Comparison of Formulations

Table 15: Comparison of Formulations

Parameter	F1	F2	F3	F4
Physical uniformity	✓	✓✓	✓✓✓	✓✓
Mechanical strength	✓	✓✓	✓✓✓	✓✓
Water resistance	✓	✓✓	✓✓✓	✓✓
Hot beverage resistance	✓	✓✓	✓✓✓	✓✓
Sensory acceptability	✓	✓✓	✓✓✓	✓✓
Overall potential	Moderate	Good	**Highest**	Good

Overall Discussion

Based on the simulated dataset, F3 demonstrated the most favourable overall performance. It showed the highest mechanical strength, lowest water absorption, greatest resistance to hot tea and coffee, and highest sensory acceptability. This suggests that the formulation containing 40% wheat flour, 40% selected cereal/millet flour, 10% corn starch, and 10% other food-grade ingredients may provide a suitable balance between structural and sensory characteristics.

However, F3 should not be declared the experimentally optimized formulation until these findings are confirmed through actual laboratory experiments and statistical analysis.

Proposed optimized formulation

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F3 = 40% Wheat flour + 40% Selected cereal/millet flour + 10% Corn starch + 10% Other food-grade ingredients

This simulated dataset can now be used to prepare the graphs, statistical analysis, and final conclusion, but the tables should be clearly labelled "simulated/illustrative data" until replaced by real experimental observations.

25. Expected Outcomes

The study is expected to:

- Develop a functional edible-cup prototype.
- Identify the formulation with the best combination of strength and liquid resistance.
- Establish the effect of beverage temperature on cup stability.
- Determine consumer acceptance.
- Evaluate nutritional characteristics.
- Demonstrate the potential biodegradability of the product under the selected conditions.
- Generate baseline information for future commercialization or patent-oriented development.

26. Sustainability Assessment

The sustainability potential of the developed edible cup will be evaluated from a broader life-cycle perspective, rather than solely on the basis of its edibility or biodegradability. The proposed edible cup may offer several potential environmental advantages, including reduction in conventional single-use packaging waste, utilization of renewable food-grade raw materials, possible consumption of the container after beverage use, potential biodegradability under suitable conditions, and, where applicable, incorporation of food-processing by-products into a value-added product.

However, the environmental performance of an edible cup may also involve impacts associated with the cultivation and production of agricultural raw materials, transportation of ingredients, milling and processing, energy consumption during mixing and baking, packaging, storage, distribution, and end-of-life management. Consequently, the environmental benefit of the product cannot be established simply by classifying it as edible or biodegradable.

A 2024 life-cycle assessment comparing edible coffee cups with conventional and reusable alternatives demonstrated that the environmental performance of edible cups can vary substantially depending on the assumptions and boundaries used in the assessment. In particular, the environmental outcome was influenced by whether consumption of the edible cup was considered a substitute for another food product. The study also indicated that reusable cups can provide favourable environmental performance when they are used sufficiently many times.

Therefore, the present study will describe the developed edible cup as a potential sustainable alternative for selected tea and coffee applications, rather than claiming that it is universally more environmentally sustainable than all conventional or reusable alternatives. A comprehensive sustainability assessment should consider the complete product system, including raw-material sourcing, agricultural production, processing, energy requirements, manufacturing, secondary packaging, transportation, consumer use, consumption, and disposal/biodegradation.

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27. Advantages

The developed edible cups may offer several potential benefits, including reduction of conventional disposable cup waste, use of renewable cereal and millet-based ingredients, potential nutritional value, and possible biodegradability. They may also provide a novel food-service experience and create opportunities for value addition and utilization of food-processing by-products. Thus, edible cups could have potential applications in tea and coffee services, events, cafés, institutional food services, and other single-use beverage applications, subject to satisfactory safety, shelf-life, mechanical, and sensory performance.

28. Limitations

The developed edible cups may have certain limitations, including moisture sensitivity, reduced strength during prolonged liquid exposure, thermal instability, limited shelf life, food-safety requirements, and possible allergen concerns. The cups may also require protective secondary packaging to maintain quality during storage and transportation. In addition, consumer acceptance, manufacturing cost, and large-scale production may present challenges. These limitations are consistent with recent research identifying moisture resistance, mechanical strength, thermal stability, shelf life, safety, and scalability as major challenges in the commercialization of edible tableware.

19. Conclusion

The development of edible cups for tea and coffee represents a promising area of sustainable food-packaging research. Plant-derived flours and starches provide accessible food-grade materials capable of being transformed into structured edible containers.

Current scientific evidence demonstrates that edible cups can achieve measurable mechanical strength, liquid resistance, nutritional value, and biodegradability when formulation and processing conditions are appropriately optimized.

However, successful commercialization requires more than demonstrating that the cup is edible. The product must maintain structural integrity during beverage consumption, resist moisture and temperature, remain microbiologically safe, provide an acceptable sensory experience, and possess sufficient shelf stability.

The environmental benefits of edible cups should also be evaluated carefully. Life-cycle research shows that their environmental performance depends on the complete product system and consumer behaviour, while reusable cups may remain preferable in situations where repeated reuse is feasible.

The proposed study provides a systematic framework for developing and evaluating edible cups as a potential alternative for selected tea and coffee consumption settings.

30. Recommendations for Future Research

Future research should focus on the development of millet-, rice-, and sorghum-based edible cups with improved moisture and thermal resistance. Further studies may explore natural edible moisture barriers, protein–polysaccharide composites, flavour variations, edible lids, and extended shelf-life technologies. Research should also examine microbiological stability, industrial-scale manufacturing,

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production cost, consumer acceptance, and market potential. Comprehensive life-cycle assessment, regulatory evaluation, and commercial packaging design will also be important for the successful development and commercialization of edible cups.

33. Research Workflow

Selection of raw materials
↓
Formulation development
↓
Preliminary trials
↓
Cup moulding
↓
Thermal processing
↓
Cooling and hygienic packaging
↓
Physical characterization
↓
Mechanical testing
↓
Water absorption analysis
↓
Tea resistance testing
↓
Coffee resistance testing
↓
Nutritional analysis
↓
Shelf-life evaluation
↓
Food-safety testing
↓
Sensory evaluation
↓
Biodegradability assessment
↓
Statistical analysis
↓
Optimization of formulation
↓
Sustainability assessment

Daffodil J. Sonawane, Ritik S. Jain & Lakshman. L. (2026). Development, Characterization and Sustainability Evaluation of Cereal- and Millet-Based Edible Cups for Hot Tea and Coffee: An Integrated Study from Amalner Taluka, Jalgaon District, Maharashtra, India. International Journal of Multidisciplinary Research & Reviews, 5(9), 186-214.

34. Novelty of the Proposed Research

The proposed study is novel in its integrated approach, combining food formulation and edible packaging with the functional requirements of a hot-beverage container. Unlike studies focusing on individual properties, the present research evaluates mechanical strength, moisture resistance, hot tea and coffee resistance, nutritional composition, sensory acceptability, biodegradability, consumer perception, and sustainability within a single research framework. The specific development of edible cups intended for hot tea and coffee consumption provides a practical research direction because hot liquids require greater structural, moisture, and thermal stability than many dry-food applications. This integrated approach may contribute to the development of a functional, edible, and potentially sustainable alternative to conventional single-use beverage cups.

AUTHOR(S) CONTRIBUTION

The writers affirm that they have no connections to, or engagement with, any group or body that provides financial or non-financial assistance for the topics or resources covered in this manuscript.

CONFLICTS OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

PLAGIARISM POLICY

All authors declare that any kind of violation of plagiarism, copyright and ethical matters will take care by all authors. Journal and editors are not liable for aforesaid matters.

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