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A Preliminary Evaluation on the Development of Edible Drinking Straw from Guso *(Eucheuma cottonii)* Seaweeds

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Abstract: *This study aims to develop edible drinking straws using Guso seaweeds with varying plasticizer concentrations such as 25% glycerol (M1), 30% glycerol (M2), 25% sorbitol (M3), and 30% sorbitol (M4) (w/v basis). Straws are assessed for biodegradability, water absorption, tensile strength, elongation, hardness, and adhesiveness. Plasticizer type and concentration do not significantly affect hardness and adhesiveness. Glycerol-plasticized straws degrade faster than sorbitol-plasticized samples. M1 absorbs less water (44.69%) than M3 (58.86%). Higher sorbitol concentration enhances tensile strength and elongation from 124.10 MPa to 179.50 MPa and 15% to 22.70% for M3 and M4, respectively. Conversely, more glycerol reduces tensile strength but increases elongation. In summary, this preliminary study highlights the potential of Guso seaweeds for fabricating drinking straws. However, further research is needed to fully harness the possibilities offered by these resources.*

Keywords: Edible Drinking Straw, Guso Seaweeds, Plastic Pollution, Biodegradable Drinking Straw.

1. INTRODUCTION

The plastic straw is usually made up of polypropylene, a low-density thermoplastic polymer that is made by polymerizing propylene monomer [1]. However, as reported by Maddah [2], wastes from polypropylene (PP) require approximately 20 to 30 years to disintegrate in landfills. This results in the accumulation of plastic waste that is harmful to the environment and living things. Nowadays, one of the most relevant issues that every country is experiencing is environmental pollution. Around 80-95% of plastic contains ocean debris [3] [4] and most of it comes from straws, packaging, bottles, packaging, and other plastic items [5] [6]. Furthermore, petroleum-based plastic items require a large amount of energy to produce and large energy production results in environmental pollution by emission of particulates, burning of fuels, and other negative impacts [7]. Therefore, the need for an edible and biodegradable alternative for these single-used plastics is of high significance [8].

In recent years, some research studies have been made focusing on the development of edible and biodegradable drinking straws from subgrade pineapple peels and flesh [9], flour [10], bacterial cellulose [11], carboxymethyl cellulose as a main component, and carnauba wax as a water-insoluble coating [12], biodegradable drinking straws from Stereo-Complexed Poly-Lactic Acid (PLA) [13], bamboo gelatin [14], cornstarch, PLA, wheat, cane, paper, pasta, and rice straws [15].

The main constraints of this biomaterial are the availability and the higher cost of production. Hence, it is desirable to use another biomaterial that overcomes these constraints such as Guso seaweeds. Seaweeds are attractive options for bioplastic development because they have a higher growth rate and a high carbon dioxide fixation rate [16]. Because seaweeds are multicellular, macroscopic, benthic algae, unlike other terrestrial plants, seaweeds are more efficient in terms of photosynthesis which results in rapid accumulation of this biomass due to a higher growth rate [17]. They are abundant and readily available because they grow well in an aquatic ecosystem [18] [19], they are also marked as the major aquaculture products in the Philippines [20] Furthermore, in terms of cultivation, it requires no land preparation, no fertilizers, pesticides, and freshwater [21]. There is a great area to be planted by seaweeds, making them a more appealing option than terrestrial biomass. Owing to these reasons, FAO [22], reported that from 2005 an estimated total production of 14.7 million tons had doubled in 2015 with an estimated total volume produced of 30.4 million tons for both cultured and wild harvest. So, it can be forecasted that the total volume of seaweed production globally will continue to increase making them more appealing as a biomaterial source that the total volume of seaweed production globally will continue to increase making them more appealing as a biomaterial source.

Seaweed-based straws have gained attention as an innovative and practical solution to the plastic waste problem, and they have the added benefit of being edible, making them not only eco-friendly but also fun and functional. This research study has aimed to develop edible and biodegradable drinking straws using Guso seaweeds (*Eucheuma cottonii*) as the main component blended with different concentrations of glycerol and sorbitol plasticizer and then evaluate its potential in terms of biodegradability, water absorption, tensile strength (TS), elongation at break (EAB), hardness, and adhesiveness. Edible drinking straws from Guso seaweed have emerged as a possible replacement to single-use plastic straws or even paper straws. This breakthrough innovation holds great promise for reducing plastic waste and promoting sustainable consumption while providing a nutritious alternative to conventional plastic straws. The development of this product is one of the life-changing steps that can help reduce plastic pollution in oceans and waterways in a few years. Reducing the chances that can harm marine life. This is one of the solutions that can reduce the use of plastic that pollutes our environment. Consumers should be concerned about the health and environmental benefits of the use of edible straws.

2. Materials and Methods

2.1 Materials

Guso seaweeds, the primary component in this study, were purchased in Cabadbaran Public Market in Agusan del Norte, the Philippines. To avoid sample discrepancies caused by seasonal and agricultural practice variations, samples were gathered from the same vendor at the same time. Food-grade Sodium Hydroxide (NaOH) was bought from Dalkem Corporation in the Philippines. In addition, local chemical stores sold sorbitol and glycerine, while local food stores sold starch and distilled water.

2.2. Sundrying of Guso Seaweeds

Guso was sun-dried until the constant weight was attained at around 40% of the original weight of seaweed [23]. The Guso seaweed was taken to the Caraga State University Science Laboratory for further cleaning after sun drying. The primary goal of the pretreatment of dried seaweeds is to separate and remove contaminants from the sample and to eliminate any salt content that remained since these are crucial elements that have a substantial impact on the carrageenan gelling characteristic [24].

2.3. Extraction of Carrageenan

After being neutralized by soaking in distilled water heated to 26°C for 10 minutes, the sun-dried Guso seaweed was strained through a strainer. 4.40% (m/v basis) food-grade sodium hydroxide (NaOH) pellets were dissolved in distilled water to create the extraction solution [25]. The Guso seaweed was cleaned and rinsed before being put in a 1-liter beaker with water that had NaOH pellets dissolved in it for 3.5 hours on a hot plate. Cooking the Guso seaweeds in a hot aqueous solution of Alkaline solution causes desulfation at the 6-position of the galactose units of the carrageenan, to create recurring 36 anhydrous galactose polymers by dehydration and reorientation [26]. After the extraction was carried out, alkaline-treated Guso seaweeds were filtered using a strainer and remove the filtrate.

2.4. The process of straw development

Carrageenan, starch, distilled water, and varying concentrations of plasticizer (sorbitol and glycerin) as tabulated in Table 1 were mixed in a blender for 5 mins to form a paste. Subsequently, the homogeneous paste was placed in a beaker for the heating process. Using a hotplate, the paste was then heated under 200°C for 30 minutes and was carefully stirred at 10 minutes intervals. The developed paste was placed and rolled to flatten in parchment paper until homogeneous thickness was obtained and was then placed in a rectangular steel plate. Using a Labtech oven, the paste was oven dried under 65°C for 1.5 hours. Then, using a semi-dried paste, a molding procedure was carried out using a cylindrical stainless drinking straw. Another 1 hour of drying time at 65°C was performed for the straw to be completely dried. Afterward, the samples were placed at room temperature to cool down and carefully removed from the molder.

Table 1. Samples with different treatments.

M1	M2	M3	M4
100 ml distilled water	100 ml distilled water	100 ml distilled water	100 ml distilled water
10 grams starch	10 grams starch	10 grams starch	10 grams starch
12.5 grams (25%) glycerin	15 grams (30%) glycerin	12.5 grams (25%) Sorbitol	15 grams (30%) Sorbitol

2.5. Characterizations

The developed drinking straw as displayed in Figure 1 was characterized in terms of water absorption, biodegradability, tensile strength, and elongation.

Figure 1. The developed drinking straw samples

2.5.1. Water Absorption Test

Samples were soaked in a beaker filled with distilled water at 26°c and the amount of water absorbed was measured every 1, 3, 5, 10, 15, and 20 minutes. The percentage of water absorbed was determined using Equation 1.

Equation 1.

$$WA_{(\%)} = \frac{w_{wet} - w_{dry}}{w_{wet}}(100\%)$$

Where: $WA_{(\%)}$ = Percentage of water absorbed
w_{wet} = Weight of wet samples
w_{dry} = Weight of dry samples

2.5.2. Biodegradability Test

For this test, the standard soil burial test was carried out to measure the percentage of weight loss every day for 7 days. Using the Equation 2, the percent of weight loss was measured.

Equation 2.

$$WL_{(\%)} = \frac{w_0 - w_1}{w_0}(100\%)$$

Where: $WL_{(\%)}$ = Percentage of weight loss
w_0 = Initial weight
w_1 = Final weight

2.5.3. Mechanical Property Test

The tensile strength and elongation of the samples were measured using a Micro-computer screen hydraulic universal testing machine (UTM), China.

2.5.4. Textural Property Test

Thirty-three (33) tasters were invited to take the sensory tests. Each tester was given four samples representing the four mixtures. The panels tested each sample and selected the terms that were suitable for the texture of the sample. The drinking straws were analyzed in terms of hardness (1-Soft, 2-Firm, and 3-Hard) and adhesiveness (1-Tacky, 2-Gooey, and 3-Sticky. Then, a questionnaire was distributed to determine the consumer's acceptance of the product given. The students were lectured and instructed regarding the ISO5492:2008 (International Organization of Standardization, 2008) texture terms and the definition of those terms and attributes using reference foods indicated in the study [27] [28].

2.5.5. Data Analysis

In this study, two major statistical analyses were performed from the collected data which include the descriptive analysis and post hoc test. The basic descriptive analysis and post hoc test were executed using Statistical Tool for Agricultural Research (STAR) Software. The data were statistically analyzed as a completely randomized design (CRD) with three replications (for biodegradability and water absorption test only) using analysis of variance. Tukey's HSD test at P≤0.05 was employed to identify the significant variations between the mean of the different treatments.

3. RESULTS AND DISCUSSIONS

3.1. Water Absorption

The determination of moisture absorbed by edible and biodegradable plastic made from biomaterial is necessary for characterization. The higher rate of water absorption will generally influence and destroy the mechanical properties of the sample [29]. Thus, a lower amount of absorbed water for a given period is a desirable characteristic of a drinking straw for maintaining stability. For this study, the amount of water absorbed by the straw in 26°C distilled water was investigated, and results were presented in Figure 2.

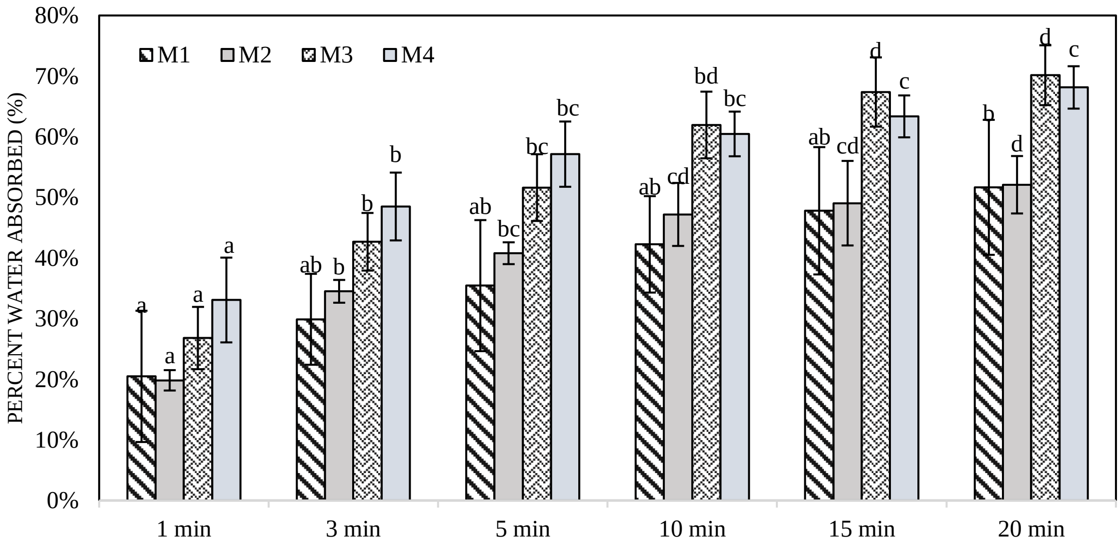

Figure 2. Percent of water absorbed representing different time intervals

Based on the graphical representation of the findings, it can be inferred that among all treatments, M1 has demonstrated a promising result as it absorbs a lesser amount of water throughout the time interval in comparison to M2, M4, and M3 with 51.65%, 52.08%, 68.13%, and 70.15%, respectively. The findings also explained that the glycerol concentration formed a stronger hydrogen bond with carrageenan, inhibiting the water molecule from combining with carrageenan or glycerol. Sorbitol-plasticized samples were able to absorb significantly higher water in comparison to glycerol-plasticized samples. This is expected since sorbitol has 6 hydroxyl groups (OH) as compared to glycerol with only 3 OH groups [30], enhancing the sample's ability to absorb water [31]. Higher OH groups provide more sites for water molecules to interact with and form hydrogen bonds, resulting in increased water absorption. The hydroxyl groups present in the plasticizers can act as hydrogen bond donors and acceptors, which can form hydrogen bonds with water molecules. Thus, the higher number of hydroxyl groups in sorbitol-plasticized bioplastics provides more opportunities for water molecules to interact with the plasticizer, leading to higher water absorption. This can be a crucial factor in determining the effectiveness of drinking straws as higher water absorption can affect the functionality of the product. Despite that, regardless of the plasticizer used, the amount of water absorbed is still relatively high. This finding is in line with the assertions that relate to the hydrophilic property of carrageenan from Guso, therefore influencing their water sensitivity. The results are similar to the findings of Ballesteros-Mártinez et al. [32] who reported the highest solubility for sweet potato starch-based plasticized with sorbitol as compared with glycerol plasticized samples.

In brief, in terms of stability, glycerol plasticized samples particularly M1 are the most desirable as they absorb a lesser amount of water. However, Ballesteros-Mártinez et al. [32] have pointed out that the highest water solubility for edible samples is also a good manifestation since they easily melt and dissolve in the month making sorbitol plasticized samples somehow acceptable.

3.2. Biodegradability

According to Goswami & O'Haire [33], biodegradability is the capacity of living organisms to biologically break down organic compounds, such as carbon dioxide, water, methane, basic elements, and biomass, down to their substructures. An essential quality of the material is its capacity to deteriorate in typical environmental circumstances. The breakdown of the material depends on several factors, including bacteria, fungi, microbes, and even environmental factors like temperature, humidity, soil moisture content, and acidity. The call for environmentally friendly production and biodegradability is due to the emphasis on environmental protection and sustainable development. For instance, this study has investigated the biodegradability of drinking straws derived from Guso, and the results were displayed in Figure 3. Samples that exhibited a higher percentage of weight loss are the most desirable as they provide a reliable practical application.

Based on the results, glycerin plasticized samples (M1 & M2) have exhibited a higher percentage of weight loss as compared to sorbitol plasticized samples (M3 & M4) with 48.61%, 45.36%, 31.04%, and 27.65% of weight loss at day 7 for M2, M1, M3, and M4, respectively. M1 and M2 samples were completely degraded on day 30 and day 31, respectively. Meanwhile, M3 and M4 were able to completely disintegrate on day 33 and day 35, respectively. The strong connection between soil moisture and microbial activity is to account for the greater disintegration of all samples. In other words, when more water is absorbed by straw throughout the burial process, the rate of decomposition accelerates for all samples. This further shows that the microbes devour the starch content, form gaps and pits on the sample's surface, damage the polymer's structure, reduce the sample's mechanical qualities, and hasten disintegration [34]. In general, the complete decomposition of the samples took place at a very close day interval.

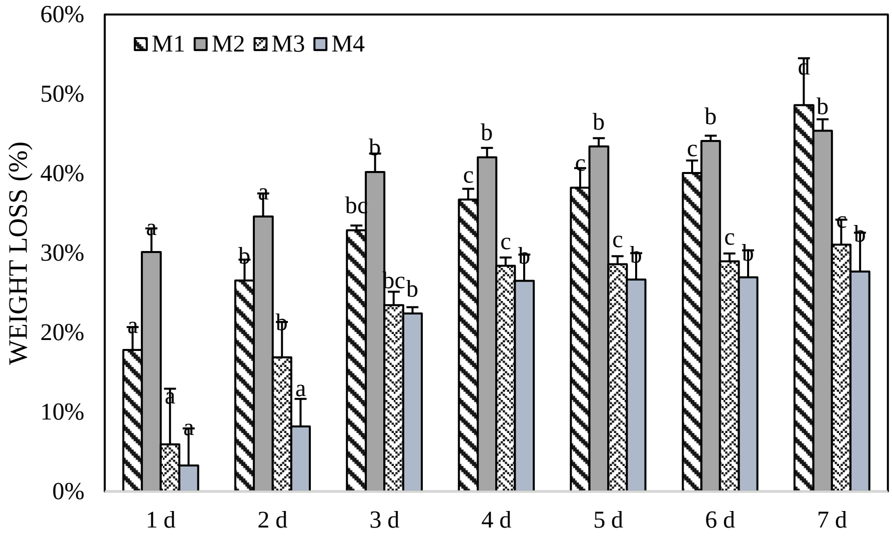

Figure 3. Biodegradability at normal soil representing different days interval

3.3. Mechanical Properties

According to Wu et al. [35], mechanical properties relate to a material's mechanical qualities in various settings and under diverse external stresses. Different kinds of materials possess different mechanical properties. Variations in the type and concentration of plasticizer will generally affect the mechanical properties of the final product [36]. Tensile strength and elongation are significant examples of mechanical properties. For instance, this study revealed the influence of sorbitol and glycerol plasticizers of varying concentrations on the tensile strength and elongation of Guso-made straw.

Based on the results in Figure 4, M4 exhibited the highest tensile strength followed by M1, M2, and M3 with 179.5 MPa, 154.5 MPa, 140.5 MPa, and 124.1 MPa, respectively. The concentration of sorbitol plasticizer has a directly proportional effect to its tensile strength in comparison to glycerol plasticized straw. Similar to the findings of Tarique et al. [37] who reported a significant reduction in sample tensile strength with the addition of glycerol plasticizer. Due to glycerol's strong compatibility with starch and carrageenan, which allows it to interfere with amylose packing inside the starch matrix due to H-bonding, higher tensile strength at lower glycerol concentration is achieved [38]. Drinking straws made from Guso seaweeds had tensile strengths that were much greater than those of plastic and paper straws, ranging from 15.58 to 47.98 MPa and 10 to 13.29 kN/m, respectively [39].

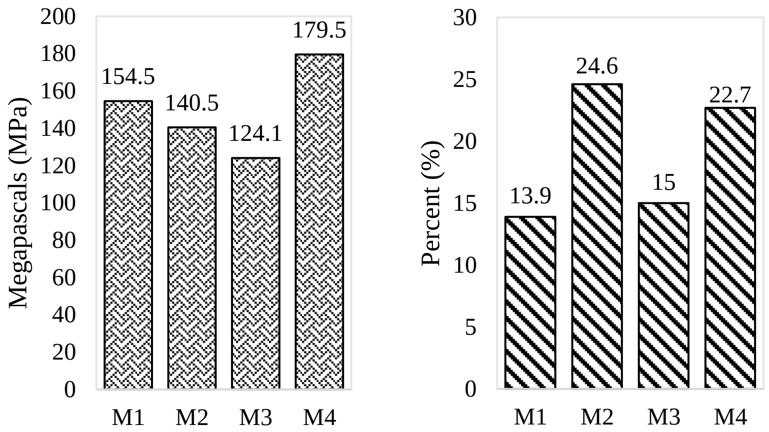

Figure 4. Tensile strength (left), and Elongation of the developed samples (right)

Based on the results obtained, it appears that there is a trend of increasing elongation with an increase in plasticizer concentration for both glycerol and sorbitol plasticizers. Specifically, comparing M1 and M2, which have the same plasticizer type (glycerol) but different concentrations, there is an increase in elongation from 13.9% to 24.6%, indicating that an increase in glycerol concentration leads to an improvement in sample elongation. Similarly, comparing M3 and M4, which have the same plasticizer type (sorbitol) but different concentrations, there is an increase in elongation from 15% to 22.7%, indicating that an increase in sorbitol concentration also leads to an improvement in sample elongation. M2 has the highest elongation value of 24.6%, which indicates that it can withstand a greater amount of stretching before breaking. On the other hand, M1 has the lowest elongation value of 13.9%, which suggests that it is more brittle and less flexible compared to the other formulations. M3 and M4 have intermediate elongation values of 15% and 22%, respectively. These results are important because the flexibility of the material affects its suitability as a drinking straw, with a more flexible material being more desirable to prevent breakage during use. The obtained value of EAB is higher as compared to bioplastic straws with 6-9 [40], biodegradable drinking straws from a combination of rice bran and unused rice with 0.43-1.71% [41]. A higher EAB indicates greater flexibility and durability, which are desirable properties for a drinking straw.

Similar findings were observed by Dianursanti et al. [42], Ballesteros-Mártinez et al. [32], Tarique et al. (2021) [37], and Sanyang et al. [43] who reported an increase in samples elongation with the rise in plasticizer concentration, both sorbitol and glycerol. The improvement in the mechanical properties of straw is explained by blending carrageenan with starch matrix [44]. The increase in elongation as plasticizer concentration increased is explained by the starch content in the sample. Plasticizers reduce the intermolecular connections between amylose, amylopectin, and amylose–amylopectin in the starch matrix and replace them with hydrogen bonds produced between plasticizer and starch molecules, resulting in increased film elongation [43].

3.4. Textural Properties

The textural property of the food product plays a vital role in consumers' acceptability [45]. It is one of the properties used by consumers to assess food quality [46]. Food texture can be assessed when we feel the food in our mouth and can be evaluated in terms of hardness and adhesiveness. Hardness is one of the most important textural properties and is often used to determine the freshness of food which relates to its overall quality. Also, adhesiveness is an important textural attribute of food products and is directly linked to their quality and consumers' acceptability. In most food production systems, the adhesion force is a mix of adhesive and cohesive forces in any given situation. When the adhesive force is large and the cohesive force is low, a food substance is viewed as sticky. This study has also investigated the effects of glycerol and sorbitol plasticizers on the adhesiveness and firmness of the drinking straw after using it in conveying water to the drinker's mouth.

All developed samples were made of completely edible and food-grade materials, ensuring safety and suitability for human consumption. A panel of testers was then selected to evaluate the samples for hardness and adhesiveness, providing valuable insights into the bioplastic products' texture and overall sensory experience. Using the drinking straw before testing can affect the sample's textural properties. As displayed in Figure 5, glycerol-plasticized drinking straws, particularly M2, and M1 demonstrated the highest firmness with 23 (69.70%) and 21 (63.64%) responses, respectively. Meanwhile, sorbitol plasticized drinking straws have shown the highest hardness responses with 22 (66.67%) and 21 (63.64%) responses for M4 and M3, sequentially. It is important to note that using the straw to convey water before testing may affect the firmness and hardness responses due to changes in the straw's structure caused by hydration. Nevertheless, increasing the concentration of glycerol and sorbitol plasticizers in the samples directly affected the sample's firmness and hardness, respectively.

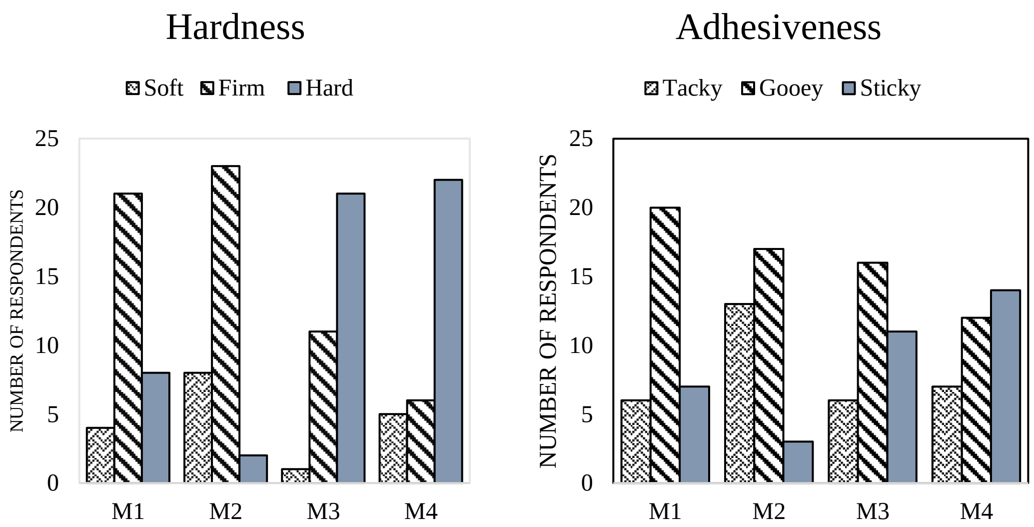

Figure 5. Effects of glycerol and sorbitol plasticizer on the hardness and adhesiveness of the drinking straw as judged by 33 panels.

Meanwhile, in terms of adhesiveness, it can be observed that the gooeyness value of the sample exponentially decreased from M1, M2, M3, and M4 with 20 (60.61%), 17 (51.52%), 16 (48.48), and 14 (42.42%) number of responses, respectively. The increase in glycerol concentration has led the sample's stickiness to decrease while increasing its tackiness. Furthermore, the increase in sorbitol concentration in the drinking straw has caused the sample's tackiness and stickiness to increase. In brief, glycerol plasticized drinking straw is gooier as compared to sorbitol plasticized drinking straw while sorbitol plasticized drinking straw is stickier in comparison to glycerol plasticized drinking straw.

Based on the results of the panel evaluation, it can be concluded that the differences in texture between the edible drinking straws were noticeable, but the taste was not distinguishable among the samples. It has been observed that consumers are increasingly seeking out environmentally friendly and sustainable alternatives to single-use plastics, and edible straws present an innovative solution to this problem. Additionally, the sensory properties of the straws can play a role in their overall acceptance by consumers. Therefore, it is important to understand the texture and sensory attributes of the straws to ensure their marketability and success as a sustainable alternative to traditional plastic straws. In brief, increasing the glycerol concentration causes a decrease in the sample's hardness and adhesiveness while increasing the sorbitol concentration led to the sample's hardness and adhesiveness increasing. This is in line with the assertion of Hanon et al. [47] that the TS of the material has demonstrated a linear correlation with the hardness over the entire range of the strength value. Materials that have a higher tensile strength also tend to have a higher hardness. This is because a material that can withstand high tensile stresses without breaking must also have a high level of resistance to localized deformation. Similarly, adhesiveness also increases with the increase in solubility [48].

4. Conclusions and Recommendations

The current study has highlighted the use of a local variety of Guso seaweed for the development of edible and biodegradable drinking straws. All samples were found completely degraded within 35 days regardless of the plasticizer used. Further, M1 and M2 samples exhibited lower water absorption rates as compared to M3 and M4 samples. This phenomenon is explained by more hydroxyl groups in sorbitol which enhances the sample's ability to absorb water. Glycerol plasticized samples, particularly M1 can be an indication that the developed straw can still operate in water for up to 20 mins. However, the higher water solubility of sorbitol-plasticized samples (M3 & M4) is a good manifestation of its edibility as samples with higher solubility can easily melt and dissolve in the mouth. The increase in sorbitol concentration causes an increase in the sample's tensile strength and percentage of elongation from 124.1 MPa to 179.5 MPa, and 15% to 22.7% for M3 and M4, respectively. In contrast, the increase in glycerol concentration causes a decrease in the sample's tensile strength while increasing its elongation. The firmness of the samples was directly proportional to the concentration of glycerol plasticizer while the hardness was directly proportional to the concentration of sorbitol plasticizer. In conclusion, glycerol is the most recommended plasticizer as results from the study revealed that glycerol-plasticized samples have more integrity and are more operational with lower water uptake as compared to sorbitol-plasticized samples. Although the percentage of water absorbed through time does not exhibit desirable practical applications, it is important to note in further studies to incorporate water-insoluble coatings to enhance the integrity of the sample when used in water. Additionally, future studies may consider testing the mechanical properties of the samples before and after use in water to investigate the effect of water absorption on their mechanical properties.

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