CHAPTER I

INTRODUCTION

Urbanization and rapid industrialization have contributed to an increased production and utilization of Single Use Plastics (SUP) including cutlery and crockery, designed to use once and then discarded, ends up as landfills and destroy the marine ecosystem thus creating a negative impact on biodiversity. The growing demand for ecofriendly and edible alternatives is constantly increasing to replace conventional SUPs made of synthetic polymers. Consumer awareness for responsible consumption and government regulations and bans on synthetic SUP including bags, cutlery and crockery and other disposable items lays a foundation to develop a sustainable solution. The present research is a small footprint towards innovating edible millet tableware as a sustainable substitute for single-use cutlery in the food service-based sectors.

Moshood *et al*. (2022) stated that, plastic pollution is an alarming global issue, with more than 380 million tons of plastics being produced annually, out of which only 9 per cent were recycled. SUP, contributing nearly 40 per cent of the total plastic pollution, that leads to 8 million tons of waste entering into the oceans yearly, harming marine life, ecosystem, and human health (Kibria *et al*., 2023; Kumar *et al*., 2021). The global plastic production was around 350 million metric tonnes in 2018, and SUPs shared half of the total (Chen *et al*., 2021; Kankanige and Babel, 2020; Boucher *et al*., 2019).

The increase in plastic waste was directly linked to the growing need for plastic cutlery due to its convenience in the food packaging industry (Sazeli *et al.*, 2021). The demand and usage of disposable single use cutlery is increased owing to the modernized takeaway services in the food and beverage industries, and fast-paced lifestyles. It includes disposable cup, plate, spoon, fork and other cutlery that is manufactured from petroleum-based materials, namely, polystyrene, polypropylene, or polyethylene. It is non-biodegradable, that accumulates in landfills and ecosystems, and eventually break down into macro-, micro- and nano-plastics due to irradiation, heat or mechanical stress (Shen *et al*., 2020; Boucher *et al*., 2019). Microplastics has become the widespread environmental pollution causing numerous health hazards and researchers found microplastics everywhere including food chains, drinking water and bodily fluids, posing significant health risks and impeding the achievement of several Sustainable Development Goals (SDGs), making it a pressing global challenge.

Recent studies found, microplastics in human organs and bodily fluids, including liver, blood, heart, placenta, breast milk, semen and urine. In particular, microplastics are found in 38 per cent of breast milk sample (23 out of 59) and the sources of microplastics are identified from polymers (polypropylene, polyethylene, polystyrene, and polyvinyl chloride) used in the manufacturing of SUP (Saraluck *et al*., 2024; Enyoh *et al*., 2023). Migration of microplastics from packaging materials into food items decreases its nutritive value, safety and organoleptic properties (Muzeza *et al*., 2023). Inhalation of microplastics leads to respiratory issues, oxidative stress, inflammation and toxicity (Li *et al*., 2022a). Microplastics breaks the intestinal epithelial barrier causing inflammatory bowel disease (Yan *et al*., 2021); and deregulation in microRNA that leads to cancer (Tiwari *et al*., 2023).

The effects of microplastics from SUPs has created a strong need to find a safe and sustainable packaging materials (Walker *et al*., 2021). Initially, researchers have developed a paper disposable tableware as an eco-friendly alternative to plastic cutlery which is coated with polyethylene to make it liquid-resistant. However, the polyethylene coating on paper disposables could migrate and contaminate food or beverages and its recycling process is also complicated. Large-scale production of paper tableware contributes to deforestation, biodiversity loss, climate change, and soil degradation, are the limitations that caused environmental challenges and highlighted the need for sustainable alternatives (Buxoo & Jeetah, 2020). The limitations of paper-based cutlery are addressed by biodegradable and ecofriendly packaging material which is the sustainable alternative.

Biodegradable packaging material is an eco-friendly alternative that would be, low in density, cost effective, and easy to process, and to support advanced packaging designs (Poonkodi *et al.,* 2022). The global market for biodegradable packaging is projected to grow at a Compound Annual Growth Rate (CAGR) of 15.3 per cent from 2021 to 2028, driven by rising environmental concerns and stringent regulations on SUPs. Survey on consumption and acceptance of ecofriendly and edible packaging found that, 64 per cent of consumers are willing to pay a premium cost for food products that are both sustainable and beneficial to health (Mintel 2023; Grand View Research, 2022). Biodegradable plastics offers an alternative in combating plastic pollution due to its degradation properties, but its production cost and manufacturing process is a big investment making it as a costlier product than SUP (Moshood *et al*., 2022). These challenges emphasize the growing need for sustainable solutions (Kumar *et al*., 2021); that also leads to the increasing demand for sustainable, affordable, and eco-friendly packaging solutions like edible and compostable materials (Kibria *et al*., 2023; Moshood *et al*., 2022).

Recent developments in edible packaging have shown promising potential to replace conventional plastic materials and also to increase the nutritional value and functional properties. Research has explored a variety of plant-based materials, such as seaweed, rice bran, and potato starch, for the formulation of biodegradable edible packaging and coatings that effectively enhance shelf life of various packed foods by providing protective barriers against spoilage and microbial contamination (Otoni *et al*., 2017). Researchers and innovators around the world found a sustainable solution to overcome the growing issues of SUP cutleries through edible cutlery and crockery. It was formulated from edible sources including plants and seaweeds that was biodegradable, consumable and nutritious (Gupta & Sanghi, 2023). The market demand for edible cutlery was USD 41.9 billion in 2023 that would expect to increase, 10.7 per cent from 2023 to 2030. Government regulations, awareness among people to use edible cutlery and its ease of disposal and biodegradable in nature increased the growth rate of edible and ecofriendly cutlery (Grand View Research, 2024 – 2030).

Edible cutlery provides an innovative solution to plastic pollution by addressing the growing consumer demand for eco-friendly products. The formulation and standardisation of edible packaging, such as millet-based bowls, serve as biodegradable alternatives to single-use plastics (SUPs) that plays an important note in reducing the environmental impact caused by SUPs (Jaspal *et al.,* 2024; Chowdhury *et al.,* 2021). Developing functional and biodegradable packaging materials from millets especially sorghum presents a significant research gap with both economic and environmental benefits (Anal *et al.,* 2024). Edible cutleries and crockeries are gaining popularity which reduces plastic waste and promotes health and entrepreneurship (Kabir *et al*., 2022). Edible cutlery made from millets, cereals, soy protein isolate, brewers' spent grain, and fruit peels has been successfully developed using traditional baking methods (Jaspal *et al*., 2024; Nehra *et al*., 2024; Wulandari *et al*., 2023). The present study focused on formulating edible tableware from millets that provides a nutritious, non-toxic, and sustainable alternative to plastics and meets the growing consumer demand for eco-friendly alternatives.

India designated 2018 as the "Year of the Millets," and the Food and Agriculture Organization (FAO) recognized 2023 as the "International Year of the Millets," underscoring millets' value as one of the oldest and most nutritious crops, surpassing wheat and rice in nutrient content (Meena *et al.,* 2024). The inclusion of millets in different forms should be promoted as they contain abundant nutrients as similar to cereals. It can be included in diet to assist the need for protein, energy, B complex vitamins and fiber and to

meet daily requirement. Millets are easily affordable, locally available, that requires minimal processing or can be consumed as whole, adds diversity in diet and provides satiety with several health-promoting properties (Priya *et al.,* 2024).

Millet, a resilient cereal crop from the grass family (Poaceae), often called as the "miracle grain" or "crop of the future" due to its sustainable cultivation, requiring minimal resources, thriving in marginal soils, and adapting to diverse climatic conditions with low irrigation needs (Chaurasia *et al.,* 2023; Mohod *et al.,* 2023)**.** Sorghum, pearl millet, finger millet are the major millets and barnyard millet, proso millet, kodo millet, little millet and foxtail millet are the small or minor millets (Chaurasia *et al.,* 2023; Kumari *et al.,* 2023; Sukumaran Sreekala *et al.,* 2023) which suits to various agroclimatic conditions that is commonly cultivated in India as well as in various countries (Sathish Kumar *et al.,* 2022; Bhatt *et al.,* 2022; Singh *et al.,* 2020). Over 20 per cent of the world's millets are produced in India, which also accounts for roughly 20 per cent of the world's millet growing area. The two most common millet crops are sorghum and pearl millet, and pearl millet accounts for more than 90 per cent of the world's millet output whereas sorghum accounts for 65 per cent among the cultivated millet (Sachan *et al.,* 2023; Bhatt *et al.,* 2022).

Consumption of millet in daily diet have been decreased over the period of time due to lack of knowledge, increased cooking time, and insufficient varieties of processed food items (Bhatt *et al.,* 2022). Government and food manufacturers took efforts to increase the consumption and utilization of millets, particularly sorghum, to help farmers to cultivate more resilient crops and have an initiative to overcome hunger, among vulnerable population (Kane-Potaka *et al.,* 2021). Pearl millet and sorghum are the two major millets that are commonly cultivated in India which is chosen for the present study to formulate and standardise edible tableware.

Pearl millet, the world's sixth most cultivated, produced and consumed grain and the fourth most significant tropical cereal grain after rice, maize, and sorghum that thrives in marginal, arid, and semiarid tropical and subtropical regions. It is also rich in essential nutrients like folate, copper, zinc, iron, magnesium, calcium, vitamin B complex, and unsaturated fatty acids (Bhatt *et al.,* 2022; Saini *et al.,* 2021). Pearl millet also exhibits good textural and water-holding properties, offers as an excellent raw material for formulating a variety of food applications (Meena *et al.,* 2024).

Pearl millet is considered as the poor man’s bread and the conventional and modernized techniques provides an extensive choice of numerous products including extruded and baked products. Traditionally, it is consumed in the form of fermented

beverage (uji and dolo) but the modernized processing techniques altered the consumption pattern into ready-to-eat products and breakfast cereals (Nengparmoi *et al*., 2024).

Pearl millet is superior in protein, dietary fiber and micronutrients which can be enhanced through processing and non-thermal processing methods (UV irradiation, high pressure processing, pulsed electric field) shows potential increase in nutrient content and decreases the antinutritional factors (Mundassery *et al*., 2024; Eduru *et al*., 2021). Consumption of pearl millet as staple food reduce malnutrition among general population and reduce chronic metabolic diseases like diabetes, obesity and aids in weight loss management (Jindal *et al*., 2023). The gluten-free nature of pearl millet plays a vital role in multigrain and gluten free food products which is suitable for celiac patients and persons suffered by irritable bowel disease (Rotela *et al*., 2021).

India is the prime capital for producing and consuming millets and sixth largest producer of sorghum globally. Sorghum is one of the nutritious millets, outranking cereals such as rice and wheat. It has evolved into five major species (*bicolor, guinea, caudatum, kafir, and durra*) and ten intermediate hybrids based on panicle and spikelet structures. *S. bicolor*, in particular, was globally cultivated for food, fodder, alcoholic beverages, and biofuel production (Bhatt *et al.,* 2022; Li *et al.,* 2022b). Sorghum can be consumed as a cereal substitute which is packed with micronutrients and a good source of fibre, protein, antioxidants, and bioactive compounds, but its anti-nutritional factors like phytic acid and tannin, prevent from achieving its full nutritional potential. The effects of several wet and dry processing techniques, including steeping, fermentation, germination, roasting, and popping reduces the antinutritional factors of sorghum flour. The processing of sorghum, proved to have positive impact on the structural and chemical characteristics (Paliwal & Sharma, 2022; Anjitha *et al*., 2021). The primary phenolic compounds in sorghum are tannin, phenolic acids and 3-deoxyanthocyanidins with potential antioxidant activity. Consuming whole sorghum improves the gut health, lowers the risk of chronic diseases (Pontieri *et al.*, 2022) and is used as a promising raw material to standardise edible tableware.

Sorghum flour can be used as a better alternative for wheat flour as it was gluten free. 20 to 50 per cent can be blended in composite mixture for the preparation of bakery products. Sorghum consists more of slowly digestible resistant starch that reduces postprandial hyperglycemia and potentially reduce total calorie intake **(**Hassan *et al.,* 2021). Millet grains are abundant in nutrients and phenolic compounds that provides many functional properties and suitable for consumption for all age group community. Roasting

the sorghum, as a technique is used to yield bakery products with better functional and pasting properties and also increases the bioavailability of nutrients and antioxidant property. Hence, it is recommended for the celiac disease patients. Germination of millets showed the increase in nutritional quality and availability of B complex vitamins, iron, zinc and free sugars that helps in baking (Bajaj *et al.,* 2021). The global market for roasted sorghum products is expanding, driven by their gluten-free nature and appealing flavour profile. Recent research underscores the potential of sorghum and other millets in developing value-added products for health-conscious consumers, yet this potential remains largely untapped (More *et al.,* 2024; Madhu *et al.,* 2023).

The growing interest of consumers towards the inclusion of bioactive compounds in the daily diet has initiated the research on edible flowers. It is known for its ornamental value and nowadays, the scenario has shifted towards its nutritional and medicinal properties (Teixeira *et al*., 2023; Takahashi *et al*., 2020). The food industries have focused on consumer demand for nutritious and functional products, the utilization of novel ingredients such as fruits, vegetables, and edible flowers in new product development is on the rise, and it also emphasizes the ornamental, nutritional, and medicinal properties of edible flowers (Rashwan *et al*., 2021; Hnin *et al*., 2021). Edible flowers consist of 97 families, 100 genera, and 180 species, and its usage has increased due to its therapeutic properties in culinary applications and in food industries. Edible flowers are known for its high vitamins, minerals, and antioxidant content, that enhance the aesthetic appeal, taste, and flavour of food items and exhibits health benefits including protection against oxidative stress-related illnesses (Rivas-García *et al*., 2021; Skrajda-Brdak *et al*., 2020; Purohit *et al*., 2021). It exhibits less protein, and high carbohydrate and fibre content that could be recommended for carbohydrate-restricted diets in small amounts due to its dietary fibre content and the presence of abundant antioxidants that aids in reducing lifestyle disorders (Takahashi *et al*., 2020). Solar and shade drying are the standardised preservation techniques to enhance its nutritional value (Rivas-García *et al*., 2021; Purohit *et al*., 2021). Among the different edible flowers, agathi (*Sesbania grandiflora* (L.) Poir.), moringa (*Moringa oleifera* Lam.), hibiscus (*Hibiscus rosa-sinensis* L.), and rose (*Rosa damascena* Herrm.) are selected for the present study owing to its native, cost effective, nutritious and functional properties.

Agathi flowers are larger with red or white petals and its consumption offers numerous health benefits. It is used in treating fever, headache, diabetes and blood urea nitrogen which exhibits anti-diabetic and anti-microbial property and traditionally consumed in the form of infusions or decoctions. The flowers are rich in B complex vitamins

and its extract were used to cure several ailments (Baessa *et al.,* 2019). Agathi flowers are abundant in flavonoids and phenolic compounds that exhibit anti-bacterial properties against pathogens like *S. aureus, Shigella flexneri, Salmonella Typhi, E. coli,* and *Vibrio cholera*, which acts as an anti-microbial agent in food products. The presence of phenolic compounds and bioactive compounds aids in reducing oedema and inflammation and support nerve health by preventing acetylcholine degradation (Prabawati *et al*., 2021; Tun *et al*., 2021).

Moringa flowers are small, edible with potential therapeutic applications. It is rich in bioactive pigments, such as chlorophyll, anthocyanins, carotenoids, and lycopene, derivatives of fats and flavonoids. The flowers also have essential compounds such as alkaloids, flavonoids, flavanols, phenols, polyphenols, and anthocyanins, known for their potent antioxidant properties that help reduce the risk of chronic diseases (Patil *et al*., 2022; Hodas *et al*., 2021; Milla *et al*., 2021). Moringa flowers are non-toxic that exhibits better anti-inflammatory and enzyme-inhibitory properties which can be used in reducing oxidative stress and regulates biochemical reactions in the body (Fahmy *et al.,* 2024).

Rose flowers have long been used in traditional foods and ayurvedic medicine due to its therapeutic properties and edible in nature (Hegde *et al*., 2022). Rose is valued in traditional and modern medicine for its essential oils, that poses antioxidant, antibacterial, antimicrobial, and anti-inflammatory properties and were used to treat conditions like menstrual bleeding, inflammatory bowel disease (IBD), and gastroesophageal reflux (Trendafilova *et al*., 2023; Akram *et al*., 2020). Rose flowers provide a rich source of dietary phytochemicals, carotenoids, and phenolic acids, making them potent antioxidants with anti-inflammatory, anti-cancer, anti-aging, antimicrobial, hepatoprotective, and neurogenic properties (Hegde *et al*., 2022).

Hibiscus, recognized for its therapeutic benefits, adds a natural sour flavor and vibrant colour to foods and beverages and exhibits significant anti-bacterial, antioxidant, lipid-modulating, and insulin resistance-reducing effects (Shelke *et al*., 2021). Hibiscus flowers are rich in organic acids and phenolic compounds such as myricetin, quercetin derivatives, kaempferol, and anthocyanins, exhibit strong nutraceutical potential without cytotoxic effects (Dos Santos Silva *et al*., 2023). The bioactive phytochemicals present in rose and hibiscus flowers contributes significant health-promoting properties. Rose contains a variety of flavonoids, anthocyanins, proanthocyanidins, phenolic acids and resveratrol. Similarly, hibiscus provides phenolic acids, flavonoids, organic acids, lutein, tannins, and various anthocyanins, further enhancing its functional potential (Vasić *et al*., 2023; Shelke *et al*., 2021).

Edible flowers are a promising commercial horticultural crop that enhances the visual appearance and nutritive value of the food products and research on utilization of edible flowers in different food applications is highly needed. Inclusion of edible flowers in formulating food products would satisfy the market demand for healthy and functional foods (Pires *et al*., 2023). Hence, the present study focuses on enriching the millet tableware by adding the shade dried selected edible flower powder.

NEED OF THE STUDY

Plastic pollution has become the global concern and single use plastics represented a significant contributor. Among SUP waste, plastic cutlery from food packaging and service sector has increased due to its convenience which migrate into the food items as microplastics. The microplastics causes serious health issues and affects the ecosystem. It also decreases the nutritive value and sensory acceptance of the food. The increasing reliance on SUP in the food service sector has led to severe environmental consequences, including pollution, non-biodegradability, and ecological harm have created a pressing need for sustainable and alternative packaging material. Hence, the present study focuses on formulating edible and ecofriendly tableware from selected millet and enriching by selected flower powder to replace single-use cutlery in food service sector which would be a sustainable solution.

It is an innovative approach to address the alarming environmental impact of single-use plastic cutlery through the development of edible millet tableware from pearl millet and sorghum. The pearl millet and sorghum tableware are enhanced through conventional processing namely, germination and roasting that improves the functional properties of the edible tableware and contributes to add health benefits.

This study is a novel initiative to formulate, standardise and evaluate the quality of edible cup, bowl, katori, spoon and plate by addition of edible flowers in pearl millet and sorghum tableware. It enhances the antioxidant capacity and sensory appeal of the standardised tableware and offers a new approach in edible packaging research by formulating healthy, non-toxic and sustainable millet tableware.

The need for this study arises from the pressing environmental challenges posed by conventional disposable tableware, which is primarily made from non-biodegradable plastics, synthetic polymers or paper coated with petrochemical substances. While initial efforts have been made to develop edible and eco-friendly cutlery using millet as a raw material, these approaches have primarily relied on manual molding and oven baking. Such

methods are lack in scalability and further precision is required for broader commercial adoption. So, the study aims to address these limitations by focusing on developing millet tableware using specific closed molds in standardised shapes which can be easily reproduced and offers as a sustainable and biodegradable alternative to SUP.

Millets, being nutrient-dense, locally abundant, and environmentally friendly, presents as a promising raw material for developing edible and biodegradable tableware. Utilization of pearl millet and sorghum, the two abundant and nutrient-dense major millet as primary ingredient in significant quantities, to develop a sustainable alternative to single-use plastic cutleries with the better functional properties. The study also focusses on enhancing the mechanical strength, nutrient profile, and sensory attributes.

Conventional processing methods such as germination and roasting not only enhances the functional properties of millet but also makes it more adaptable for innovative applications. Incorporating native antioxidant-rich flowers further improves the practicality and appeal of millet tableware. By replacing single-use plastics with such eco-friendly solutions, this study aligns with global sustainability goals and offers an innovative approach to reduce plastic waste while promoting health and environmental benefits.

The significance of this study lies in its potential to offer a viable solution to the growing environmental health concerns associated with disposable tableware, while simultaneously promoting the use of underutilized millets, thereby supporting agricultural sustainability and reducing the ecological footprint of the food service industry. By addressing the current research gap, the present study contributes to the advancement of innovative, edible and biodegradable alternative for the global market to achieve Sustainable Development Goals (SDG).

RESEARCH HYPOTHESES

The research hypotheses of the present study are as follows,

i. The standardisation of edible millet-based tableware from pearl millet and sorghum that is enhanced by conventional processing techniques (germination, roasting) and enriched with antioxidant-rich flower powder provides a sustainable, eco-friendly, and functional alternative to single-use cutleries in the food service sector.

ii. Incorporating antioxidant-rich native flowers improves the sensory, and mechanical properties of millet tableware, making it suitable for practical use in the food service industry.

SCOPE OF THE STUDY

This study focuses innovating, edible and ecofriendly millet tableware, including cup, bowl, katori, spoon and plate, standardised using unique molds to promote sustainable practices in the food service sector. The study enhances the nutrient profile, sensory appeal, functional and mechanical properties of standardised millet tableware through conventional techniques such as germination and roasting of pearl millet and sorghum. The pioneering approach also aims to provide a viable alternative to single-use plastics, which pose significant environmental challenges. The integration of antioxidant-rich native flowers further improves the nutritional and functional attributes of the tableware. The strength and durability of the standardised and enriched millet tableware is confirmed through functional and textural properties. The shelf life and toxicity are determined by total microbial count and brine shrimp lethality assays. The present comprehensive study demonstrates the feasibility of millet tableware as a sustainable and innovative solution to reduce the environmental impact of single-use plastics, offering a pathway toward eco-conscious consumer choices in the food service industry including hospitality, entertainment, airline, and catering services.

OBJECTIVES

Primary Objectives

The primary objectives of the present study include,

- To analyze the properties of pearl millet and sorghum in unprocessed, germinated and roasted forms.
- To formulate and standardise millet tableware including cup, bowl, katori, spoon and plate using unique molds.
- To enrich the standardised millet tableware with selected flower powder to serve food and beverages at ambient, hot and cold temperature in the food service sector.

Secondary Objectives

The secondary objectives of the present study include,

- Identification and selection of major millets and native edible flowers.
- Formulation, standardisation and characterisation of millets tableware.
- Incorporation of selected flower powder and characterisation of standardised flower-enriched millet tableware.
- Shelf-life, toxicity and degradability analysis of the standardised flower-enriched millet tableware.