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Exploring the potential of mosambi peel and sago powder in developing edible spoons

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Nowadays, waste disposal is a major problem due to industrialization and urbanization. Agricultural waste and plastic waste disposal have increased heavily in the last few decades. Plastic cutlery is most used for food, but it contains many toxins and carcinogens that are harmful to humans and the environment. Also, agricultural waste dumped or burned in public places leads to environmental pollution. The aim of the study was to develop edible spoons by utilizing mosambi peel waste and sago and to evaluate their proximate composition, water absorption capacity, sensory attributes and their biodegradability. Developed spoons were ready to eat and biodegradable. A total of 11 samples were made of which two samples were considered controls namely, C1 (100% sago) and C2 (100% mosambi). In the remaining samples, the concentration was varied. Spoons were evaluated for their physicochemical properties: moisture (6.67 to 33.33%), ash (6.67 to 8.33%), fat (0.94 to 4.96%), and protein (1.65 to 2.33%). The water absorption tendency of spoons ranged between 56.67 and 172.67% and was found to increase with an increase in mosambi peel powder. Color values were L^* 0.10 to 45.23, for the a^* axis 6.90 to 70.83, and the b^* value ranged between 9.90 and 45.46. The concentration of mosambi peel powder had a significant effect on the color of the spoons. Sensory analysis was performed by using 9-point hedonic scales and S5 was highly acceptable by panellists with an overall acceptability of 8.67 ± 0.577. Spoons were found to be 46 to 60% degraded within 12 days. Based on the results, it can be inferred that utilizing mosambi peel powder along with sago starch could offer a viable and sustainable method for developing edible spoons that hold promising nutritional properties.

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Sustainability spotlight

This research paper sheds light on the pressing environmental challenges arising from waste disposal due to rapid industrialization and urbanization. With a particular focus on agricultural and plastic waste, this study seeks to address the detrimental impact of these waste streams on both human health and the environment. In response to the concerning consequences of conventional plastic cutlery usage, this research endeavors to propose an innovative and sustainable solution in the form of edible spoons. The motivation behind this study is to tackle the increasing accumulation of agricultural waste and plastic cutlery, which contribute significantly to pollution and pose a serious threat to the ecosystem. The researchers aim to harness the potential of mosambi peel waste and sago, creating biodegradable edible spoons. These spoons are designed to be both safe for consumption and ecologically friendly. The results of the study showcase promising findings, with the edible spoons demonstrating substantial degradation rates of 46 to 60% within a mere 12-day period. This indicates their potential to reduce waste accumulation and environmental pollution, making them a viable and sustainable alternative to conventional plastic cutlery.

1. Introduction

Cutlery, which is used worldwide for consuming food, seems simple but is a very useful device. Who exactly invented these is still unknown. Spoons are the oldest pieces of equipment that have been utilized by human beings for eating food. In olden times they were made with natural elements such as wood, animal bones, and seashells. The first known piece of evidence of spoons dates back to 1259 in England.[1] In the 18th century, forks and knives were also introduced. Silver, being non-reactive to foods, was the preferred metal for cutlery until the introduction of stainless steel, which was easy to maintain, non-reactive, and sturdy so preference was given to it. The introduction of plastics in the market brought down the prices of cutlery drastically and made its availability very easy. A lot of varieties and sizes were introduced for people to choose from, such as cups, plates, spoons, forks, knives, *etc.*[2]

With increased urbanization women have started their jobs; they have hardly any time for cooking and washing utensils.[3] So, the demand for plastic containers increased. The value of the

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plastic industry is 3000–4000 cores in India itself. According to the Ministry of Environment, Forest and Climate Change of India, more than 15 000 tons of plastic waste are generated in India every day, of which around 9000 tons are recycled and the remaining 6000 tons are disposed of in landfills.[4] The disposal of plastic is a huge issue in India.[2] Moreover, plastic is made from polystyrene referred to as Styrofoam which is very hard to recycle so it goes to landfills leading to solid waste. Plastic cutlery contains chemicals that are neurotoxic and carcinogenic.[5] These chemicals leach into food and cause harm to human health and the environment.[6] These problems can, to some extent, be solved by replacing plastic cutlery with edible cutlery. Edible cutlery is the quintessential alternative to harmful plastic cutlery; it is not only ecological but also enriched with nutritious ingredients. Several studies have been reported where edible cutlery is developed by utilizing wheat and sorghum flour,[7,8] cassava, and saba banana.[9] It is fully biodegradable and edible. It can be used to eat all types of food whether it is hot or cold, solid, or liquid. It can be provided during wars and in disaster-prone areas where there is a scarcity of food due to a lack of resources.[3] Another benefit of using this edible cutlery is that it may help in utilizing agricultural waste which is a significant problem nowadays. Agricultural waste causes soil contamination and air and water pollution and releases harmful gases, smoke, and dust. So, the concept of edible cutlery may help reduce agricultural waste. Biodegradable polymers from agricultural by-products, algae, and food waste are widely used to develop biodegradable disposable cutlery.[10,11] Biodegradable edible cutlery was developed by utilizing soy protein isolate incorporated with morning glory stems. Similarly,[12] finger millet, refined flour, and xanthan gum-based edible bowls fortified with brewer's spent grain were fabricated. Alternatively, fruit by-products such as peel and pomace can be exploited for developing edible cutlery.

Mosambi (*Citrus limetta*) is one of the most desired and widely accepted fruits and is consumed by removing its peels which are discarded. However, peels contain vital nutrients with numerous health benefits. It is a good source of flavonoids, pectin, and essential oil.[13] Mosambi peel is bumpy from the outside and has white pith under it. It is good to use it as a zest for beverages and foods rather than consuming it raw. Many useful by-products can be obtained from mosambi peel, such as pectin, candied peel, marmalades, beverage bases, peel seasoning, purees, dried pulp, citrus alcohol, bland syrup, citric acid, seed oil, and flavonoids.[14] It has antibiotic and antioxidant properties and is rich in vitamin C and contains essential nutrients, potassium, folate, calcium, niacin, phosphorus, magnesium, riboflavin, pantothenic acid, and phytochemicals.[15–17] It contains 1.58% fat and 17.6% crude fibre and due to its high pectin content, it helps lower blood sugar and cholesterol, helps maintain digestive health such as preventing constipation and may protect against certain types of cancer.[14] Table 1 shows the proximate composition of mosambi peel powder.

Table 1 Proximate composition of mosambi peel powder[42]

Parameters	Amount (%)
Moisture	10.00 ± 0.12
Ash	2.50 ± 0.36
Fat	1.82 ± 0.89
Protein	2.00 ± 0.58
Total dietary fiber	2.74 ± 0.90

Sago is a starch extracted from the stems of palm trees, especially *Metroxylon sagu*. It is derived from the spongy core tissue or the pith of various tropical palm stems. Sago contains linear chain amylose (27%) and branched chain amylopectin (73%).[18,19] Sago has a high amount of carbohydrates (84.7/100 g), which is higher than that in rice (80/100 g) and wheat flour (77.3/100 g). It has a very low amount of proteins, vitamins, or minerals but contains resistant starch and antioxidants.[20] Due to its gelatinization properties, it is used as a binding agent in food.[21] It is also used in baking, bread, noodles, and puddings and as a thickener in many foods and can be added to boiling water to make a paste.

Gum arabic is a pure tasteless gum found naturally. It is extracted from *Acacia senegal* and *Acacia seyal* trees. It is a complex branched chain heteropolysaccharide primarily consisting of arabinose and galactose. It has glue-like properties and acts as a binder in foods.[22] Gelatin is a natural polymer derived from animal body parts and a protein called collagen. Gelatin is a translucent, flavorless, colorless, food ingredient. It is a gelling agent used in various foods to make a gel that binds ingredients together. In the food industry, it is used for texturizing, foaming and stabilizing the food structure.[23]

Even though edible spoons have been made previously no work has been reported on the utilization of mosambi peels for the preparation of the same. Mosambi peels were used because they are a rich source of dietary fibre and pectin, whereas sago starch has gelatinization and retrogradation properties which affect the hardness of the spoons.[24,25] Thus, this study was aimed at the development of edible spoons from the mosambi (*Citrus limetta*) peel and sago along with the addition of gum arabic and gelatin. The developed spoons were further studied for various physicochemical properties.

2. Materials and methods

2.1. Procurement of materials

Mosambi peels were procured from local juice shops near Integral University, Lucknow. Fresh mature and pre-mature peels were collected with their colors varying from green to yellow. Based on their color, peels were sorted, and yellow ones were selected for the experiment. Sago (Do Bhai), gum arabic (variety: senegal), and gelatin were procured from the local market.

2.2. Methodology for the development of edible spoons

After procurement, mosambi peels were washed to remove dirt or any other impurity. De-bittering was performed to remove the bitterness of mosambi peel. In this process, mosambi peels were treated with sodium chloride. The de-bittering process was

Table 2 Experimental design

Sample	Sago (%)	Mosambi (%)	Gum arabic (%)	Gelatin (g)
C1	100	0	30	1
C2	0	100	30	1
S1	90	10	30	1
S2	80	20	30	1
S3	70	30	30	1
S4	60	40	30	1
S5	50	50	30	1
S6	40	60	30	1
S7	30	70	30	1
S8	20	80	30	1
S9	10	90	30	1

performed by taking 300 gm of sample peels, then adding salt equal to 30% of their total weight and keeping them for 4 hours. The peels were then washed with potable water to remove soluble compounds and salt. The cleaned peels are then dried at 65 °C in a hot air oven for a few hours until they become dry. Dried samples were ground to a powder form using a lab grinder. Sago and gum arabic were also ground to a powder form and a gum with a concentration of 30% was prepared. Weighing of each sample was performed according to the proportion needed to make an edible spoon. A total of 11 spoon samples were made of which C1 and C2 were considered control. C1 comprised 100% sago while C2 was 100% mosambi and the remaining 9 other samples were developed using mosambi and sago in different proportions as given in Table 2. Gum arabic and gelatin were added to all the samples and were kept constant as given in Table 2. All the samples were prepared into a smooth dough. The shape of the spoon was given using a spoon mold with dimensions of 10 cm × 0.7 cm × 1 cm. Thereafter, samples were dried in a hot air oven at 80 °C for 2 hours and then allowed to cool in a desiccator. The samples were left out at room temperature for 24 hours and then packed in an air-tight high-density polyethylene pouch. Fig. 1 shows the process flowchart for development of edible spoons.

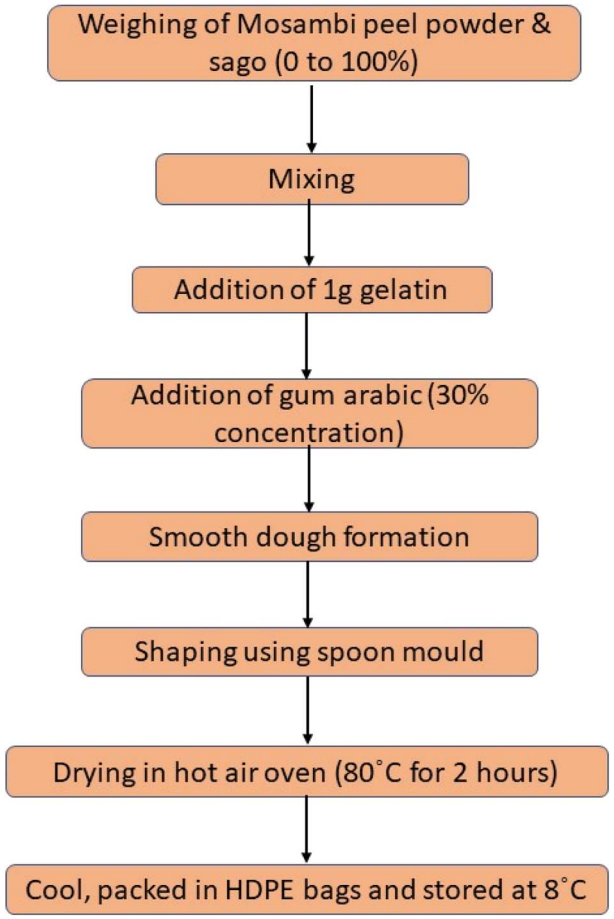

Fig. 1 Process flowchart.

2.3. Physicochemical evaluation

The final product was evaluated for physical as well as nutritional constituents by using standard methods.

2.3.1. Moisture content. Moisture content determination was essential to control the quality as well as the shelf-life of the food.[26] The aim was to determine the amount of moisture present in the sample. A 2 g sample was accurately weighed and placed in a hot air oven at 70 °C for 3–4 hours. After drying, the samples were cooled in a desiccator and weighed. Moisture content was calculated using the following equation:[27]

$$\text{Moisture content } (\%) = \frac{w - d}{w} \times 100$$

where w = initial weight of the sample; d = weight after drying.

2.3.2. Ash content. The main aim of ash content determination is to measure the inorganic substance in food. It was performed by burning organic substances, leaving inorganic minerals. It is important for determining the amount of minerals present in food. A 2 g sample was taken in a tared crucible and placed in a muffle furnace. The samples were burned at a temperature of 550 °C for 4 hours. Afterward, samples were allowed to cool in a desiccator and then weighed.[28] It was calculated using the formula:

$$\text{Ash content } (\%) = \frac{(z - x) \times 100}{y - x}$$

where x = weight of the crucible, y = sample + crucible weight, and z = crucible weight after ashing.

2.3.3. Fat content. Fat content determination was performed by using the Soxhlet apparatus in which lipids are extracted from the solid material. The procedure for the determination of fat content in edible spoons was carried out by washing a boiling flask. The flask was dried and labelled. 2 g of sample was transferred into pre-weighed thimbles, plugged with non-absorbent cotton, and then placed straight in the Soxhlet extraction tube. The extraction tube was filled with *N*-hexane solvent and the heaters were switched on. The extraction process was carried out for 2–3 hours. The solvent present in the flask is then evaporated leaving fat behind and a flask with oil was weighed.[28]

$$\%\ \text{fat} = \frac{w_1 - w_2}{S} \times 100$$

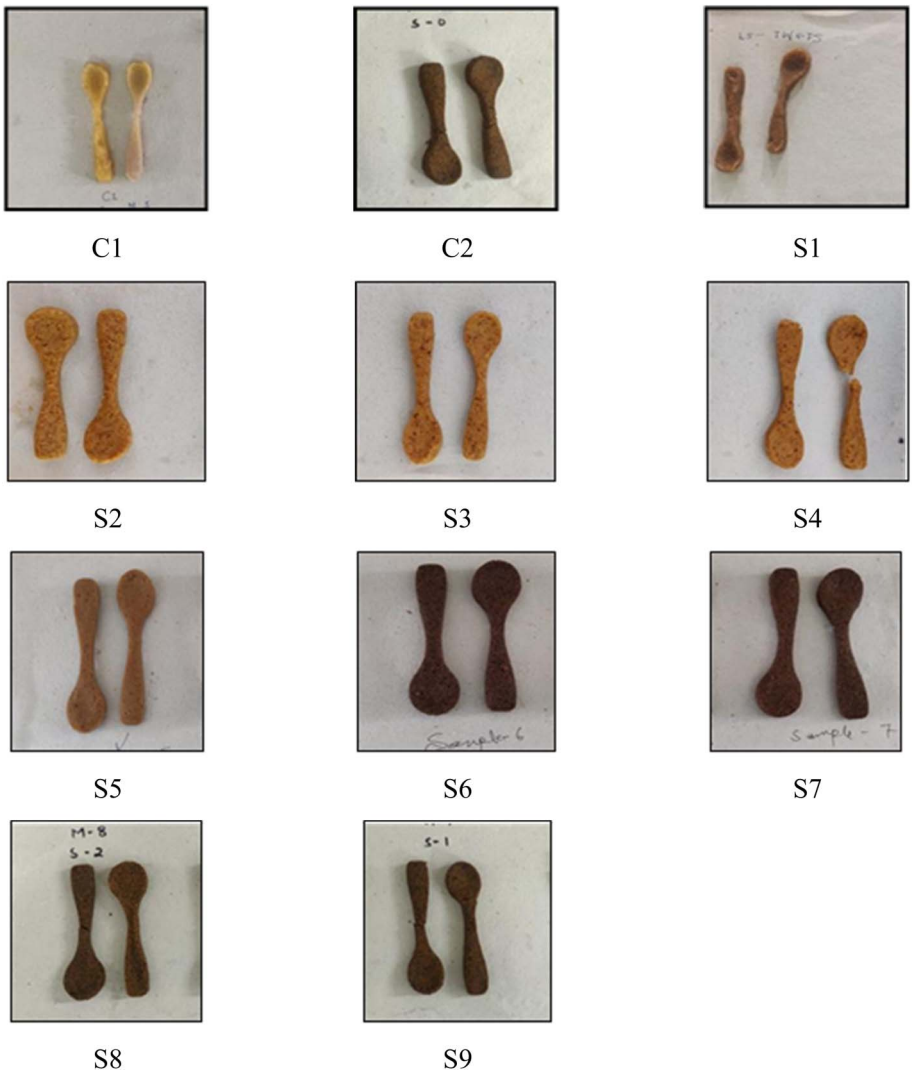

Fig. 2 Developed edible spoons.

where w_1 = weight of the empty flask (g), w_2 = weight of the flask and extracted fat (g) S = weight of the sample.

2.3.4. Protein content. The protein content of the edible spoons was estimated by the Kjeldahl method. The sample was digested in a digestion flask with sulfuric acid in the presence of a catalyst. The alkaline reaction product was neutralized using NaOH. The ammonia gas formed is liberated into a receiving flask, which has an excess of boric acid. The nitrogen content is then estimated by titration of the liberated ammonia. The result is multiplied by the conventional factor of 6.25 to obtain the crude protein content (Fig. 2).[29]

2.4. Water absorption

In water absorption, 2 g sample from each spoon was immersed in water in a beaker. After a particular time, the sample was taken out of the beaker, and excess water was removed with the help of tissue. Changes in the weight of the spoons were recorded.[6] Water absorption was calculated using the formula:

$$\text{Water absorption } (\%) = \frac{(w_2 - w_1)}{w_1} \times 100$$

where w_1 = weight of cutlery before water absorption; w_2 = weight of cutlery after absorption.

2.5. Organoleptic evaluation

The organoleptic (sensory) evaluation was carried out using a standard 9-point hedonic rating scale. This is essential for ensuring that products comply with organizational and customer requirements. Spoons were evaluated by a panel of eight judges for attributes such as taste, texture, aroma, color, and OA (overall acceptability) on a 9-point hedonic scale. The 9-point hedonic scale consists of a series of 9 verbal categories representing degrees of liking from 'dislike extremely' to 'like extremely'. For statistical analysis, the verbal categories are generally converted to numerical values: 'like extremely' as '9' and 'dislike extremely' as '1'.[30]

2.6. Color test

A colorimeter application (Lab Tools, version 1.6.6.6) was used to perform the $L^*a^*b^*$ test as per the method followed in ref. 11. The lightness, L^*, represents the darkest black at $L^* = 0$, and the brightest white at $L^* = 100$. The color channels, a^* and b^*, will represent true neutral grey values at $a^* = 0$ and $b^* = 0$. The red/green opponent colors are represented along the b^* axis, with blue at the negative b^* values and yellow at positive b^* values.[11]

2.7. Biodegradability

Edible cutlery pieces were initially weighed and buried in sterile soil for a set duration of time, after which the samples were taken out and the change in weight was recorded. The biodegradability of the sample was determined by a percentage change in the weight of the sample.[31]

2.8. Statistical analysis

All the analysis was performed in three replicates and data is reported as mean ± SD. Statistical significance was calculated by one-way ANOVA using "SPSS" Statistics Version: 28.0.0.0 (190). P values less than 0.05 ($P < 0.05$) were considered statistically significant. LSD (least significant difference) was calculated to obtain descriptive data and Duncan's multiple range tests were performed to determine significant differences among means.

3. Results and discussion

Edible spoons were prepared with the objective of the utilization of mosambi peel waste because of its nutritional properties. 11 samples were made among which 2 samples were considered controls, C1 (100% sago) and C2 (100% mosambi). The remaining other samples had varied compositions and their effects are discussed.

3.1. Moisture content

The moisture content of all the spoon samples is shown below in Table 3. Initial moisture content observed in controls C1 and C2 was 8.33% and 23.33%, respectively. A significant difference ($P < 0.05$) was found in all the values of the moisture content of edible spoons. Sample S1 had the highest amount of moisture in which the sago concentration was 90% and the amount of moisture found was 33.33%. This is because sago starch tends to attract water molecules because of its hydrophilic nature and contains a high amount of amylopectin which affects the water-holding capacity.[32] In addition, the values of moisture content for samples S3 and S7 were the same as those for C1 *i.e.*, 8.33%. Sample S2 had a moisture of 13.33%. Similarly, S4 and S6 had the same amount of moisture which was 11.67%. The least amount of moisture (6.67%.) was determined in sample S5 which comprises both sago and mosambi. So, this proves that S5 was the ideal sample of a spoon with regard to moisture content because a higher moisture amount is not desirable for the spoons to sustain the shelf-life. When the concentration of mosambi peel was increased in sample S6 then a sudden increase in moisture content was observed, hence proving that an increase in pectin content will lead to a gain in moisture because of the hygroscopic nature of the pectin which is highly absorbent.[33] Similarly, spoons with higher concentrations of sago starch had more moisture content due to the hydrophilicity of starch, making them susceptible to moisture.[25,34]

3.2. Ash content

Ash content is used to measure the inorganic substance present in food. It is obtained by incineration of organic matter, leaving inorganic minerals.[35] A significant difference ($P < 0.05$) was found in the values of ash content. The ash content of the edible spoons ranged from 3.07 to 4.73% as shown in Table 3. The amount of ash determined in control C1 and C2 was 0.97 and 3.87%, respectively. The concentration of the sago did not have any considerable effect on the ash content. Ash content was found to be increasing with an increase in the concentration of peel in the formulation. The highest ash content of 4.73% was observed in S9 which had the highest concentration of peel powder. The ash content was comparatively higher than that of the edible cutlery developed using sorghum flour.[3,8,29]

3.3. Fat content

The total fat content of spoons was determined (Table 3). The fat percentage varies in the results of control C1 and C2. More

Table 3 Moisture, ash, fat, and protein content of edible spoons

Sample	Moisture content (%)	Ash content (%)	Fat (%)	Protein (%)
C1 (sago 100%)	8.33 ± 2.89^{cd}	0.97 ± 0.15^{h}	0.94 ± 0.03^{h}	1.62 ± 0.02^{c}
C2 (peel 100%)	23.33 ± 2.89^{b}	3.87 ± 0.23^{cd}	2.31 ± 0.05^{e}	2.17 ± 0.15^{ab}
S1 (sago 90% and peel 10%)	33.33 ± 2.89^{a}	3.07 ± 0.12^{g}	1.35 ± 0.01^{g}	1.65 ± 0.01^{c}
S2 (sago 80% and peel 20%)	13.33 ± 2.89^{c}	3.30 ± 0.17^{fg}	1.40 ± 0.01^{g}	1.68 ± 0.01^{c}
S3 (sago 70% and peel 30%)	8.33 ± 2.89^{cd}	3.57 ± 0.12^{ef}	1.55 ± 0.03^{f}	1.70 ± 0.01^{c}
S4 (sago 60% and peel 40%)	11.67 ± 2.89^{cd}	3.60 ± 0.17^{de}	1.66 ± 0.02^{f}	1.78 ± 0.03^{c}
S5 (sago 50% and peel 50%)	6.67 ± 2.89^{d}	3.73 ± 0.06^{cde}	4.96 ± 0.057^{a}	2.30 ± 0.17^{ab}
S6 (sago 40% and peel 60%)	11.67 ± 2.89^{cd}	3.90 ± 0.17^{c}	4.60 ± 0.17^{b}	2.33 ± 0.12^{a}
S7 (sago 30% and peel 70%)	8.33 ± 2.89^{cd}	4.23 ± 0.23^{b}	4.56 ± 0.15^{b}	2.30 ± 0.10^{ab}
S8 (sago 20% and peel 80%)	13.33 ± 2.89^{c}	4.50 ± 0.10^{ab}	4.23 ± 0.05^{c}	2.23 ± 0.15^{ab}
S9 (sago 10% and peel 90%)	11.67 ± 2.89^{cd}	4.73 ± 0.12^{a}	4.06 ± 0.11^{d}	2.14 ± 0.05^{b}

Means in columns followed by different letters are significantly different ($P < 0.05$).

amount of fat was found in C2 which was 2.31% while C1 had 0.94% fat. This is because mosambi peel contains more amount of fat than sago. A significant difference ($P < 0.05$) was found in the ash content of the edible spoons. C1 which was 100% sago had the least amount of fat with respect to other samples because sago contains fat less than 1%.[36] Samples S1, S2, S3, and S4 had minor differences in their percentage of fat content. Sample S1 had 1.35% fat while S2 had 1.40%, S3 had 1.5%, and 1.66% fat was found in S4. Similarly, samples S5 to S9 showed very slight variations in their values. Sample S5 had the highest amount of fat which was 4.96% which indicates that sample S5 shows better results in the case of fat content. Fat content increased by increasing the concentration of mosambi peel powder in the samples. Sample S6 had 4.60% fat, 4.56% fat was determined in sample S7 and sample S9 contains 4.06% fat content. The results were comparable to those of edible cutlery developed using finger millet and rice/wheat flour where 3.7% fat content was reported.[37]

3.4. Protein content

The protein content of edible spoons was found to be in the range of 1.65 to 2.33% (Table 3). Significant differences ($P < 0.05$) in protein content were found among the samples. C1 reportedly had 1.62% proteins while C2 had 2.17%. Samples S1, S2, and S3 had no significant differences. The highest protein content of 2.33% was found in sample S6. The results show that protein content increased with an increase in peel powder up to 60% which was comparable to that obtained in ref. 27 for edible tableware developed using fruit wastes.

3.5. Water absorption

The water absorption test was performed to determine the strength of spoons by observing how much time it takes for one spoon to absorb water and start dissolving because the longer it takes to dissolve the longer they last. It was performed at room temperature (29 °C). The amount of water absorbed by all the spoon samples is shown in Table 4. C1 withstands 15 minutes and absorbs 58.50% of water because during baking starch gets gelatinized and makes the substance stiff; hence, it provides strength to spoons. C2 absorbs 172.67% of water in 5 minutes because, in C2, the concentration of pectin was high. Since pectin is a hydrophilic polymer, it absorbs more water.[38] So, the results show that C1 was more durable than C2. A significant difference ($P < 0.05$) was found in the water absorption test of all the samples. Sample S1 absorbed 64% in 12 minutes, sample S2 absorbed 50% in 10 minutes, sample S3 absorbed 60% in 9 minutes, sample S4 absorbed 56.67% in 7 minutes and sample S5 absorbed 65% of water in 5 minutes before fully disintegrating in water. The water-absorbing tendency of the above-mentioned samples was lower because the concentration of sago was high in these samples. When the concentration of pectin increased in samples S6 to S9 their water absorption capacity increased because pectin is a water-loving substance. Hence, these samples had more amount of water. Sample S6 absorbed 85% of water, and samples S7 and S9 absorbed 133.33% of water in 5 minutes. Sample S8 absorbed 136.67% amount of water in 8 minutes. Samples with low water absorption are desirable as this implies that an edible spoon can maintain its structural integrity and functionality as a spoon for an extended duration before disintegration or loss of form occurs.[9] It was found that sample S2 in which the concentration of sago and peel was 80% and 20% respectively, had the least water absorption and was more durable among all the other samples.

3.6. Color test

L^* a^* b^* is a color space that is defined by the International Commission on Illumination. In 1976, CIELAB was officially accepted, utilizing the values of L^*, a^* and b^* as parameters to analyze color. L^* represents brightness on a scale of 0 to 100, where 0 signifies black and 100 denotes white. The coordinate a^* represents the range between red (+) and green (−), while b^* pertains to the range between yellow (+) and blue (−). The boundaries for a^* and b^* are approximately around +80 or −80.[39] Table 4 displays the L^*, a^*, and b^* values of all the spoon samples. Notably, a significant difference ($p < 0.05$) was

Table 4 Water absorption (%) and color (L^*, a^*, and b^*) values of edible spoons

		Color		
Sample	Water absorption (%)	L^*	a^*	b^*
C1 (sago 100%)	58.50 ± 3.04^{de}	38.16 ± 0.25^{d}	10.83 ± 0.05^{g}	23.50 ± 0.20^{f}
C2 (peel 100%)	172.67 ± 2.25^{a}	31.90 ± 0.10^{f}	10.76 ± 0.05^{g}	20.76 ± 0.15^{g}
S1 (sago 90% and peel 10%)	64.00 ± 1.32^{d}	18.60 ± 0.20^{h}	6.90 ± 0.10^{i}	9.90 ± 0.10^{j}
S2 (sago 80% and peel 20%)	50.00 ± 5.00^{e}	39.13 ± 0.97^{c}	21.10 ± 0.17^{b}	38.43 ± 0.41^{c}
S3 (sago 70% and peel 30%)	60.00 ± 5.00^{d}	45.23 ± 0.15^{a}	20.67 ± 0.15^{c}	36.20 ± 0.20^{d}
S4 (sago 60% and peel 40%)	56.67 ± 7.63^{de}	44.33 ± 1.10^{b}	19.76 ± 0.15^{d}	41.20 ± 0.20^{b}
S5 (sago 50% and peel 50%)	65.00 ± 5.00^{d}	35.43 ± 0.25^{e}	13.76 ± 0.11^{e}	31.76 ± 0.15^{e}
S6 (sago 40% and peel 60%)	85.00 ± 5.00^{c}	18.00 ± 0.26^{h}	9.03 ± 0.05^{h}	13.76 ± 0.05^{i}
S7 (sago 30% and peel 70%)	133.33 ± 7.63^{b}	24.23 ± 0.25^{g}	13.10 ± 0.10^{f}	15.86 ± 0.05^{h}
S8 (sago 20% and peel 80%)	136.67 ± 5.77^{b}	0.10 ± 0.10^{j}	70.83 ± 0.05^{a}	9.93 ± 0.11^{j}
S9 (sago 10% and peel 90%)	133.33 ± 7.63^{b}	16.83 ± 0.15^{i}	10.76 ± 0.05^{g}	45.46 ± 0.15^{a}

Means in columns followed by different letters are significantly different ($P < 0.05$).

Table 5 Overall acceptability and biodegradability (%) of edible spoons

Sample	Overall acceptability	Biodegradability (%)
C1 (sago 100%)	7.67 ± 0.57^{ab}	59.23 ± 0.55^{d}
C2 (peel 100%)	7.67 ± 0.57^{ab}	67.80 ± 0.35^{a}
S1 (sago 90% and peel 10%)	7.33 ± 0.57^{b}	46.10 ± 0.36^{g}
S2 (sago 80% and peel 20%)	7.67 ± 0.57^{ab}	52.77 ± 0.40^{f}
S3 (sago 70% and peel 30%)	7.33 ± 0.57^{b}	52.90 ± 0.17^{f}
S4 (sago 60% and peel 40%)	7.00 ± 1.0^{b}	60.60 ± 0.50^{c}
S5 (sago 50% and peel 50%)	8.67 ± 0.57^{b}	64.13 ± 0.46^{b}
S6 (sago 40% and peel 60%)	7.00 ± 1.0^{b}	60.83 ± 0.46^{c}
S7 (sago 30% and peel 70%)	7.67 ± 0.57^{ab}	60.43 ± 0.06^{c}
S8 (sago 20% and peel 80%)	7.33 ± 0.57^{b}	54.33 ± 0.23^{e}
S9 (sago 10% and peel 90%)	7.67 ± 0.57^{ab}	54.20 ± 0.40^{e}

Means in columns followed by different letters are significantly different ($P < 0.05$).

identified in the L^*, a^*, and b^* values across all the samples. The L^* value of C1 was more than that of C2 which indicates that C1 was brighter in color than C2 because sago is lighter in color than mosambi peel. S8 with an 80% concentration of mosambi peel had the lowest L^* value which indicates that it was the darkest sample in comparison to the rest of the samples. All the samples exhibited positive a^* and b^* values, indicating the presence of red and yellow hues in the respective samples. a^* values were found to be similar to those obtained for sorghum-based edible spoons enriched with natural colors from beetroot and jamun.[29]

3.7. Organoleptic evaluation

A 9-point hedonic scale was employed to assess consumer satisfaction regarding organoleptic qualities such as taste, flavor, texture, color, and overall acceptability.[40] The outcomes are shown in Table 5 and according to the result of overall acceptability, no significant difference ($p > 0.05$) was found among C1, C2, S2, S7, and S9. S5 was highly acceptable among all the samples, which had an equal composition of both sago and peel. S4, consisting of 60% sago and 40% peel, along with S6, which had 40% sago and 60% peel, exhibited the lowest overall acceptability rate of 7.00 ± 1.0 among all the samples created.

3.8. Biodegradability

Edible spoon specimens buried in soil showed a reduction in their weight. Samples showed 46.10 to 64.13% biodegradability over a period of 12 days (Table 5). A significant difference ($p < 0.05$) was observed in the biodegradability of samples. C1 (sago 100%) had 59.23% while C2 (peel 100%) showed 67.80% degradability. The highest biodegradability of 64.13% was observed in S5. Since all the raw materials such as mosambi peel powder, sago, and gum arabic used for the development of edible spoons are of organic origin, they were easily degraded in soil by the action of microorganisms. Edible cutlery developed using sorghum–wheat–ragi flour enriched with Indian ginseng root powder was found to be completely degraded in 4 to 5 days while the one developed using moringa pod husk showed 100% degradation in 20 days.[8,41]

4. Conclusion

Edible spoons were developed using mosambi peel powder and sago starch along with gum arabic and gelatin. These spoons were subjected to physical and chemical analysis. The lowest amount of moisture content (6.67%) was observed in S5, which has both mosambi peel and sago starch. Fat content was the highest (4.96%) in S5, which suggests that S5 showed better outcomes regarding the same. Protein content increased as the concentration of mosambi peel powder increased up to 60% and the highest amount of protein was found in S6 (2.33%). This experiment revealed that in the water absorption test, among all the samples, S2, containing 80% sago, displayed the least amount of water content and demonstrated greater durability. It was found that S3 had the highest L^* value, whereas S8, containing 80% mosambi peel powder, had the lowest L^* value, signifying the lightest and darkest color of the spoons, respectively. According to a^* and b^* values, spoons were more inclined towards red and yellow colors, respectively. Among all the samples, S5 garnered the highest level of overall acceptability (8.67); this might be attributed to its balanced combination of sago and peel powder. Conversely, S4 and S6 exhibited the lowest acceptability rates in comparison to the other samples created. Since all the components used in creating the edible spoons were biodegradable, the developed spoons were reported to be degradable in soil. S5 displayed the greatest level of biodegradability, reaching 64.13%. From the observed outcomes, it can be concluded that edible spoons are more environmentally preferable compared to conventional plastic ones. Consequently, these spoons offer a solution to minimize the utilization of plastic, contributing to a reduction in plastic waste. S5, consisting of an equal amount of mosambi peel powder (50%) and sago (50%), was superior among the rest. More value-added and nutritious substances can be integrated into the edible spoons to enhance their taste. Moreover, natural pigments and flavoring agents can be introduced to make them more visually appealing. Additionally, the formulation can extend beyond spoons to encompass cutlery, plates, bowls, and other commonly used items. Despite the potential of edible

spoons, the expense could pose a challenge for the general public. Therefore, it is crucial to conduct further research to expand the production of bio-based products on a large scale, ensuring their affordability for everyday use.

Conflicts of interest

There are no conflicts to declare.

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