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Nutritive enriched edible, bioplastic straw from red seaweed, *Gracilaria verrucosa* as an effort application of marine resources for health

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Abstract: This study was aims to introduce edible and bioplastic straws from the red seaweed *Gracilaria verrucosa* to reduce the use of domestic plastic straw and determining the characteristics of prepared edible bioplastic straw. The dried *G. verrucosa* were purchased from a local market in Colombo, Sri Lanka. Biofilms were directly separated by boiling seaweed in water (20 g: 600 ml),which is the most cost-effective method for preparing biofilms using these materials. Coconut oil was added as a plasticizer to enhance the moisture barrier properties. Sensory evolution (color, texture, taste, and oder), antioxidant properties, water solubility, and customer survey analyses were performed to check straw quality. In the sensory analysis color, texture, taste, and odor were observed. Data was collected over a six-month period and the experimentation place in a laboratory setting at the Ocean University of Sri Lanka and the color, odor, texture, and taste did not change during this period. The antioxidant capacity of *G. verrucosa* was evaluated using a 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay. Free radical scavenging activities of seaweed extracts showed higher activity in 100 µl/ml and 75µl/ml methanol concentration when compared with 50 µl/ml, and 25 µl/ml methanol ($p = 0.959$). The average solubility of the seaweed films is reported 93.11% after 15 min, 93.77% after 90 min, and 95.73% after 16 h, respectively, indicating a high solubility in water at room temperature. This study found that seaweed straws used for drinking cold beverages could be used longer than straws used for drinking beverages at room temperature, making it suitable for cool drinks. Customer survey results showed that customers were satisfied with the edible seaweed straw. Prior to this study, no preliminary research had been conducted on the production of edible biodegradable bioplastic straws from *G. verrucosa.* These findings hold great promise for promoting sustainability and reducing the use of single-use plastic straws.
Keywords: *Biofilm, Edible bioplastic, Edible straw, Gracilaria verrucosa, Red seaweed.*

1. Introduction

Plastics have become a cornerstone of modern life due to their low cost, durability, and versatility across various applications, including packaging, household items, and industrial products. However, the widespread use of plastics has resulted in significant environmental challenges. Discarded plastics frequently accumulate in landfills, beaches, rivers, and oceans, where they persist for decades without breaking down[1]. Plastic waste constitutes a troubling 80–95% of ocean debris, with single-use items such as straws and stirrers contributing significantly to this issue [2,3].

The persistent environmental impact of plastics has spurred research into biodegradable alternatives that can alleviate these issues. Bioplastics, derived from renewable sources such as plants, bacteria, and algae, offer a promising solution. Unlike traditional plastics, bioplastics decompose through microbial action and do not release harmful pollutants [2,4]. They offer advantages such as reduced reliance on fossil fuels, non-toxicity, ease of recycling, and overall sustainability[5,6].

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Among the various bioplastic sources, seaweeds present a particularly compelling option for sustainable material development. Seaweeds, or macroalgae, are marine organisms that have been used for centuries due to their rich content of polysaccharides, proteins, vitamins, and minerals. Seaweeds are categorized into three main groups: brown, red, and green algae. Seaweed-derived hydrocolloids, such as alginate, agar, and carrageenan, offer a wide range of applications as biopolymers in bioplastic synthesis[4].

Red seaweeds, specifically those in the Rhodophyta division, are especially noteworthy for their diverse applications in food, medicine, and industrial processes. Agar is a polysaccharide that is commonly found in the *Gracilariaceae* and *Gelidiaceae* families of red seaweed (*Rhodophyceae*). Bioplastics made from agar have been shown to have excellent physical and mechanical qualities, as well as outstanding flexibility and tensile strength, making them suitable for commercial usage[2,4,6].

Gracilaria verrucosa, a prominent red seaweed found in tropical and subtropical regions such as Sri Lanka, is notable for its high agar content. Agar, a gelatinous substance with exceptional gelling and emulsifying properties, is derived from the cell walls of red seaweeds. It is extensively used in food, pharmaceuticals, and biotechnology due to its ability to form reversible gels and its non-toxic, hydrophilic nature[2,7].

In Sri Lanka, despite the historical and economic significance of seaweeds like *Gracilaria verrucosa*, their potential remains largely untapped. The abundance of this seaweed in regions such as Kalpitiya, Trincomalee, and Mannar represents an opportunity for innovation and local processing[8]. Utilizing *Gracilaria verrucosa* for bioplastic production can address the pressing issue of plastic waste and provide a sustainable, eco-friendly alternative.

This study aims to develop nutritive enriched edible bioplastic straws from *Gracilaria verrucosa.* By harnessing the properties of this red seaweed, the study seeks to offer a viable solution to the problem of single-use plastic straws, highlighting the benefits of seaweed-based bioplastics in reducing plastic waste and promoting the sustainable use of marine resources.

2. Materials and Methods

2.1. Materials

The primary material used in this experiment was dried *Gracilaria verrucosa* red seaweed, which was procured from a local market in Colombo, Sri Lanka. Coconut oil, used as an additive, was also sourced from a local supplier.

2.2. Preparation of Bioplastic Samples

The bioplastic samples were prepared using the film-casting method as described by (Asif et al., 2021) [10]. The dried *G. verrucosa* seaweed was first thoroughly washed with water to remove any foreign materials such as salts and debris (Figure. 1a). The washed seaweed was then boiled in water at 100°C for 20 minutes in an open pot, using a ratio of 20g seaweed to 600ml water to extract agar from the seaweed.

2.3. Film Formation

The boiled seaweed solution was sieved to remove residual solid material. The filtered solution was divided into two separate batches:

Batch 1: The solution was directly poured into sterile trays to form bioplastic films without any additives.

Batch 2: Coconut oil (10 ml) was added to the solution before pouring it into sterile trays. Coconut oil was used as a plasticizer to enhance the flexibility and durability of the films, as well as to improve their moisture barrier properties. Barrino *et al.*[9] have shown that coconut oil, being hydrophobic and acting as a plasticizer, can significantly reduce the brittleness of bioplastic films and decrease water vapor permeability, making the films more suitable for applications like straws.Both batches were left to dry at room temperature (25°C) for 4-5 days until completely dry (Figure. 1d). Once dried, the biofilms were carefully removed from the trays and stored in sealed bags for further use.

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2.4. Straw preparation

The seaweed films from both batches were manually rolled into straw shapes. A glass rod was placed at one end of the seaweed film, and the film was gently pressed and rolled forward to form the straw shape. The edges of the rolled films were sealed using a hoseaweed and water solution. The prepared straws were then allowed to dry for 1-2 hours (Figure 1f).

2.5. Water solubility

Water solubility was determined according to the Asif method [10], 300 mg of pieces of biofilm were placed in a beaker with 40 ml of distilled water for 16 h at 22 ^{0}C. The solution was filtered through a Whatman No.1 filter paper for 15 min, 90 min, and 16 h. To recover the remaining undissolved film, which was desiccated at 200^{0}C for 1 hour. The film solubility was calculated at each time by using the following equation.

Film Solubility (%) = (W1−W2)* W1 X 100%

where W1 is the initial weight of the film expressed as dry mass and W2 is the weight of the undissolved desiccated film residue. All tests were performed in triplicated.

2.6. Dissolution rate and temperature of the straw

The dissolution temperature of the straw was measured using a thermometer. Bioplastic seaweed straws (10 cm in length) were placed in beakers containing water, milk, 15 ^{0} C and 23^{0} C to assess their stability under different conditions.

2.7. Descriptive Sensory Analysis

Color changes in the biofilm were evaluated visually, consistency/ texture were evaluated by sight and touch, and oder and taste were evaluated by sensory evolution. Sensory analysis was performed individually with ten individuals using the questionnaire form [11].

2.8. 2, 2 diphenyl-2-picrylhydrazylhydrazyl (DPPH) Free Radical Scavenging Activity

1 g of the dried seaweed sample was suspended in 10 ml of methanol for 72 h. The solution was then filtered and evaporated to dryness using a rotary evaporator. 5 mg of dried extracted seaweed powder was dissolved in methanol (1 ml of methanol, boiled and cooled, and centrifuged at 2500 rpm for 10 min). The obtained supernatant was used for further experiments. The assay was carried out with freshly prepared solution of DPPH using the spectrophotometry method[12]. DPPH is a stable free radical. Upon accepting hydrogen from the corresponding donor, its solutions lose their characteristic deep purple color. The reaction mixture was prepared using 2.5ml of 6.5 X 10^{-5} M D M DPPH solution and l of the sample dissolved in methanol (0.5ml of methanol to 2.5ml of 6.5 X 10^{-5} M). The control was prepared by adding DPPH solution instead of the sample. 0.5 ml was taken from the prior sample solution and added to 2.5 ml of 6.5 x 10^{-5} DPPH solution. Five dilutions were prepared in the same manner in triplicate. All samples were incubated at room temperature for 30 min in the dark and absorbance was measured at 540 nm using a spectrophotometer. The percentage of DPPH radical scavenging activity was determined at five different concentrations using the following equation:

Scavenging activity %= A0− As /A0* 100

where, As- absorbent of the DPPH solution of the sample,

A0- Absorbance of the DPPH solution in the presence control sample[12].

2.9. Statistical Analysis

Means and standard deviations were determined for each analysis and analyzed using Microsoft Excel and SPSS.

2.10. Customer Survey

The purpose of this survey was to introduce a new product and gather customer feedback on edible biodegradable bioplastic straws, focusing on the shape, texture, odor, and taste of the straw before consumption. Additionally, the survey aimed to evaluate participants' preference for the flavor of the soft drink consumed through the straw, the flavor of the straw after finishing the soft drink, and their liking of the appearance and mouthfeel of the straw both before and after consumption. The survey was conducted among 50 participants, chosen to provide a more statistically significant sample size, following guidelines for sensory evaluation panels (Singh and Maharaj, 2014). Participants were asked to physically attend the survey and respond to a structured questionnaire that used a 5-point Likert scale, with questions related to taste, texture, odor, color, and overall satisfaction. The responses were recorded and analyzed using Microsoft Excel and SPSS for descriptive and inferential statistical analysis[14].

3. Results

3.1. Visual Observation

The sensory analysis of the bioplastic straws made from *Gracilaria verrucosa* focused on key attributes such as color, texture, taste, and odor. Raw seaweed film (Batch 1) and the coconut oil added seaweed film (Batch 2) were chosen for further analyses. The observations indicated that the color of the straws remained consistent throughout the six-month study period, maintaining a natural reddish-brown hue derived from the seaweed. The texture of the straws was smooth and slightly flexible, which made them suitable for use in drinking cold beverages. No significant changes in taste or odor were detected over time, which suggests that the bioplastic straws retained their sensory quantities well (Table 1 and Table 2).

3.2. Water Solubility

The seaweed film and the seaweed with coconut oil film demonstrated high water solubility during the tested time intervals. There were slight variations in water solubility between two films. The water solubility of the seaweed film was 93.1%, 93.7%, and 95.7% at 15 min, 90 min, and 16 h, respectively and water solubility for the seaweed tested with coconut oil was 93.7%, 93.8%, and 94.6% at the same respective time intervals, respectively (Figure 2). Overall, the water solubility of the seaweed film was slightly higher than that of the seaweed with coconut oil film, particularly at the 16 h time point. Solubility of the straw made from *G. verrucosa* (Batch 1) was significantly affected by different times ($F (2, 6) = 138.218$, $p < 0.001$). The between-group variability was relatively high (mean square = 5.615), whereas the within-group variability was relatively low (mean square = 0.041), indicating that most of the variability in the data was due to differences between the different times. Post-hoc analysis of ANOVA showed that the solubility of the straw containing *G. verrucosa* varied significantly at different times. There was a significant difference in the solubility the *G. verrucosa* straw with coconut oil (Batch 2) between the different times for the four [$F (2, 6) =3.982$, $p=0.079$]. Overall, the ANOVA results indicate that the solubility of the straw in the *G. verrucosa* varies significantly at different times.

3.3. Dissolution Rate and Temperature of the Seaweed Biofilm Straw

The dissolution temperature of the seaweed biofilm, was studied to determine its stability when exposed to different temperatures of beverages. The study was conducted using three different types of beverages, and it was observed that the dissolution temperature of the seaweed biofilm did not change between the different types of beverages .The results showed that the biofilm was rubbery in nature when dipped into beverages at room temperature. In cold beverages, the biofilm was also rubbery when dipped for around 15 seconds, but was still functional as a drinking straw. However, the consumption time of the straw increased when the beverage was cold (Table 5).

3.4. DPPH Radical Scavenging Activities

An ANOVA showed no significant differences in the free radical scavenging activities between *G. verrucosa* seaweed samples in four methanol concentrations (25, 50, 75, 100 µl/ml; $F (3, 12) = 0.098$, $p = 0.959$) (Table 6). Within-group variability was relatively high (mean square = 429.021), whereas between-group variability was relatively low (mean square = 42.224), indicating that most of the variability in the data was due to individual differences within each group. The results indicate that the radical scavenging activities of *G. verrucosa* is unaffected by varying concentrations of methanol,

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although, the free radical scavenging activities were higher concentrations of methanol were used (Figure 3).

3.5. Customer Survey

50 volunteers were randomly selected from the local community through convenience sampling to participate in the customer survey. Participants were chosen based on their preference for using plastic straws over paper straws. All volunteers were regular consumers of cold beverages, particularly in social settings, with an average age of 30 years (range 20-50 years). There were no specific eligibility criteria for participation. Participants were familiar with paper straws but despite that, they still used plastic straws when consuming a cold beverage. The survey evaluated two batches of seaweed straws: Batch 1, made from *Gracilaria verrucosa* without additives, and Batch 2, which included coconut oil as an additive to enhance the straws' properties. Initial Impressions: Fifty percent of participants rated the initial appearance of the Batch 2 straw (with coconut oil) as "Fantastic," compared to forty percent for Batch 1. This suggests that the addition of coconut oil may have enhanced the visual appeal of the straws. Additionally, eighty percent of participants rated Batch 2 straws as "Good," reflecting a generally positive first impression, while seventy percent rated Batch 1 similarly. Taste Before Consumption: The survey revealed that thirty percent of participants rated the taste of the Batch 2 straw as "Fantastic" before consuming the cold beverage, compared to ten percent for Batch 1. This indicates that the addition of coconut oil may improve the initial flavor profile of the straw. Seventy percent of participants rated the taste of the Batch 2 straw as "Good" compared to ninety percent for Batch 1, with no participants rating the taste of either batch as "Bad." Taste After Consumption: After consuming the cold beverage, forty percent of participants rated the taste of the Batch 2 straw as "Neutral" and sixty percent as "Not Bad," suggesting that while the flavor remains acceptable, it may not be as appealing as before consumption. For Batch 1, forty percent of participants rated the taste as "Not Bad," and the remaining sixty percent rated it as "Bad," indicating a lower level of acceptance post-consumption. Color Perception: The majority of participants (seventy percent) rated the color of the Batch 2 straw as "Fantastic," compared to no participants for Batch 1, where fifty percent rated the color as "Good" and fifty percent as "Neutral." This finding highlights the significant visual improvement attributed to the addition of coconut oil. Flavor of the Soft Drink: Eighty percent of participants rated the flavor of the soft drink consumed through Batch 2 straws as "Good," suggesting that the presence of coconut oil does not negatively impact the drink's flavor. Conversely, seventy percent of participants rated the flavor of the soft drink through Batch 1 straws as "Good." Taste After Finishing the Soft Drink: Finally, sixty percent of participants rated the flavor of the Batch 2 straw as "Fantastic" after finishing the soft drink, compared to no participants for Batch 1. For Batch 1, sixty percent rated the taste as "Not Bad," indicating a less favorable post-consumption experience compared to Batch 2 (Figure 4). Notably, no participants rated the product as "Bad."

4. Discussion

The study successfully demonstrated the potential of using Gracilaria verrucosa, a red seaweed species, as a raw material for producing edible and biodegradable bioplastic straws. The sensory analysis confirmed that the bioplastic straws maintained their color, texture, taste, and odor over the six-month period, making them suitable for use in various beverages, particularly cold drinks. The high antioxidant activity observed in the seaweed extract suggests additional health benefits, making these straws not only eco-friendly but also potentially beneficial for consumers. The solubility was slightly higher than that observed in the study of Asif *et al.*[10], in which the gradual increase in polymer content inversely affected the solubility rates, likely attributable to the maximum undissolved mass of agar and its nature of being insolubility at low temperatures [15]. In this study, plasticizers were not added to the biofilm preparation solution. Therefore, the water solubility percentage of the biofilms was high. Asif et al. (2019) showed that water solubilities of bioplastics blended with glycerol were significantly higher solubility (81.5% and 74%) than those plasticized with sorbitol (65.5% and 62.5%), indicating that the sorbitol films were more resistant to moisture degradation. The solubilities obtained in our study were comparatively higher than the solubility rate of bioplastic film from *Gracilaria*

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corticata[10], agar/alginate/collagen ternary blend [16], and agar/agar gelatin. However, such solubility trends are comparable to those reported in previous studies. The high solubility of the bioplastic films in water is a critical factor that supports the sustainability goals of the product, as it ensures that the straws will degrade quickly in the environment, reducing plastic waste. Scavenging of DPPH free radicals has been widely used to investigate the ability of algal extracts and fractions, or compounds to act as free radical scavengers or hydrogen donors. Change in the absorbance produced by DPPH has been used to evaluate the ability of test compounds to act as free radical scavengers. Antioxidants play a vital role in protecting the human body from oxidative stress, by preventing the accumulation of reactive oxygen species (ROS). ROS can cause cellular damage and lead to various diseases such as cancer, cardiovascular disease, and neurodegenerative disorders. Seaweeds are a readily available and sustainable source of antioxidants, offering an attractive alternative to synthetic antioxidants. The average DPPH free radical scavenging percentage values of the methanol extract were found to be 46%%, 42%, 39%, and 39% in 25, 50, 75, and 100, respectively. The algal extracts were more active in 75 µl/ml and 100 µl/ml methanol (Figure 3). Various researchers have obtained similar outcomes[12]. Water extract of macroalgae exhibit maximum antioxidant activity[17] and it is likely, therefore, that they have different antioxidant capabilities in different extraction mediums. This may be due to the different polarities of individual antioxidant components that occur in seaweeds[18] . The use of seaweed to manufacture biodegradable edible drinking straw holds significant promise for creating a more sustainable future [19]. The antioxidant and antimicrobial properties of seaweeds, along with their potential as a biodegradable alternative to synthetic packaging, render them a promising food packaging material. Seaweed films have high water solubility, which can be enhanced by adding additives or other biomaterials. Future research will focus on evaluating seaweed-based bioplastics, especially their physical and mechanical properties like tensile strength, modulus, and flexibility. Additionally, reducing plastic waste requires joint efforts from various stakeholders, including the public, businesses, and government agencies. The use of biodegradable edible drinking straws made from seaweed can help play a role in reducing plastic pollution and preserve environmental health for future generations. With advancements in biotechnology and genetic engineering, it is expected that seaweed-based bioplastics will become a viable and cost-effective alternatives to conventional plastics in the near future. Additionally, the positive feedback from the customer survey indicates a strong market potential for these edible straws as an alternative to traditional plastic straws.

5. Conclusion

This study presents promising evidence for the use of *Gracilaria verrucosa* as a source of edible and biodegradable bioplastic straws. The findings highlight the sensory stability, antioxidant properties, and high solubility of the seaweed bioplastic films, making them an effective and sustainable alternative to single-use plastic straws. The positive reception from consumers further reinforces the feasibility of commercializing seaweed-based straws, which could significantly reduce the environmental impact of plastic waste. Future research should focus on enhancing the mechanical properties of these bioplastic straws to expand their application to a wider range of beverage types and exploring ways to scale up production for commercial use. Seaweed-based edible drinking straws have the potential to provide significant benefits to both human health and the environment. Seaweed are a nutrient-rich source of vitamins and minerals that can provide additional health benefits when consumed. The biodegradability of seaweed-based drinking straws makes it a more sustainable alternative to traditional plastics, and the ability to incorporate nutrients into the straws provides an additional benefit for human consumption. However, further research is needed to fully understand the effects of seaweed on human health and the environment, as well as to refine the production process of seaweed-based drinking straws. By incorporating seaweed-based drinking straws into our daily lives, we can take steps towards a more sustainable future, while also improving our health and well-being.

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Table 1.
Visual observation of the raw seaweed film (Batch 1).

Visual observation	Month					
	March	April	May	June	July	August
Color	×	×	×	×	×	×
Odor	×	×	×	×	×	×

Texture	×	×	×	×	×	×
Taste	×	×	×	×	×	×

Note: √- Changed
×- Not Changed.

Table 2.
Visual observation of the coconut oil added seaweed film (Batch 2).

Visual observation	Month					
	March	April	May	June	July	August
Color	×	×	×	×	×	×
Odor	×	×	×	×	×	×
Texture	×	×	×	×	×	×
Taste	×	×	×	×	×	×

Note: √- Changed
×- Not Changed.

In the sensory analysis color, texture, taste, and odor were observed. Data was collected over a six-month period. Color remained constant over the duration of the six-month experimentation period, and no discernible changes in taste or odor were observed over time. These data suggest that the bioplastic straws effectively retained their sensory characteristics over time.

Table 3.
ANOVA table of the solubility of the raw *G. verrucosa* seaweed film (Batch 1).

Sum of squares	df	Mean square	F	p
11.229	2	5.615	138.218	0.000
0.244	6	0.041		
11.473	8			

The seaweed film was 93.1%, 93.7%, and 95.7% soluble in water at 15 min, 90 min, and 16 h, respectively. The solubility of the G. verrucosa straw (Batch 1) varied significantly with different durations ($F(2, 6) = 138.218$, $p < 0.001$). The difference in variability between groups was quite large (mean square = 5.615), while the variability within groups was quite small (mean square = 0.041), suggesting that the majority of variability in the data stemmed from differences across various time periods.

Table 4.
ANOVA table of the solubility of the coconut oil added *G. verrucosa* seaweed film (Batch 2).

	Sum of squares	df	Mean square	F	p
Between groups	1.460	2	0.730	3.982	0.079
Within groups	1.100	6	0.183		
Total	2.560	8			

Water solubility experiments on the seaweed drinking straw made with coconut oil (batch 2). The seaweed film with coconut oil had water solubility of 93.7%, 93.8%, and 94.6% soluble in water at 15 min, 90 min, and 16 h,respectively. The solubility of G. verrucosa straw in coconut oil (Batch 2) varied significantly for each of the four occasions [$F(2, 6) = 3.982$, $p = 0.079$].

Table 5.
Dissolution temperature of the biodegradable straw with different beverages.

Beverage type	Dissolution temperature time	
	At room temperature (23°C)	At refrigerator temperature (15°C)
Water	5 seconds	15 seconds

Vanilla milk	5 seconds	15 seconds
Fruit juice	5 seconds	15 seconds

Table 6.
Radical scavenging activities of *G. verrucose*.

	Sum of squares	df	Mean square	F	p
Between groups	126.671	3	42.224	0.098	0.959
Within groups	5148.25	12	429.021		
Total	5274.92	15			

The free radical scavenging capabilities of G. verrucosa seaweed samples at four different methanol concentrations (25, 50, 75, and 100 µl/ml; $F (3, 12) = 0.098$, $p = 0.959$) did not differ significantly, and the findings showed that individual differences within each group accounted for the majority of the variability, with within-group variability being quite high (mean square = 429.021) and between-group variability being relatively low (mean square = 42.224).

Table 7.
Consumer survey data percentages.

Question	Total	Fantastic	Good	Neutral	Not Bad	Bad
1.Shape of the straw before consume	10	40%	50%	10%	0%	0%
2.Color of the straw before consume	10	70%	20%	10%	0%	0%
3.Odor of the straw before consume	10	10%	90%	0%	0%	0%
4.Taste of the straw before consume	10	0%	60%	0%	40%	0%
5.Flavor of the soft drink consumed through the straw	10	0%	80%	10%	10%	0%
6.Flavor of the straw while consumed the soft drink	10	0%	40%	20%	40%	0%
7.Shape of the straw after consume	10	0%	10%	20%	70%	0%
8.Color of the straw after consume	10	0%	30%	50%	20%	0%
9.Flavor of the straw after finish the soft drink	10	0%	0%	40%	60%	0%

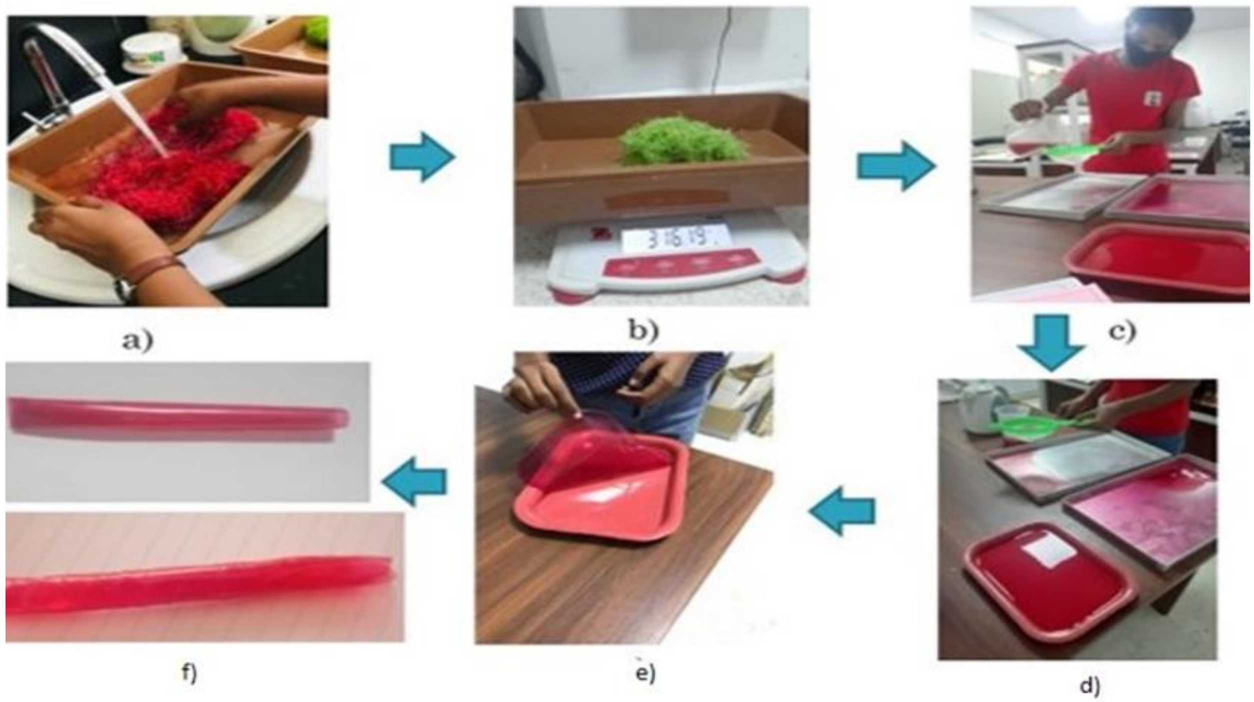

Figure 1.
Methodology of bioplastic seaweed straw making.
a) Washing dried seaweeds b) Weighing c) Pouring the solutions to the trays
d) Let solution dry to 4-5 days e) Peel of the seaweed film f) Paste film and make straw

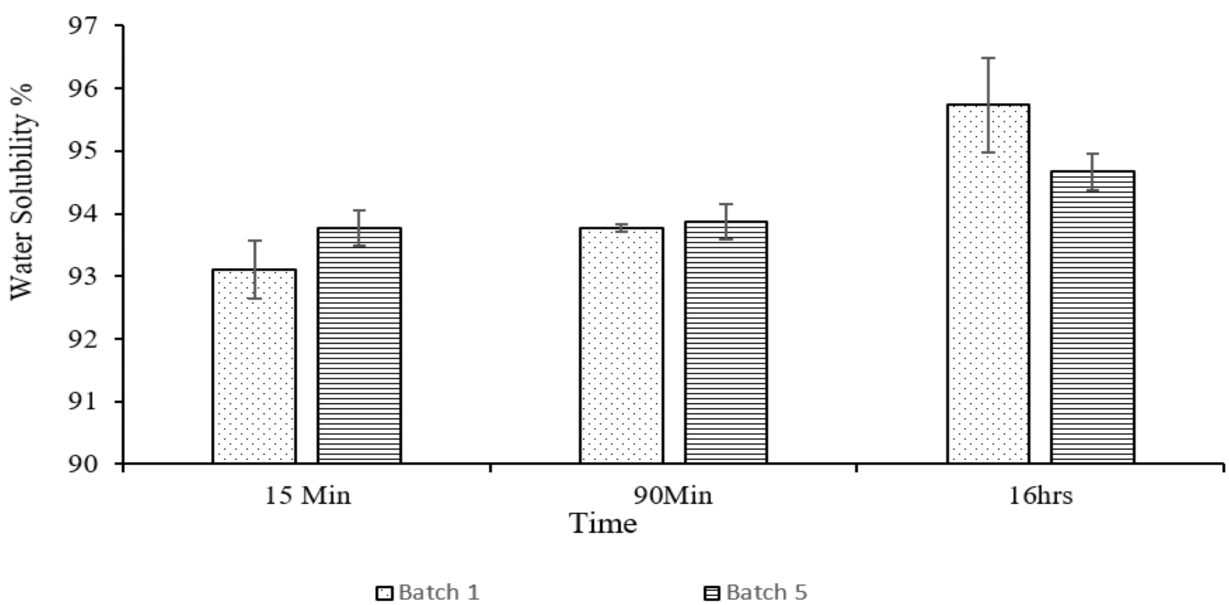

Figure 2.
Water solubility percentage of the seaweed biofilms (Batch 1- Raw seaweed film, Batch 5- Coconut oil added seaweed film).

The seaweed film's water solubility was 93.1%, 93.7%, and 95.7% at 15, 90, and 16 hours, respectively. The water solubility of the seaweed tested with coconut oil was 93.7%, 93.8%, and 94.6% at

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the same time intervals. Overall, the water solubility of the seaweed film was slightly greater than that of the seaweed with coconut oil film, particularly at the 16-hour mark.

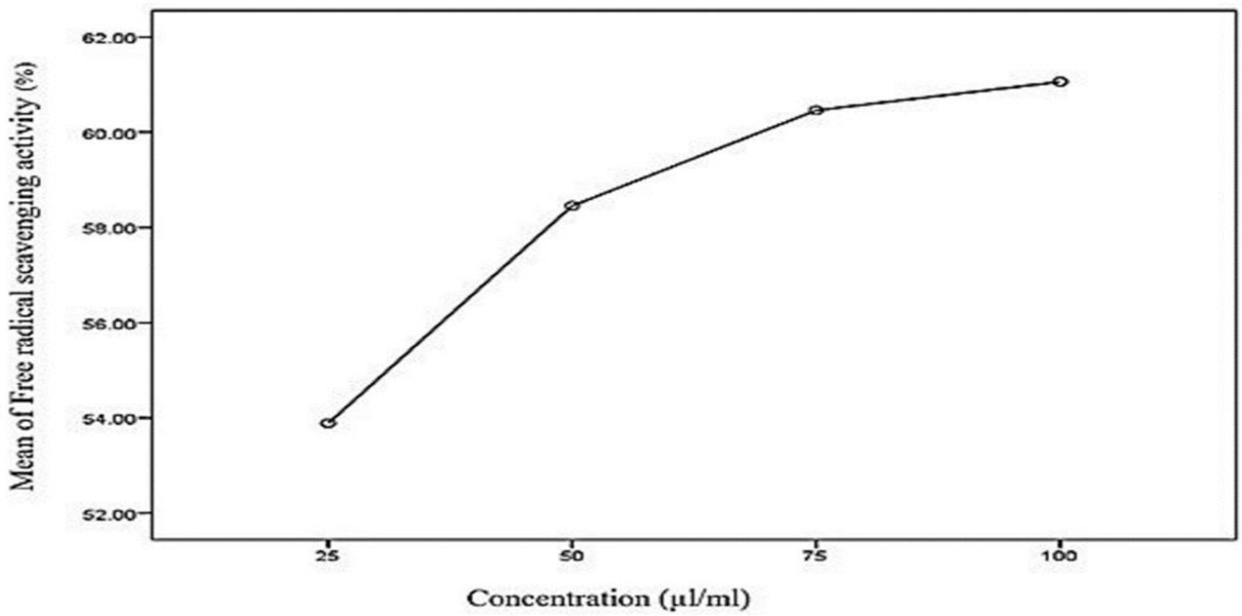

Figure 3.
The mean of DPPH free radical scavenging potential of methanol extracts of *G. verrucose.*

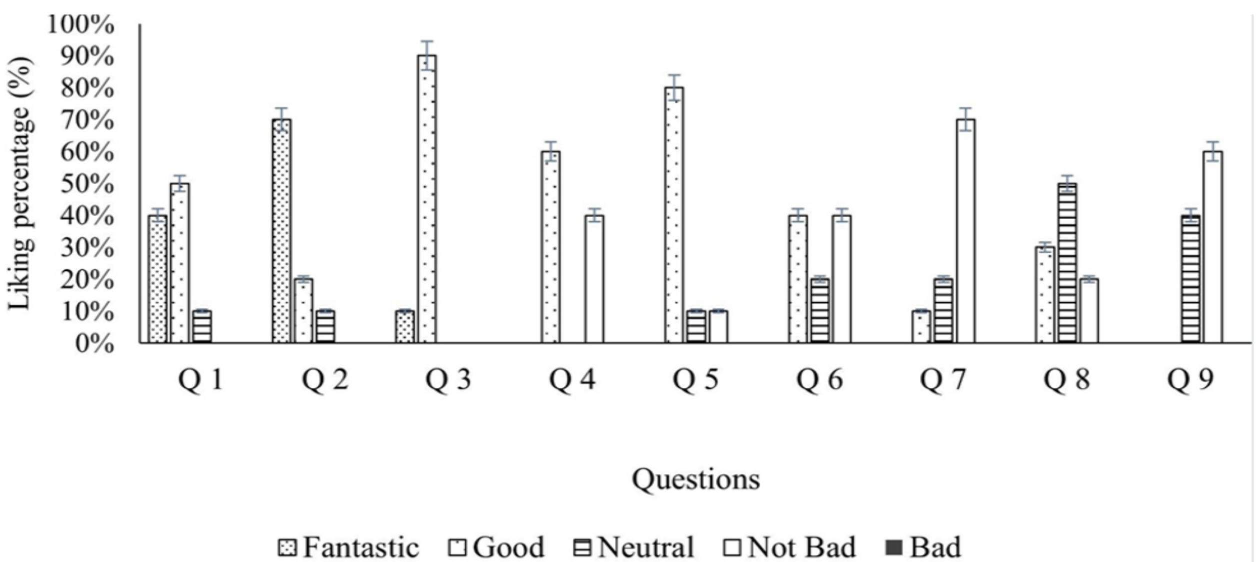

Figure 4.
Customer survey data analysis; 50% of respondents rated the appearance of the seaweed straws as "Fantastic," while 30% assessed their taste as "Fantastic." Following consumption, 60% rated the taste as "Not Bad," indicating a favorable level of acceptance among participants. 80% reported that the flavor of the soft drink consumed through the seaweed straws was "Good," suggesting a generally positive sensory experience. Notably, no participants rated the product as "Bad."

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