Asia-Pacific Journal of Science and Technology: Volume: 28. Issue: 05. Article ID.: APST-28-05-06. Research Article

Asia-Pacific Journal of Science and Technology

https://www.tci-thaijo.org/index.php/APST/index

Published by the Research and Graduate Studies Division,
Khon Kaen University, Thailand

Evaluation of guso seaweeds as potential material for the development of edible drinking straw

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Received 2 August 2022
Revised 24 September 2022
Accepted 28 September 2022

Abstract

Single-used plastics such as drinking straws are marked as a major source of total plastic waste around the world. Due to their tiny size and lack of recycling potential, plastic straw trash is often overlooked in comparison to other plastic garbage resulting in a tremendous environmental burden such as plastic pollution. For these reasons, the need for edible and biodegradable drinking straws derived from renewable sources such as guso seaweed is of high significance. Therefore, the main objective of this study was to develop a drinking straw made from guso seaweeds using different plasticizer concentrations such as 25% glycerol (T1), 30% glycerol (T2), 25% sorbitol (T3), and 30% sorbitol (T4) (w/w basis). The developed drinking straw was then characterized in terms of biodegradability, water absorption, tensile strength (TS), and elongation at break (EAB). The results showed that the type and concentration of plasticizers have no significant effects ($p>0.05$) on the TS and EAB of the samples. Glycerol plasticized drinking straws also showed quick degradation compared to sorbitol plasticized samples. In terms of water absorption, significant changes ($p\leq 0.05$) were found where T1 obtained a value ranging from 44.63-50.42%. This demonstrated a promising result as it absorbs a lesser amount of water in comparison to T3 (57.65-70.44%). The study concluded that the incorporation of plasticizers can enhance the properties of drinking straws made from carrageenan of guso seaweeds and is potential to produce edible drinking straws out from guso seaweeds.

Keywords: Edible drinking straw, Biodegradable drinking straw, Plastic pollution, Guso seaweeds, Sustainable straw

1. Introduction

Single-use plastics have become a part of our everyday life due to their convenience and simplicity of use, resulting in a tremendous environmental burden such as plastic pollution. In 2015, it was reported that approximately 300 million tons of plastic were produced, where 30 million tons and 50 million tons of which were dumped on land and burned, respectively [1]. Furthermore, an estimated 5-15 million tons of them were also dumped in oceans, rivers, and rural landscapes [1]. For these reasons, plastic pollution is marked as the world's most serious problem nowadays, with dire effects for marine life as well as people.

As reported by the World Bank Group [2], the Philippines is the third-largest contributor of plastic waste, with an estimated 0.75 million metric tons of mismanaged plastic entering the ocean annually. There has been a rise in awareness of plastic waste management in the Philippines, bringing the issue of plastic pollution to the forefront of consumer consciousness. However, only a small amount of plastic waste has been recycled, and mostly it ends up in oceans, rivers, and waterways, and drinking straw is one of them.

A drinking straw is a tube that uses sucking pressure to convey drinks from a container to the drinker's mouth and is usually made from plastics. The plastic straw is generally made of polypropylene, a low-density thermoplastic polymer that is made by polymerizing a propylene monomer [3]. However, Maddah [4], reported that wastes from polypropylene (PP) require approximately 20 to 30 years to disintegrate in landfills. It resulted in the accumulation of plastic waste that is harmful to the environment and living things. For instance, the Ocean Conservancy [5] has reported that plastic straw is the fifth primary source of the total plastic waste worldwide. Straw and stirrers are among the top sources of plastic waste that end up in oceans together with other disposable plastic products. Because of its tiny size and lack of recycling potential, plastic straw trash is often overlooked in comparison to other plastic garbage. Despite that, the plastic straw is still widely used worldwide, especially in restaurants, fast food chains, cafes, convenience stores, and other stores with food and drinks due to their high availability and low price.

Though a basic need, plastic products have become an intrinsic part of our daily lives. The development of biodegradable materials and edible products in order to replace plastics is desirable. The use of edible products as replacements for plastic could help people to detach from the use of plastics. As Patel [6], mentioned, proteins and carbohydrates, the building blocks of biological polymers present in plant tissues, would provide the ultimate edible packaging. It can also be used to develop edible plastic items such as edible drinking straws.

Although, eco-friendly straws made of sustainable materials such as paper straws were proposed to replace plastic straws. The significant constraints of paper straws are their stability and quality, as they lose strength and absorb liquid during usage. Hence, it is essential to propose and develop adequate alternatives for single-use plastic items such as drinking straws that meet the requirements in terms of stability, functionality, and overall quality. Additionally, there is no study that focuses mainly on the exploitation of the potential of guso seaweeds as shown in Figure 1 for the development of edible drinking straw. As a response, the present study aimed to develop an edible drinking straw made of completely edible ingredients such as carrageenan extracted from guso seaweeds blended with starch and characterize the developed edible drinking straw in terms of biodegradability, water absorption, and mechanical properties. The straw made of edible materials is a variety of straws with properties such as being flexible, lightweight, translucent, readily formed, waterproof, impact-resistant, and safe to eat. The desire to develop edible and biodegradable drinking straws is governed by the need to address the rapid growth of plastic pollution problems and contribute to significant innovation in the food industry.

Figure 1 Guso Seaweeds (*Eucheuma Cottonii*).

2. Materials and methods

2.1 Preparation of materials

The main ingredient used in this study was guso seaweeds, which were bought at Cabadbaran Public Market, Agusan del Norte, Philippines. Samples were collected at the same vendor to prevent sample disparity due to seasonal and cultivation practice variation. Food grade Sodium Hydroxide (NaOH) was purchased from Dalkem Corporation, Philippines. Sorbitol and Glycerine were purchased from local chemical stores, while the starch and distilled water were purchased at local grocery stores. The guso was sun-dried until the constant weight was obtained with approximately 40% of the seaweed's original weight. After sun drying, the guso seaweed was carried out at Caraga State University Science Laboratory for further cleaning. The main aim of pretreatment of dried seaweeds is to sort and remove impurities in the sample and eliminate the remaining salt content, which is an important factor that significantly influences the carrageenan gelling property.

2.2 Carrageenan extraction and straw formation

The sun-dried guso seaweed was neutralized by soaking in distilled water for 10 minutes and filtered by a strainer. For the preparation of the solution for extraction, 4.40% (m/v basis) food grade NaOH pellets were dissolved in distilled water. The cleaned and washed guso seaweeds were placed in a 1-Liter beaker with dissolved

NaOH pellets in water and placed on a hot plate at 90°C temperature for 3.5 h. Carrageenan, starch, distilled water, and varying concentration of plasticizers such as 25% glycerol (T1), 30% glycerol (T2), 25% sorbitol (T3), and 30% sorbitol (T4) (w/w basis) were mixed in a blender for 5 min to form a paste. The developed paste was then oven-dried using a Labtech oven for 3 h at 65°C in a cylindrical mold.

2.3 Characterizations

The developed drinking straw with an average length of 152 mm and 11.50 mm diameter as displayed in Figure 2, was characterized in terms of water absorption, biodegradability, tensile strength, and elongation. Every test was carried out in three replications to ensure the validity of data obtained.

Figure 2 The developed drinking straw samples.

2.3.1 Biodegradability test

For the biodegradability test, the standard soil burial test was carried out to measure the percentage of weight loss every day for seven (7) days. Using Equation 1, the percent of weight loss was calculated.

$$WL_{(\%)} = \frac{w_0 - w_1}{w_1}(100\%) \tag{1}$$

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

2.3.2 Water absorption test

Samples were soaked in a 1 L beaker of three different water temperatures such as 5 and 10°C. The amount of water absorbed was measured periodically every 1, 3, 5, 10, 15, and 20 min. After each observation, the samples were taken out from water and then wiped carefully to eliminate the water present in the surface of the samples and then measured using electronic balance. The percentage of water absorbed was calculated using Equation 2.

$$WA_{(\%)} = \frac{w_{wet} - w_{dry}}{w_{wet}}(100\%) \tag{2}$$

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

2.3.3 Mechanical property test

Tensile strength and percentage of elongation are two of the most important mechanical properties. The tensile strength and elongation of the samples were measured using Universal Testing Machine (Micro-computer screen hydraulic universal testing machine, China).

3. Results and discussion

3.1 Biodegradability test

Biodegradability is the ability of living organisms to biologically degrade organic substances down to their substructures, such as carbon dioxide, water, methane, basic elements, and biomass. The ability of the drinking straw to degrade under normal environmental conditions is an essential property of the material to consider. The developed drinking straw from guso seaweeds and starch is made up of organic materials. The developed drinking straw from guso seaweeds and starch is made up of organic materials. Therefore, they are easily degraded by a variety of organisms present in soil. Several parameters, including bacteria, fungi, microorganisms, and even environmental conditions such as temperature, humidity, soil moisture content, and acidity, play an essential role in the decomposition of the material. Samples that exhibited a higher rate of biodegradability are the most desirable as it provides great potential in terms of addressing the concern related to plastic pollution. In this study, the ability of edible drinking straws to degrade under normal soil conditions was investigated, and the results were presented in Figure 3. Results revealed that the percentage of weight loss for T1, T2, T3, and T4 from 1 d of burial to 7 d in normal soil ranged from 11.14%-41.38%, 19.43%-46.50%, 12.53%-38.47%, and 13.19%-33.25%, respectively. As supported by Tukey's HSD test at $p \leq 0.05$, significant changes were observed in the percentage of weight loss of drinking straws in all treatments applied under normal soil conditions.

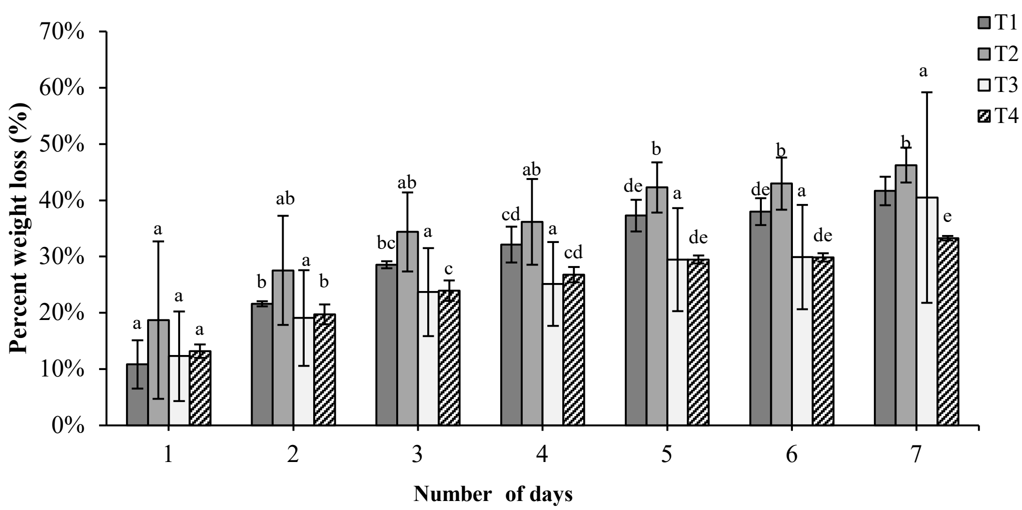

Figure 3 Biodegradability of guso-based drinking straw plasticized with different concentrations (25% and 30%) of glycerol and sorbitol under normal soil conditions. Error bar shows standard deviation while different small letters at every time interval are represented.

However, among all treatments, T1 and T4 showed consistent significant changes at $p \leq 0.05$ in weight loss for this soil condition. It implies that the plasticizer concentration has influenced the drinking straw's ability to degrade under normal conditions. In comparison, the T3 was found insignificant ($p>0.05$). This result may be associated with the packed structure of samples with 25% sorbitol concentration, and more bubbles were observed, causing some air bubbles to trap in T3 samples as seen by naked eyes. As a result, the dense structure of the poly matrix of the sample has decreased, while the water absorption capability has increased, promoting microorganism growth as compared to other samples [7]. The higher value of standard deviation (SD), particularly in T2 and T3 under normal soil, is explained by a fluctuation of environmental conditions and the dimensional disparities of the samples due to the manual molding process.

The higher the presence of starch and glycerol explains the decomposition of glycerol plasticized samples as these materials are hydrophilic, favor the water absorption, increase the water activity of the samples, and promote higher growth of microorganisms [8]. The microorganisms present in the soil, particularly in organic soil, utilize starch as the main carbon source, resulting in partial degradation of samples. The moisture absorption of drinking straws during the burial test is mainly due to the starch content of the samples. As samples absorb moisture, it is more prone to microorganisms' attack. It may allow the microorganisms such as fungi and bacteria to access the inferior of the samples by using water as a medium. It also suggests that the microorganisms consume the starch content and create voids and pits on the sample's surface, subsequently weakening the polymer's structure, decreasing the sample's mechanical properties, and promoting rapid deterioration [9].

Marium et al. [10] also demonstrated the same findings as glycerol plasticized carrageenan-based film possessed maximum decomposition compared to sorbitol plasticized films. This result is explained by the hydrophilic property of glycerol, which resulted in higher degradation of glycerol plasticized samples compared to sorbitol plasticized samples, which show a lower decomposition rate [11]. The more the water activity, the higher the microorganisms that can speed up the process of sample deterioration [11]. A similar trend was reported by Lusiana et al [12], where quick degradation of glycerol plasticized sago- poly (vinyl alcohol) (PVA) starch in comparison to sorbitol plasticized bioplastic was noticed and is explained by the fact that glycerol is more soluble in water and with the addition of starch which helps the hydrophilic property of glycerol to increase.

In brief, drinking straws plasticized with sorbitol and glycerol have shown excellent degradation with the range of 11.49-46.50% and 12.53-38.47% for the first seven (7) d under normal conditions and have demonstrated complete degradation within 35 days. This weight reduction is comparable to glycerol plasticized bioplastic derived from guso seaweeds with 49.50-56.25% weight loss for the first ten days of soil burial [13]. Higher than biodegradable plastic derived from cassava peel starch plasticized with 8.00-32.73% weight loss at first 7 days of soil burial [14], biodegradable plastic from cassava waste with 61-64 days requirement for complete degradation [15], and starch-based bioplastic with 29.89% weight reduction at day 10 of soil burial [16]. The higher decomposition of a guso-based drinking straw is ascribed to the close relationship between the moisture present in soil and its microbial action [17]. The presence of carrageenan plays an essential role in the higher degradation of all samples as compared to other bioplastics because carrageenan has more hydroxyl (OH) groups, attracting more water. Furthermore, carrageenan contains sulfate esters which are also hydrophilic and can bind easily to water.

3.2 Water absorption test

Water absorption is an important property of edible and biodegradable drinking straws. Therefore, the determination of water absorbed by edible and biodegradable plastic made from biomaterial is necessary for characterization. Absorption of water by a polymer will typically result in swelling and will result in poor mechanical properties. Low water absorption during the use of drinking straw with respect to time is desirable to maintain product integrity and stability during the usage as drinking straw is intended to work in water or beverages.

According to the results in Figure 4, the percentage of water absorbed from 1 to 20 min of the test under 10°C were also found in the range of 14.49 to 44.63% for T1, 20.51 to 57.91% for T2, 22.32 to 57.65% for T3, and 16.14 to 56.61% for T4. And the percentage of water absorbed for samples under 5°C was 18.19-49.66%, 20.16-53.03%, 30.21-62.62%, and 28.92-62.27%, respectively. Hence, the amount of water absorbed obviously varies concerning the treatment being applied and the water temperature used. As supported by Tukey's honestly significant difference (HSD) test at $p \leq 0.05$, significant variations occurred for all treatments under these water temperatures. This finding infers that the incorporation of glycerol and sorbitol plasticizer has influenced the ability of drinking straws to absorb water at 10°C and 5°C. However, samples with the highest sorbitol concentration, particularly the T3 under 5°C, were found statistically insignificant ($p>0.05$). This is because, according to Zhi et al [18], the solubility of sorbitol plasticizer is influenced by lower water temperature. The obtained data have also shown a higher SD value which is caused by the dimensional discrepancy considering the thickness, diameter, and length of the developed edible drinking straw.

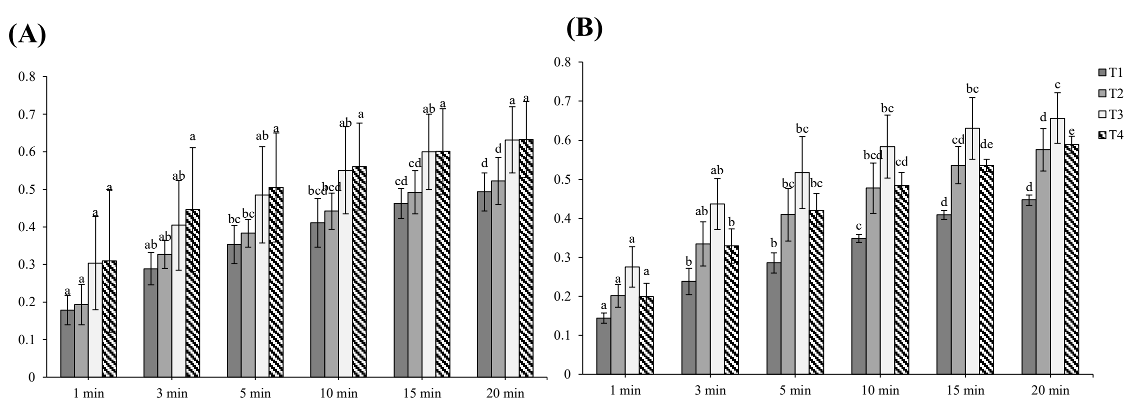

Figure 4 Water absorption of guso-based drinking straw plasticized with different concentrations (25% and 30%) of glycerol and sorbitol under (A) 5°C and (B) 10°C. Error bar shows standard deviation while different small letters at every time interval represent statistical diff difference at $p<0.05$ based on Tukey's HSD test.

A graphical representation of water absorption at 5 and 10°C was presented in Figure 4. Based on the graphs, it can be observed that glycerol plasticized samples have exhibited lower water uptake in comparison to sorbitol plasticized samples for all water temperatures. 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 could absorb significantly higher water compared to glycerol plasticized samples. It is expected due to the fact that sorbitol possesses more hydroxyl groups than glycerol, enhancing the sample's solubility [19]. This result is comparable to sweet potato starch-based bioplastic [20], biodegradable plastic derived from sago starch [21], cornstarch-based biopolymer [22], and corn starch biopolymer [23]. The formation of hydrogen bonds explains this with starch produced by the presence of hydroxyl groups inside the plasticizer molecules, resulting in a higher tendency for water absorption into plasticized polymers [23].

In general, T1 maintained up to 50% (w/w) of its integrity in water at 10°C, and 5°C, suggesting that a drinking straw with 25% glycerol concentration is partially soluble in water irrespective of water temperature used. So, in terms of stability, glycerol plasticized samples, particularly T1, are the most desirable as they absorb less water. Although, there is a need for edible drinking straw with low water absorption as it enhances product integrity and water resistance during usage. Mártinez et al. [20], have pointed out that the highest water solubility for edible samples is also a good manifestation since they easily melt and dissolve in the mouth. Solubility is a physical quality that refers to the capacity of edible samples to dissolve in water so that they can be adequately digested when consumed or degrade naturally if released into the environment [23]. It implies that sorbitol plasticized drinking straws (T3 and T4) have shown a good representation of an edible drinking straw.

3.3 Mechanical properties

The mechanical properties relate to a material's mechanical qualities in various settings and under diverse external stresses. The different kinds of materials possess different mechanical properties. Variations in plasticizer type and concentration will generally affect the mechanical properties of the final product. Tensile strength (TS) and elongation at break (EAB) are significant examples of mechanical properties. This study revealed the influence of sorbitol and glycerol plasticizer of varying concentrations on the TS and EAB of guso-made straw. The results were presented as arranged in Figure 5. As observed, the increase in glycerol and sorbitol concentration has caused to decrease in the sample's TS while increasing the value of EAB. However, as supported by Tukey's HSD test at $p \leq 0.05$, all treatment samples were not statistically significant. Therefore, the varying concentration and types of plasticizers have no significant effect on the TS and EAB of the developed drinking straw. The narrow range of both plasticizer concentrations (25%-30%) applied to the samples may have contributed to these insignificant results at $p > 0.05$ [27].

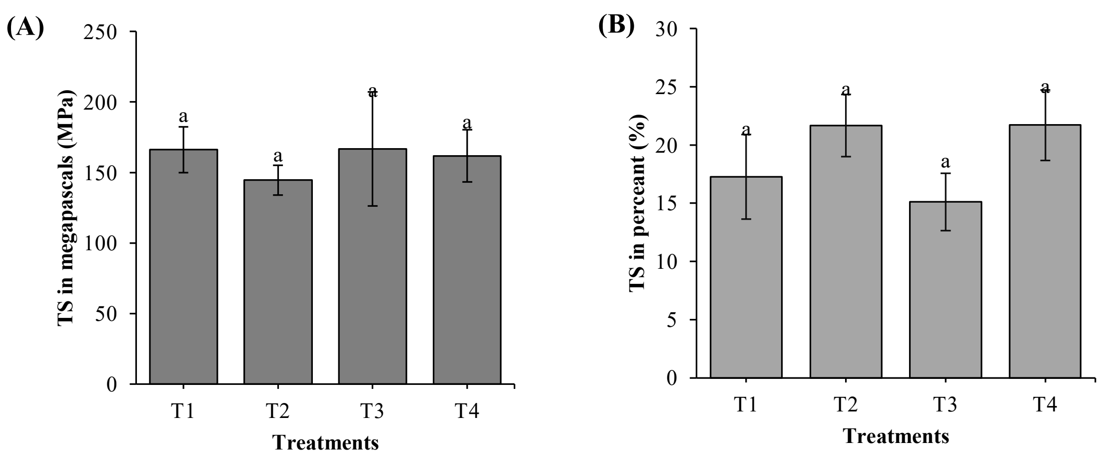

Figure 5 (A) Tensile strength (TS) and (B) Elongation at break (EAB) guso-based drinking straw plasticized with different concentrations (25% and 30%) of glycerol and sorbitol. Error bar shows standard deviation while different small letters at every time interval represent statistical difference at $p<0.05$ based on Tukey's HSD test.

Based on the results, T3 exhibited the highest TS with 166.73 MPa, followed by T1, T4, and T2, with 166.1 MPa, 161.77 MPa, and 144.53 MPa, respectively. The increase in glycerol and sorbitol concentration has decreased the sample TS value. In the same manner, Tarique et al. [26] have reported a noticeable reduction in sample tensile strength with the addition of glycerol plasticizer. Higher tensile strength at lower glycerol concentration is due to the good compatibility of glycerol with starch and carrageenan, which enables the glycerol to interfere with amylose packing inside the starch matrix due to H-bonding. Arham et al [24] also reported a decrease in the TS of agar-based film as glycerol concentration increased. The incorporation of glycerol plasticizer for developing edible film and other polymers can reduce the value of samples TS, which is explained by the interaction between seaweed polysaccharides and water molecules. Liu et al [27] also reported the same findings as starch-chitosan films exhibited a reduction in TS value with the increasing glycerol concentration. In the same manner, Lusiana et al [12] also reported a decrease in the TS of sago-PVA starch bioplastic as glycerol and sorbitol concentration increased. This phenomenon is explained by the nature of glycerol and sorbitol, which were easily bonded to other molecules. Arief et al [28] also obtained a similar result, as a reduction in TS value of bioplastic with the increasing sorbitol concentration was noticed. It is because sorbitol can reduce the molecular internal hydrogen bonds, which causes the intermolecular pull of adjacent polymer chains to reduce the TS value.

The incorporation of plasticizer into polymers is to overcome brittleness, improve toughness, impart flexibility, and prevent shrinking during the handling and storage period. Hence, the addition of plasticizers to improve the mechanical properties of an edible drinking straw is desirable. The tensile strength of drinking straws from guso seaweeds was significantly higher as compared to plastic straws and paper straws with the range of 15.58-47.98 MPa and 10-13.29 kN/m, respectively [29]. Thence, the edible drinking straw from guso seaweeds formulated with different concentrations of sorbitol and glycerol plasticizer exhibited good tensile strength, which suggests potential application as an edible and degradable drinking straw and as a replacement for plastic and paper straws.

In terms of EAB, it was observed that the rise in glycerol and sorbitol concentration has significantly increased the sample percentage of elongation. T4 with higher sorbitol concentration as compared to T3 (of 5% lower than T4) has higher EAB values with 21.70% and 15.10%, respectively. Similarly, T2 exhibited a higher elongation than T1 (of 5% lower glycerol concentration) with 26.67% and 17.27%, respectively. Similar findings were observed by Ballesteros-Mártinez et al, Tarique et al., Sanyang et al., and Dianursanti et al [20,26,30-31], 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 [32]. 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 [30].

4. Conclusion

The current study suggest that the incorporation of glycerol and sorbitol plasticizer can enhance the property of edible and biodegradable drinking straw in terms of biodegradability, water absorption, and its mechanical properties. Among these treatments, glycerol plasticized drinking straw (T1 and T2) excels in terms of biodegradability and water absorption, while sorbitol plasticized drinking straw (T3 and T4) shows good performance in terms of edibility. Despite that, the developed samples of all treatments performed better in terms of mechanical properties and shows slight disparities. Therefore, the current study has concluded that guso seaweeds can be a potential material for the development of edible and degradable drinking straw but still requires further undertaking for the enhancement of its properties.

Although, the result from characterization indicates a good representation of edible and biodegradable drinking straw characteristics. The researchers would like to recommend the incorporation of a water-insoluble edible coating such as carnauba wax to maintain the integrity of the drinking straw during usage. Furthermore, the use of an extruder is highly recommended as it allows the formation of straw with slight or no dimensional disparity which prevents variable results during the characterization. As the drinking straw is said to be edible, shelf-life, water activity investigation and toxicity test are also recommended. In further studies, it is essential to conduct an economic analysis for the developed edible drinking straw for possible commercialization or mass production and consumers acceptability test considering the demographic profile of the respondents.

5. Acknowledgements

The authors are thankful to the Department of Chemistry, College of Mathematics and Natural Sciences and Department of Agricultural and Biosystems Engineering (DABE), College of Engineering and Geosciences (CEGS), Caraga State University (CSU), Ampayon, Butuan City 8600, Philippines for the facilities and equipment provided. The authors also acknowledge the Center for Resource Assessment, Analytics and Emerging Technologies (CReATe) under Value Adding of Agricultural Wastes Project for the financial assistance and technical expertise offered during the conduct of this study.

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