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Valorization of Orange Peel Waste through the Development and Functional Characterization of Orange Peel Powder as A Value-Added Product

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Abstract

Study was aimed to develop and analyse orange-peel-powder (OPP) from citrus fruit waste and also to evaluate its application in development of starch-based-edible-straws as a biodegradable substitute for the plastic-straws. For the study, fresh orange peels were collected and were processed by cleaning, steam-blanching, drying at 55 to 60 °C, and were ground to obtain a fine powder. The developed OPP was estimated for proximate content and functional properties. Results revelealed that, OPP contained 10.60% of moisture, 4.00% of ash, 1.80% of fat, 6.20% of protein, 18.00% of crude fiber, and 59.40% of carbohydrates, with a pH of 4.70, showing its potential as a fiber-rich ingredient. Functional analysis showed that, high swelling capacity of 10.3 mL/g, hydration capacity (5.1 g/g), and water absorption capacity (5.2 g/g), along with 3.1 g/g oil absorption capacity, reflecting excellent water binding properties. The OPP powder also exhibited excellent dispersibility (80%), quick wetting ability (20 s), bulk density of 0.48 g/mL, and low solubility index (0.06 g/g), showing favorable reconstitution behavior. The OPP was incorporated into edible straws at 0%, 2%, 4%, and 6% levels along with other ingredients. Incorporation up to 4% improved bending strength, stability of straws in different beverages like water, fruit juice and milk; and sensory attributes, upto 4% incorporation showing good performance of straws. Higher the incorporation (6%) lesser the sensory acceptability attributed to bitterness of OPP. Cost analysis indicated that, the production cost was extremely low with approximately Rs. 0.88 per straw. The study concluded that OPP can effectively be utilized as a functional ingredient in edible-straws, and could be considered to support the efficient waste utilization and conversion into high value products.

Keywords: *Cost analysis; Edible-straws; Functional properties; Orange peel powder; Waste valorization.*

1. Introduction

Large quantities of agricultural waste generated during the fruit processing activities, which create environmental and economic challenges for the food industries. Usually peels weight constitute of 30 to 50% of fruit weight, people generally discard this by considerating as waste as though in contains different bioactive compounds like phenolic compounds, dietary fiber, flavonoids and pectin substances (Anwar et al., 2008; Ajila et al., 2010; Han et al., 2020). Even the organic and biodegradable compounds with improper disposal techniques can lead to environmental pollution, while proper utilization of waste can lead to sustainable food systems. So, converting citrus peels into citrus peel powder increases its storage stability and allows its inclusion in the various food formulations. Orange peel powder has been reported to affect the rheological-behavior of dough and enhance some quality attributes of food products. This improvement is mainly associated with its high content of dietary fiber and pectin, which contribute to better texture and functional properties in the final product (Kang et al., 2006; Han et al., 2020). Since, the present study, mainly focus on the development of orange peel powder and the application of orange peel powder in too few innovative products such as starch

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based edible straws.

2. Methodology

2.1. Development of orange peel powder through standardized processing technique

2.1.1. Source of Orange Peels:

For the study fresh, mould free and damaged free orange peels were collected from the local juice vendors and approximately 2 kg of fresh orange peels were collected on the same day from a single source to minimize variability.

2.1.2. Cleaning and Pre-treatment:

The collected orange peels were cleaned to remove the pulp attached and it was thoroughly washed under running water, followed by rinsing and steam branching for two minutes at 90 to 95°C to decrease the bitterness, microbial activity and enzymatic activity followed by immediet cooling.

2.1.3. Drying, Grinding, and Storage:

The pre-treated orange peels were dried in hot air oven at 55 to 60°C for 30 - 32 hours, until to get a constant weight. Later, dried peels were collected and ground by using laboratory grinder and sieved to obtain uniform particle size. The prepared orange peel powder was stored in airtight polyethylene ziplock pouches at room temperature for further analysis (Ajila et al., 2010) shown in Figure 1.

Figure 1 **Developed Orange Peel Powder**

2.2. Chemical, Functional, Physical and Reconstitution Properties of orange peel powder

2.2.1. Estimation of Proximate Composition

Proximate analysis was carried out for orange peel powder by using standard AOAC (2019) methods. Where, moisture was analysed by oven-drying method, ash content by dry ashing method, fat content by soxhlet extraction method, crude fiber by acid - alkali digestion method, protein content by kjeldahl method, and carbohydrate content by difference method. The pH of orange peel powder was estimated by using a digital pH meter following the method described by Sagar and Kumar (2010).

2.2.2. Determination of functional properties

Swelling capacity was determined by the method given by Robertson et al. (2000), Hydration capacity by Sosulski (1962), Water absorption capacity by Sagar and Kumar (2010), and Oil absorption capacity by Kinsella (1976) [1-6].

2.2.3. Physical and Reconstitution Properties of Orange Peel Powder

Dispersibility of orange peel powder was determined following the method described by Kulkarni et al. (1991), Wettability by Onwuka (2005), Bulk density by Kaur and Singh (2005), and Solubility index by Anderson et al. (1969).

2.3. Development of Orange Peel Powder Based Edible Straws

2.3.1. Formulation of Edible Straws

Edible straws were prepared by mixing different ingredients with orange peel powder in varying concentrations like 0g, 2g, 4g and 6g (Table 1). During preparation, agar-agar was dissolved in water by heating until it became a clear solution. Then glycerine and butter/oil were added to the agar solution. In a saperate bowl, all dry ingredients namely corn starch, wheat flour, rice flour, millet flour, orange peel powder, sugar, salt, and milk powder were mixed evenly. This dry mixture was slowly added to the agar and glycerine based solution with continuous mixing to form a smooth dough. The dough was slowly rolled into thin sheets and cut into strips, which were then wrapped around steel rods to form straw shapes. These were dried in oven at 80 to 100°C until they became hard. Finally, the straws were removed from the rods, cooled, and stored in

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air-tight containers shown in figure 2.

Figure 2 Development of Orange Peel Powder Incorporated Edible Straws

2.4.Evaluation of functional performance of edible straws

2.4.1. Bending (Manual Flexural Strength) Test

Orange peel powder incorporated edible straws were evaluated for manual bending test, which assess the mechanical stability of the product when advanced instrumentation is unavailable (Falguera et al., 2011; Arrieta et al., 2017). In this method, dried edible straws were placed horizontally between two fixed supports at a known distance apart [7-10]. A known weight was gradually applied at the midpoint of the straw until visible bending or fracture occurred. The maximum load sustained from the straw before breakage was recorded. The results were expressed as load-bearing capacity (g or N) shown in Table 1.

Table 1 Formulation of Orange Peel Powder Based Edible Straws (per 100 g slurry)

Sl. No.	Ingredient	T0 (Control)	T1	T2	T3
1	Corn starch	28 g	27 g	26 g	25 g
2	Wheat flour	18 g	18 g	18 g	18 g
3	Rice flour	12 g	12 g	12 g	12 g
4	Millet flour	8 g	8 g	8 g	8 g
5	Orange peel powder	0 g	2 g	4 g	6 g
6	Edible glycerine	3 g	3 g	3 g	3 g
7	Agar Agar	0.5 g	0.5 g	0.5 g	0.5 g
8	Sugar	4 g	4 g	4 g	4 g
9	Salt	1 g	1 g	1 g	1 g
10	Butter / vegetable oil	2 g	2 g	2 g	2 g
11	Skimmed milk powder	4 g	4 g	4 g	4 g
12	Water	22 to 25 mL	22 to 25 mL	22 to 25 mL	22 to 25 mL

2.4.1.1.Water Absorption Capacity

The water absorption capacity of the edible straws were determined to evaluate the straw stability in liquid environment, excessive water uptake of straw can lead to softening and loss of functionality by the straw. According to methods described by Falguera et al. (2011) and Avérous and Halley (2009) test was carried out. Weighed straw samples were immersed in distilled water for the time intervals of 5, 15, 30, and 60 minutes at room temperature. After immersion, the straws were gently tapped with tissue paper to remove surface water and weighed again.

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The percentage increase in weight was calculated as water absorption.

Figure 3 Stability Test of Straws in Different Beverages

2.4.1.2. Sensory Evaluation of Edible Straws

Sensory evaluation was conducted to assess the consumer acceptability of the developed edible straws, as they would be used for direct oral contact for consumption purpose [11-20]. The evaluation was performed using semi-trained panel members (12 in No.) by using a 9-point hedonic scale shown in Figure 3.

2.5. Cost Analysis

Total production cost was calculated by adding all raw material, operational cost, and equipment depreciation. This was divided by annual production (3000 kg) to obtain cost per kg, and further used to estimate cost per straw based on its weight.

2.6. Statistical Analysis

All experimental data obtained from analysis were subjected to statistical evaluation by using SPSS software. Each experiment was conducted in triplicate, and results were expressed as mean ± standard deviation (SD).

3. Results and Discussion

Proximate composition of the developed orange peel powder was presented in Table 2. The moisture, ash, fat, protein, crude fiber, and carbohydrate content of the orange peel powder was 10.60%, 4.00%, 1.80%, 6.20%, 18.00%, and 59.40% respectively. The pH value was 4.70, which indicating the acidic nature of citrus peel. The obtained proximate values were comparable with previously reported compositions of orange peel powders. Moisture content within 8 to 12%, reported for dried citrus peel powders, indicating good drying and storage stability (Rafiq et al., 2018). The ash content of 3 to 5% indicates the presence of natural mineral elements (Ajila et al., 2010). Low fat content and moderate protein levels were consistent with earlier findings on citrus by-products (Rafiq et al., 2018). The high crude-fiber content shows that the orange peels are rich in dietary fiber components such as pectin and cellulose, which contribute to their functional food potential (Ajila et al., 2010). The acidic pH in the powder is due to the presence of organic acids like citric acid (Sagar & Kumar, 2010) shown in Table 2.

Table 2 Proximate Composition of Developed Orange Peel Powder

Parameter	Value (%)
Moisture	10.60 ± 0.20
Ash	4.00 ± 0.10
Fat	1.80 ± 0.10
Protein	6.20 ± 0.20
Crude Fiber	18.00 ± 0.30
Carbohydrates	59.40 ± 0.40
pH	4.70 ± 0.05

*Values are expressed as mean ± standard deviation of triplicate analysis.

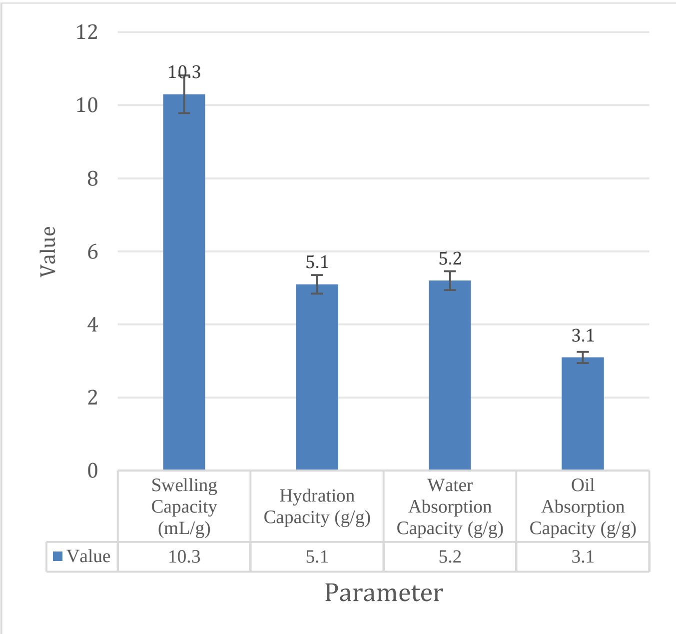

Figure 1 Functional properties of the orange peel powder

The functional properties like swelling capacity, hydration capacity, water absorption capacity and oil

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absorption capacity of the developed orange peel powder were evaluated to know its suitability for the production of value-added food product (Figure 1). The results showed that the, swelling capacity was 10.3 mL/g, hydration capacity was 5.1 g/g, water absorption capacity was 5.2 g/g and the oil absorption capacity was 3.1 g/g, Respectively. The swelling, hydration, and water absorption capacities for orange peel powder can be attributed to the presence of dietary fiber components like pectin (which contributes to gel formation and water retention in food systems), cellulose, and hemicellulose, which had hydrophilic functional groups, usually capable of binding large amounts of water. Similar functional properties were reported in previous studies where citrus fiber exhibited strong hydration and swelling behavior, enhancing the functional ability of food formulations like bakery products, soups, and beverages. The comparatively lower oil absorption capacity can be explained by the higher proportion of polar components in citrus peel fiber, which favors water binding over interaction with non-polar lipids. These functional properties show that the, orange peel powder could be used as a natural functional ingredient for improving texture, moisture retention, and stability in various food products (Nawirska & Kwaśniewska, 2005; Figuerola et al., 2005; Garau et al., 2007; Rezzadori et al., 2012) shown in Figure 2.

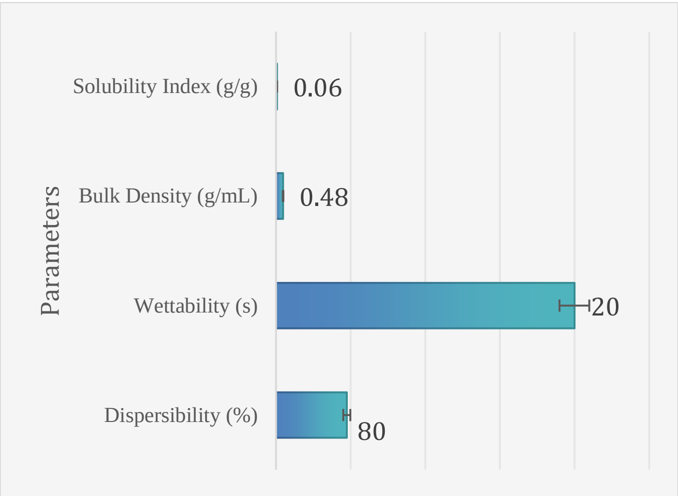

Figure 2 Physical and Reconstitution Properties of Orange Peel Powder

The physical and reconstitution properties of the orange peel powder presented in Figure 2. As can be seen from the graph, the powder exhibited a dispersibility rate of 80%, indicating the ability of the particles to distribute uniformly in water, wettability time was 20 sec, shows rapid wetting and quick sinking of powder particles when in contact with water, bulk density was 0.48 g/mL, reflecting moderate packing characteristics and relatively low inter-particle spaces. The solubility index was 0.06 g/g, indicating partial solubilization of the powder components in water. The reconstitution properties of orange peel powder shows about its functional suitability for food applications. Rapid wettabilityshows the property of hydration, which is again influenced by particle size, surface characteristics and drying conditions affecting water penetration and dispersion (Quek et al., 2007). The bulk density propert was moderate, which reflects desirable packing and handling properties, supporting the storage stability of the powder (Fellows, 2017). High-dispersibility further shows the ability of the particles to uniformly distribute in aqueous systems, which is important for reconstituted products. However, the low-solubility index can be attributed to the high proportion of in-soluble dietary fiber, such as cellulose, hemicellulose, and pectin, which gives the water absorption and swelling rather than complete dissolution (Lario et al., 2004; Rodríguez et al., 2006). Overall, these characteristics indicate that, orange peel powder can be effectively utilized as a functional, fiber-rich ingredient in food formulations shown in Figure 3.

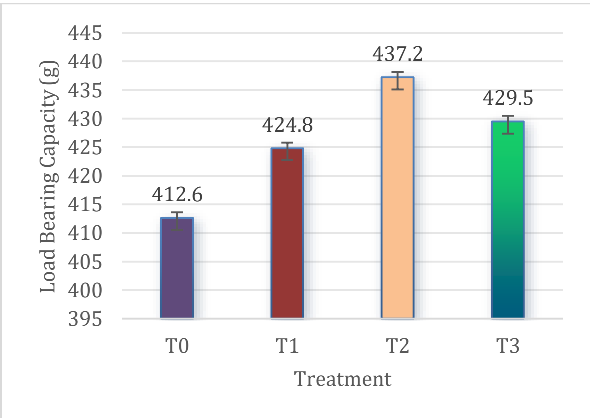

Figure 3 Effect of orange peel powder incorporation on the bending strength (manual flexural strength) of edible straws

The bending strength (manual flexural strength) of the developed orange peel powder incorporated edible straws is presented in Figure 3. The load bearing capacity of the straws increased with the incorporation of orange peel powder up to a certain level. The control sample (T0) exhibited a load bearing capacity of 412.6 g, whereas the addition of 2% orange peel powder (T1) increased the strength to 424.8 g. The highest bending strength was observed in T2 (4% orange peel powder) with a value of 437.2 g, indicating improved structural integrity of the straw matrix. However, further increase in orange peel powder concentration to 6% (T3) resulted in a slight decrease in load-bearing capacity (429.5 g), although it remained higher than that of the control treatment [21-33]. The improvement in bending strength observed with the amount of incorporation of orange peel powder, due to the presence of dietary fiber components like cellulose, hemicellulose, and pectin, which contribute to strenghening of starch-based matrices, where fiber components capable of interacting with starch through hydrogen bonding, which may give improved rigidity and structural stability (Lario et al., 2004). Also, Lario et al., 2004; Rodríguez et al., 2006 supported our findings by the stating, fiber particles can act as reinforcing fillers within the starch matrix, they improve stress distribution and mechanical resistance of the composite structure. But, excessive fiber incorporation may interfere with the continuity of the polymer matrix, leading to reduced interfacial bonding and slight decline in mechanical strength at higher concentrations. Similar behavior has been reported in starch-based biodegradable films and composites where moderate levels of plant fiber improve mechanical strength, while excessive fiber loading may weaken the structure due to poor dispersion and aggregation of fiber particles (Avérous & Halley, 2009; Falguera et al., 2011). Therefore, the higher bending strength observed in treatment T2 (4% orange peel powder) suggests that this concentration provided an optimal balance between matrix reinforcement and structural continuity in the developed edible straws which is explained briefly in the below mentioned Table 3 The water absorption capacity of orange peel powder incorporated edible straws incre increased with both immersion time and concentration of orange peel powder and the results are presented in Table 3. At 5 min of interval, water absorption ranged from 12.40 % in the control (T0) to 14.95% in T3 containing 6 % orange peel powder. A similar increasing trend was observed at 15 min and 30 min. After 60 min of immersion, the highest water absorption was recorded in T3 (43.95%), followed by T2 (41.60%) and T1 (39.20%), whereas the control showed the lowest value (36.90%). Overall, water absorption increased constantly with increasing immersion time, and treatments with higher levels of orange peel powder consistently exhibited greater water absorption compared to the control.The increase in water absorption with immersion time can be linked to the diffusion of water molecules into the starch-based matrix, which leads to swelling due to hydrogen bonding between hydroxyl groups and water (Sothornvit and Krochta, 2005). The higher absorption of water observed with increasing orange peel powder concentration is due to the presence of hydrophilic components such as dietary fiber and pectin in citrus peel, which enhance water binding capacity (Falguera et al., 2011; Ncube et al., 2020; Shafqat et al., 2021).

Table 3 Water Absorption Capacity of Orange Peel Powder Based Edible Straws

Treatment	5 min (%)	15 min (%)	30 min (%)	60 min (%)
T0 (0%)	12.40 ± 0.36	18.95 ± 0.42	26.80 ± 0.48	36.90 ± 0.55
T1 (2%)	13.25 ± 0.38	20.10 ± 0.46	28.45 ± 0.50	39.20 ± 0.58
T2 (4%)	14.10 ± 0.40	21.35 ± 0.49	30.15 ± 0.54	41.60 ± 0.62
T3 (6%)	14.95 ± 0.43	22.60 ± 0.52	31.80 ± 0.58	43.95 ± 0.67

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Table 4 Stability of Orange Peel Powder Incorporated Edible Straws in Different Beverages

Treatment	Orange Peel Powder (%)	Water (min)	Fruit Juice (min)	Milk (min)
T0	0	28.6 ± 1.2	31.4 ± 1.4	34.2 ± 1.6
T1	2	31.8 ± 1.3	34.6 ± 1.5	37.9 ± 1.7
T2	4	**35.4 ± 1.5**	**38.7 ± 1.6**	**42.1 ± 1.8**
T3	6	33.2 ± 1.4	36.5 ± 1.5	39.6 ± 1.7

The beverage stability of orange peel powder incorporated edible straws improved with the addition of orange peel powder up to the level of 4 %, but decreased slightly at the higher incorporation (6%). The control had the less stability time in all beverage types, with 28.6 min, 31.4 min and 34.2 min in water, fruit juice and milk, respectively. With incorporation of 2 % (T1) and 4 % (T2), stability of the straws was increased in each beverage; the highest stability occurred at T2, showing 35.4 min, 38.7 min and 42.1 min in water, fruit juice and milk. At 6 % (T3), stability was lower than at 4 % but still greater than the control, recording 33.2 min in water, 36.5 min in fruit juice, and 39.6 min in milk. The beverage stability for orange peel powder incorporated edible straws improved with increasing orange peel powder up to an optimum level due-to its enhanced matrix-cohesion and intermolecular interactions within the fiber polymer network. The plant derived polysaccharides and nano-cellulose are also known to iincrease hydro-stability, mechanical strength and barrier properties by increasing structural integrity and reducing water mobility properties (Avérous & Halley, 2009; Falguera et al., 2011). However, excessive fiber incorporation may disturb the matrix-uniformity and reduce stability, highlighting the need for optimized formulation.

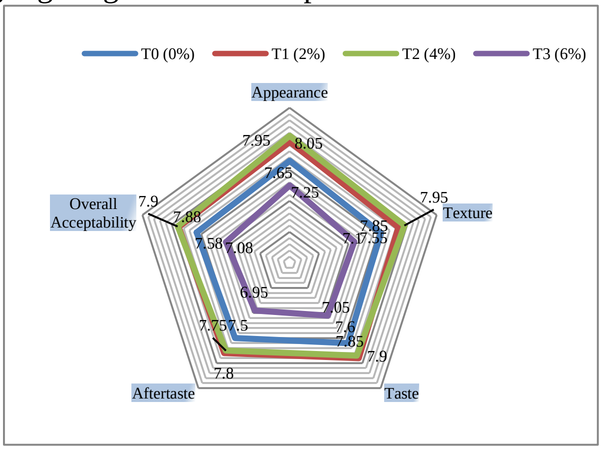

Figure 4 Sensory Evaluation of Orange Peel Powder Based Edible Straws

The sensory scores of edible straws developed by incorporating different concentrations of orange peel powder at 0%, 2%, 4%, and 6% presented in Figure 4. Among all treatments, T2 (4%) exhibited the highest score for appearance (8.05), followed by T1 (2%) (7.95), while T0 (0%) and T3 (6%) showed comparatively lower scores of 7.65 and 7.25 respectively. For texture, the highest score was also observed in T2 (7.95), followed by T1 (7.85) and T0 (7.55), whereas T3 (7.10) recorded the lowest value. With respect to taste, T1 (7.90) showed the highest score, closely followed by T2 (7.85) and T0 (7.60), while T3 (7.05) had the lowest rating. Similarly, after-taste scores were highest for T1 (7.80), followed by T2 (7.75) and T0 (7.50), whereas T3 (6.95) again showed the lowest values. Regarding overall acceptability, T2 (7.90) recorded the highest score, followed by T1 (7.88) and T0 (7.58), while T3 (7.08) had the lowest acceptability. Overall, the results indicate that incorporation of orange peel powder at 2 to 4% improved the sensory attributes, whereas a higher level of 6% indicated reduced panelist acceptance. Improved sensory scores in T1 (2%) and T2 (4%) may be because of bioactive compounds, essential oils, and natural pigments, which is present in orange peel, that enhances the flavor, aroma, and appearance. The phenolics and flavonoids contribute to color and mild citrus taste, this improves overall acceptability (Viuda-Martos et al., 2010; Sharma et al., 2017). Dietary fiber also aids in better texture and firmness at moderate levels (Rezzadori et al., 2012). However, the decline in scores at 6% (T3) is likely due to bitter compounds like limonoids and flavonoids, along with excessive fiber affecting mouthfeel (Manthey and Grohmann, 2001; Ghasemi et al., 2009; Putnik et al., 2017). Overall, 2 to 4% incorporation provides an optimal balance between sensory quality and functional benefits.

Table 5 Cost analysis of orange peel powder incorporated edible straws

Sl. No.	Particulars	Value
A	Raw material cost (Rs./year)	
1	Wheat flour, starch and additives	1,45,200
2	Orange peel powder	36,000
	Total raw material cost (A)	1,81,200
B	Operational cost (Rs./year)	
1	Labour	1,20,000
2	Electricity	48,000
3	Transportation	12,000
4	Rent	60,000
5	Miscellaneous	12,000
6	Packaging materials	60,000
	Total operational cost (B)	3,12,000
C	Equipment depreciation (10%)	35,400
	Total cost of production per year (A + B + C)	**Rs. 5,28,600**
	Annual production capacity	**3000 kg**
	Cost of production per kg of edible straws	**Rs. 176.20**
	Average weight of one straw	**5 g**
	Number of straws produced per kg	**≈ 200 straws**
	Estimated production cost per straw	**Rs. 0.88 per straw**

The cost analysis of orange peel powder incorporated edible straws is presented in Table 5. The total raw material cost for production was estimated to be Rs. 1,81,200 per year. The operational cost is accounted for Rs. 3,12,000 per year. In addition, equipment depreciation (10%) was calculated as Rs. 35,400 per year. Therefore, the total cost of production was estimated to be Rs. 5,28,600 per year. Considering an annual production capacity of 3000 kg, the cost of production per kg of edible straws was calculated as Rs. 176.20. Assuming an average weight of 5 g per straw, approximately 200 straws could be produced per kilogram, resulting in an estimated production cost of Rs. 0.88 per straw. These findings indicate that the incorporation of orange peel powder enables the production of biodegradable edible straws at a relatively economical unit cost while utilizing agro-industrial waste. The cost feasibility of the edible straws is due to the use of orange peel powder, low cost citrus by-product that supports waste valorization. Its rich fiber and pectin content enforce the development of edible straws, while reducing environmental impact (Sharma et al., 2017; Putnik et al., 2017; Mahato et al., 2019). The low production cost further highlights their potential as a sustainable alternative to plastic straws (Rujnić-Sokele and Pilipović, 2017; Siracusa et al., 2020).

Conclusion

The present study confirms the potential of orange peel waste as a valuable raw material for the development of OPP through standardized processing techniques. Incorporation of OPP into starch based edible straws further demonstrated its practical feasibility in product development while contributing to dietary fiber enrichment and sustainable waste utilization.

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