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Effects of Drying Temperatures on Drying Rates and Proximate Composition of Caulerpa Racemosa Dried Using the Tray Dryer

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Abstract
This study examined the effects of different drying temperatures (50°C, 55°C, and 60°C) on the nutritional attributes of *Caulerpa racemosa* seaweed to improve preservation techniques. The seaweed's potential as a nutrient source and the challenge of preserving it were explored by drying samples at varying temperatures to assess the impact on quality. Proximate analysis of dried samples was performed to evaluate drying effects, measuring moisture, crude ash, fiber, fat, protein, and carbohydrates using the AOAC methods. This study aimed to find the most viable drying temperature that preserves seaweed quality through a comparative analysis between the three temperatures used in the drying process. The proximate analysis results were averaged and analyzed through statistical analysis (ANOVA and Tukey's HSD Test) to determine significant differences in the data. Samples dried at 55°C for 240 minutes had the lowest ash content (60.94%) and highest fat (1.64%), protein (10.22%), and carbohydrate (19.33%) levels, with a moisture content of 14.94%. The lowest moisture was in samples dried at 60°C, and the highest fiber at 50°C. Ash and protein contents differed significantly, while carbohydrates, fiber, and fat did not. The drying kinetics of the experiment also showed no significant differences when comparing the average moisture content and drying rate at different temperatures. Therefore, it is recommended to dry seaweed at 55°C as it preserves the seaweed's attributes the most. Drying at 50°C took 30 minutes longer and impacted the sample's composition. Further research is needed to identify the best drying parameters and conditions for *C. racemosa.*

Keywords: Proximate Analysis, Seaweed Preservation, Green Seaweed, Drying

1. Introduction

Seaweed species are spread globally across the world's coastal climate regions, from tropical, temperate, and polar areas [1]. Seaweeds or marine macroalgae are a phylogenetically diverse group that is essential to maintaining oceanic balance and providing nutrients and energy [2].

Seaweeds, abundant in the Philippines, hold immense potential as a nutrient-rich food source. Seaweed provides vitamins, trace minerals, lipids, amino acids, and antioxidants, offering a wide range of health benefits. These compounds, with their numerous biological activities, are not just functional ingredients but also natural sources of functional foods [3]. Consumption of seaweed can reduce the risk of disease or chronic illnesses, making seaweeds a promising macroalgae [4].

Caulerpa racemosa, one of the seven commercialized seaweeds produced in the Philippines through mariculture [5], holds multiple health benefits. However, the perishable nature of seaweed in its fresh state, which deteriorates within a few days after harvesting due to its high water content [6], poses a significant challenge. To ensure the availability of seaweed and prolong its shelf-life, harvested seaweed often requires drying before commercial distribution.

One of the main limitations of the drying process is the high temperatures used. When exposed to such high temperatures and long drying times, organic components in seaweed risk being damaged [7]. As a result, the quality of the beneficial compounds, as well as amino acids, proteins, lipids, and fatty acids, are reduced [8].

Various drying methods can be applied to seaweed preservation: direct sunlight drying and conventional convective drying. While both provide advantages and disadvantages, conventional convective dryers are more commonly used due to its flexibility and continuous process proving to be one of the most effective methods for food dehydration [9] due to its various applications and capability to produce dried products at high volumes. The tray dryer is a drying equipment based on convection drying; hot air is used to remove moisture from the seaweed. The hot air is circulated through the drying chamber and passes over the tray as it draws moisture from the seaweed in the tray [10]. One of the drawbacks of the tray dryer is uneven drying due to poor airflow distribution through the chamber [11]. To ensure that the seaweeds are dried appropriately, the drying rate, temperature, and airflow within the chamber are controlled.

To address the challenges of seaweed preservation, this study aims to explore the most viable tray drying temperature for preserving the seaweed species *Caulerpa racemosa* and evaluate the impact of different drying temperatures on the properties of the seaweed. By evaluating this parameter, this research seeks to contribute to the advancement of seaweed preservation using the tray dryer specifically for *Caulerpa racemosa*, with the goal of extending shelf-life while retaining its essential nutritional and functional attributes.

2. Materials and Methods

Samples were purchased from Trabajo Market in the city of Manila. The seaweeds bought from the vendor were supplied from Nasugbu, Batangas.

Research Paradigm. Three trials were conducted for each drying temperature. The study aims to preserve the nutritional components and improve the shelf life of *C. racemosa.* Phytochemicals are also crucial in preserving seaweed, protecting it from bacteria and other threats. [12]. The choice of drying temperatures can significantly influence the presence of the phytochemical compounds in the seaweed, such as the total phenolic and flavonoid content [6]. The study by Fakhrulddin et al. (2022) recommended drying *C. lentillifera* at 50°C. Their study resulted in a significant concentration in the total phenolic and total flavonoid content at 50 and 60°C; adverse effects were observed at higher drying temperatures and drying at 40°C was insufficient for vaporization [13]. As *C. lentillifera and C. racemosa* share the same genus, the drying temperature for *C. racemosa* was set to 50, 55, and 60°C, to preserve these phytochemical compounds. A very long drying time can lead to nutritional degradation [14]. Air flow rate increases the rate of moisture removal resulting to shorter drying times. [15]. Adding air velocity as a fixed parameter was highly favored by the researchers. A low value for air velocity, such as 0.3 m/s, is favorable for small batch drying operations [16]. For each trial, the temperature of the drier and surroundings, relative humidity of the exiting air from the drier and surroundings, air velocity, and sample mass were recorded every hour using a digital thermometer, hygrometer, anemometer, and top-loading balance, respectively. The drying process was terminated when the mass converged. Proximate analysis was conducted to evaluate the effects of the different drying temperatures on the nutritional attributes of the seaweed.

Sample Preparation. The seaweeds were washed to remove any impurities that may have contaminated the samples, such as corals, salt, and soil debris then pat dried. The tray dryer was preheated to the desired drying temperature, allowing it to reach steady state, before samples were loaded and dried.

After dehydration, the dried seaweeds were tested using a moisture analyzer to determine the final moisture content. This quantity was used to evaluate the effectiveness of the drying parameters. The drying rate was evaluated using Equation 1,

$$\theta = \frac{Q}{AR_c}\left[(x_1 - x_c) + x_c \ln\left(\frac{x_c}{x_2}\right)\right] \quad (1)$$

where θ is the drying time, Q is the weight of the dry solid, A is the area in direct contact with the drying medium, R_c is the constant weight of moisture removed per time per drying area during the constant rate period, X_1 is the initial free moisture content during the constant rate period, X_2 is the final free moisture content during the falling rate period, X_c is the critical free moisture or boundary moisture between the constant rate period and falling rate period.

Proximate Analysis. The analysis for the nutritional attributes of the dried seaweeds and fresh seaweeds were conducted for comparative analysis. The testing for the crude ash content and crude fiber of the dried and fresh samples was conducted at the Department of Chemical Engineering research laboratory of the University of Santo Tomas, Ruano Building, following the AOAC 942.05 and AOAC 978.10 gravimetry method to measure crude ash and crude fiber content, respectively. Whereas, the analysis of the crude fat and crude protein content was conducted at the University of The Philippines Los Baños, Institute of Chemistry – Analytical Services Laboratory, located in Los Baños, Laguna. All dried samples, as well as the fresh ones, underwent AOAC 2003.05 and AOAC 2001.11 gravimetric methods to measure the crude fat and crude protein content, respectively. The total carbohydrates of *C. racemosa* were calculated by subtracting the mean percentage of protein, lipid, fiber, moisture, and ash content from 100, as described by Kasmiati et al. (2022) [17].

Statistical Analysis. Analysis of Variance (ANOVA) was employed to identify the significant differences between the mean values, and Tukey's Honestly Significant Difference test was used to identify which group was significantly different. Microsoft Excel was used for both One-Way ANOVA and Tukey's Honestly Significant Difference test with a significance level of 0.05.

3. Results and Discussion

The drying data of seaweed samples for each drying temperature is shown in Table 1. The values shown are the mean ± standard deviation. More moisture is removed as the set temperature increases, promoting faster drying. The initial moisture content of the fresh seaweeds that are dried at 50, 55, and 60°C are 96.17 ± 1.30, 97.00 ± 0.05, and 96.58 ± 1.53%, respectively. After being dried, the seaweed weighs significantly less. The drastic drop in weight from the fresh seaweed to the dried seaweed is associated with the high moisture content of seaweed. Much of the original weight is lost. The results are coherent with food dehydration, where moisture is reduced to low levels to improve shelf life [8].

Table 1. Drying Data of *C. racemosa*

Set Temperature (°C)	**50**	**55**	**60**
Initial total mass of seaweed (g)	400.77 ± 0.14	401.30 ± 1.08	400.99 ± 0.24
Final total mass of seaweed (g)	19.09 ± 2.77	14.24 ± 0.74	15.76 ± 1.71
Experimental initial moisture of seaweed (%)	96.17 ± 1.30	97.00 ± 0.05	96.58 ± 1.53
Mass of dry solid (g)	15.35 ± 5.22	12.03 ± 0.23	13.73 ± 6.14
Experimental equilibrium moisture of seaweed (%)	18.54 ± 2.52	14.94 ± 2.64	13.29 ± 3.31
Total Drying time (min)	270 ± 0	240 ± 0	240 ± 0
Air velocity (m/s)	0.33 ± 0.01	0.31 ± 0.01	0.31 ± 0.01

Drying Evaluation. The primary intention of this evaluation is to observe the samples' drying kinetics. For this purpose, the drying curve between the moisture content and drying time is presented, as shown in Figure 1. It shows that the moisture content, on a dry basis, decreases continuously with the drying time. It is also evident that the moisture content of the seaweed reduces faster when the drier operates at a higher temperature. Increasing the drying air temperature accelerates the drying process, resulting in a lower equilibrium moisture content. The increase in air temperature activates water molecules, causing them to become less stable and break away from the water-binding site of food materials, thereby reducing the equilibrium moisture content [18].

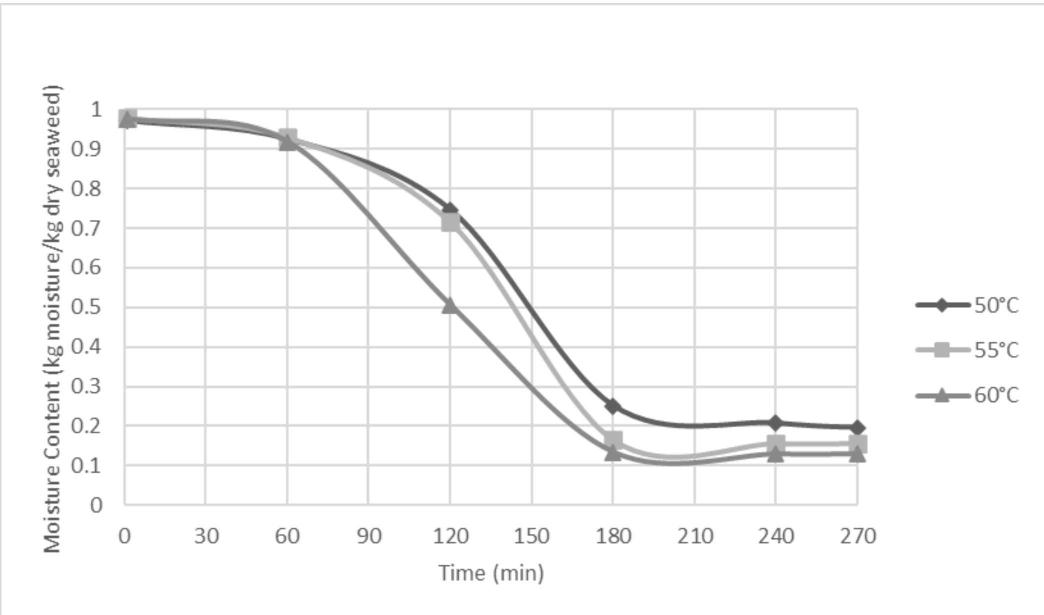

Figure 1. Moisture content vs Drying time at different drying temperatures

During the initial hour, the drying curve revealed a consistent decrease in moisture content. Subsequently, there was a rapid decrease in moisture content, indicating that most of the moisture was removed during the falling rate period, while the amount of surface moisture removed during the constant rate period was minimal [19]. Similar observations from previous studies have been reported for the drying of *Caulerpa* *lentillifera* [13, 20], and other seaweeds such as *Eucheuma spinosum* [21]. A one-way ANOVA ($p = 0.97$) revealed that there were no statistically significant differences between the means of the average moisture content at three different sets of temperatures. This insignificant difference may relate to the small variance between each set of temperatures. Moisture content reduces exponentially over time for all temperatures; and studies by Ismail et al. (2019) and Rosli et al. (2020) produced similar results, wherein the small variance in drying temperatures in their respective drying experiments did not have a significant impact on the resulting moisture content [22, 23].

Figure 2 shows the relationship between the drying time and the drying rate. The drying rate decreases continuously throughout the drying period. The drying of the seaweeds took place in both the constant rate period and the falling rate period. The constant rate period for temperatures 50, 55, and 60°C occurred during the first 45, 40, and 35 minutes, respectively; while the bulk of the overall drying process occurred during the falling rate period.

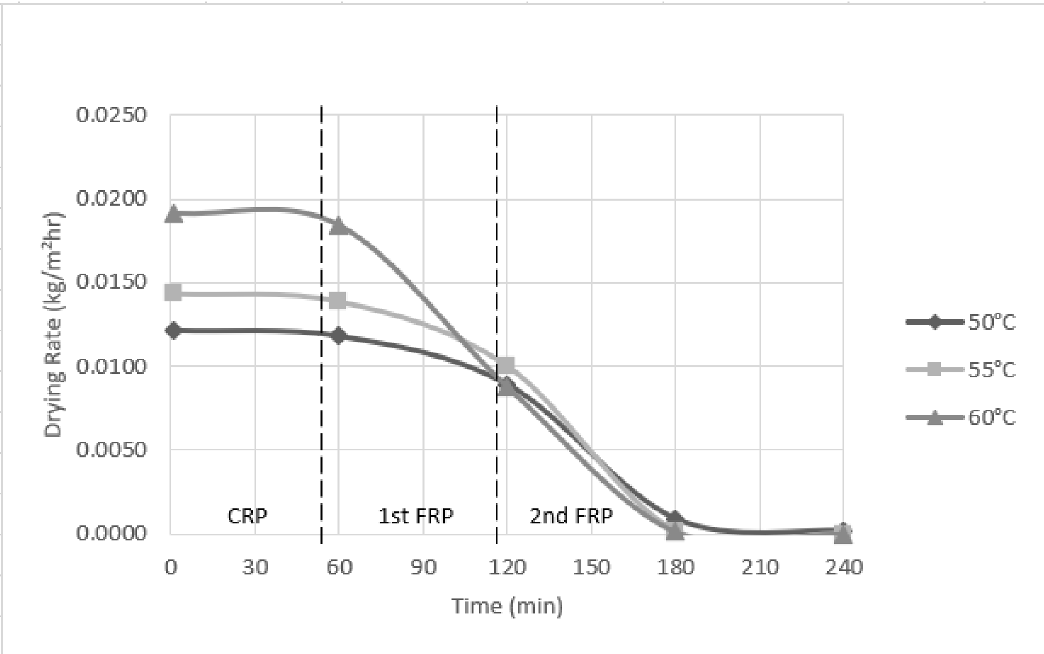

Figure 2. Drying rate vs Drying time at different drying temperature

Figure 2 also shows the changes in drying rate at different drying temperatures. Increasing the drying temperature resulted in a higher drying rate. As the air temperature increases, less moisture is in the air. Thus, a larger moisture gradient is formed between the seaweed surface and the surrounding air. As a result, a larger driving force is produced for moving the moisture from the seaweed surface to evaporate in the air [21]. Similar observations agreed with earlier studies on other food sources [24]. After performing the one-way ANOVA ($p = 0.61$), there were no statistically significant differences between the means of the average drying rate at three different sets of temperatures. The insignificant difference between the means of the average drying rate may also relate to the small variance between each set of temperature and drying time. A study of Rosli et al. (2020) in drying of seeds reported similar behavior, where the drying temperatures of 55, 60, and 65°C produced near drying times of 300, 260, and 240 minutes, respectively [23]. This implies that the small gap between sets of temperatures and their respective drying times didn't have a significant impact on the difference with their respective drying rates. This observation is in line with the with the results from the means of the average drying rate of *C. racemosa* at three different sets of temperatures.

Proximate Analysis and Statistical Analysis. The primary intention of the proximate analysis is to estimate the proximate composition of the dried *C. racemosa*. Table 2 shows the proximate composition of the *C. racemosa* dried at 50°C, 55°C, and 60°C on a dry basis.

Table 2. Proximate Analysis of Dried *C. racemosa*.

	50°C	***55°C***	***60°C***
% Moisture	18.54 ± 2.52^{a}	14.94 ± 2.64^{a}	13.29 ± 3.31^{a}
% Ash	69.38 ± 0.63^{a}	60.94 ± 0.70^{b}	66.89 ± 2.31^{a}
% Fiber	8.98 ± 1.30^{a}	8.69 ± 0.52^{a}	8.38 ± 0.15^{a}
% Fat	1.56 ± 0.09^{a}	1.64 ± 0.02^{a}	1.60 ± 0.06^{a}
% Protein	7.10 ± 0.03^{a}	10.22 ± 0^{b}	8.02 ± 0.02^{c}
%Carbohydrates	12.98 ± 0^{a}	19.33 ± 0^{a}	16.08 ± 0^{a}

Values are denoted as mean ± standard deviation.
Different superscript letters within a row indicate significant differences between sample groups at the level of $p < 0.05$

Moisture Content. As seen from Table 2, the moisture content is highest in the *C. racemosa* that were dried at 50°C and the lowest at 60°C, which is expected as the higher the temperature, the higher the rate of moisture evaporation. The increase in energy promotes greater mobility in the water molecules, leading to faster diffusion. The *C. racemosa* dried at 55°C are closer in moisture content to 60°C than 50°C. At 55°C, the moisture redistribution kinetics may have led to a more homogeneous moisture distribution throughout the *C. racemosa* samples than those dried at 50°C, where moisture removal may have been more localized or uneven due to the low temperature. The observed moisture content aligns with the basic principles of moisture removal through drying processes, where higher temperatures facilitate faster-drying. The resulting p-value ($p = 0.15$) from one-way ANOVA shows that there is no significant difference in the moisture content of all the different temperature groups.

Seasonal factors may lead to significant changes in the seaweed's moisture content. According to the study of Duran-Frontera (2017), significant differences in the moisture content were due to changes in temperate seasons [25]. During the drying experiments, there was no change in the seasons, resulting in no significant changes. The study of Abbasi et al. (2009) also said that operational temperatures and drying times that are close to each other may lead to no significant results [26].

Crude Ash Content. The ash content indicates the overall mineral composition of organic matter. The high ash content observed in this study may be due to salt and various minerals in the dried *C. racemosa* [27, 28, 29]. As seen from Table 2, the ash content of *C. racemosa* dried at 50°C was higher than those dried at 55°C and 60°C. In general, seaweed ash content varies with salt and the diverse minerals present, as seaweeds can absorb minerals from its environment [29]. The crude ash content of the dried *C. racemosa* exhibited significant differences among the temperature groups, with a p-value of 0.03. The resulting Tukey's test showed that the crude ash content of *C. racemosa* dried at 55°C significantly differed from those dried at 50°C and 60°C.

The significant difference between the samples was an unexpected result as crude ash remains after combustion at 550°C. Since the drying temperatures of this study were within the range, the ash content should show no significant difference [30]. In a study of varied drying temperatures of *C. fluminea*. The samples that were dried at 75°C to 105°C with an increment of 5°C for each sample resulted in no significant difference ($p>0.05$) when ash content was evaluated [31]. This study reflects a different result, with the highest crude ash content found in the samples dried at 50°C; this may be due to the initial moisture of these fresh samples presenting the lowest moisture content (96.17%), followed by 60°C (96.57%) then at 55°C (97.00%), crude ash content is higher when the water content is lower as food becomes concentrated so that the minerals left behind in the food material increase [32]. The resulting significant difference in this study may have been due to the presence of confounding variables, such as inconsistent sample size and sample homogeneity while determining crude ash [33], which may have influenced the outcome, leading to unexpected significance [34].

Crude Fiber Content. The high polysaccharides in the seaweed's cell wall provide a high fiber content, an essential constituent in nutrition. A high fiber content is desirable as it consists of numerous essential nutrients that are helpful for the human diet [35]. As seen in Table 2, the *C. racemosa* dried at 50°C presented the highest crude fiber content compared to those dried at 55°C and 60°C. According to a study conducted by Peerajit (2012) on lime residues, the reason for the high dietary fiber content at lower temperatures is that dietary fiber is composed of various components such as cellulose, hemicellulose, and lignin, which can be sensitive to heat. Drying at lower temperatures like 50°C may help preserve these heat-sensitive components better than drying at higher temperatures, resulting in a higher retention of dietary fiber [36]. The one-way ANOVA for the crude fiber content of the dried *C. racemosa* produced a p-value of 0.98, indicating no significant variations in the crude fiber content of all the different temperature groups.

Natural fiber components degrade at different temperatures depending on the type of fiber; hemicellulose degradation starts at around 150-260°C, cellulose at about 210-360°C, and lignin between 250-500°C [37]. For this study, the low temperatures of (50 to 60°C) resulted in no significant degradation between the samples compared. Degradation of fiber increases at higher temperatures [38], hence the decrease in crude fiber content of the samples with increasing temperature.

Crude Fat Content. The lipid content of seaweed is relatively low compared to other plants, such as soy and sunflowers. However, lipid quality is vital because it contains essential fatty acids like omega-3 and other fat-soluble vitamins [39]. As seen in Table 2, the *C. racemosa* dried at 55°C presented the highest crude fat content compared to those dried at 50°C and 60°C. The low lipid content of *C. racemosa* makes it desirable for consumption and can be incorporated in low-fat diets. One of the essential components in lipid content of seaweeds are polyunsaturated fatty acids which have shown to have activity against cancer, oxidative stress, hypertension, and inflammation [40]. Retaining these components is crucial for the advancement of *C. racemosa* as a food ingredient. One-way ANOVA was accomplished for the crude fat content of the dried *C. racemosa*. The test generated a p-value of 0.15, revealing no significant distinction in the crude fat content of all the different temperature groups.

A study conducted by Badmus et al. (2019) observed that the short drying time controls the issues related to long-term exposure to light or high temperatures, which can result to lipid oxidation in seaweeds [8]. Rodriguez et al. (2016) also reported that the great loss of lipid in dry matter is due to extended drying times allowing liquefied lipid to leak out [41]. These observations are in line with the results of the crude fat content of the *C. racemosa* dried at different temperatures, which all groups have almost similar drying durations; and may explain the insignificant differences in the crude fat content.

Crude Protein Content. Protein content in seaweeds is comparable to that of traditional protein sources, such as meat, eggs, soybean, and milk, making seaweeds a viable protein source [42]. All amino acids required for human nutrition are present in seaweeds, especially glycine, alanine, arginine, proline, glutamic and aspartic acids [43]. According to Nakhate (2021), green seaweeds such as the *Caulerpa spp.* are characterized to typically have a relatively high protein content ranging from 15% to 25%. However, the protein content may vary due to species, geographic area, seasonality, and environmental conditions [44]. As seen in Table 2, the *C. racemosa* dried at 55°C presented the highest crude protein content compared to those dried at 50°C and 60°C. The presence of all essential amino acids in seaweed protein makes it surpass terrestrial plant proteins. Therefore, maintaining the seaweed protein even after drying is vital for *C. racemosa* to function as an exceptional food ingredient. A p-value of 0.00000108 was generated after conducting one-way ANOVA for the crude protein content of the dried *C. racemosa*, suggesting a significant difference from the crude protein content of the different temperature groups. For that reason, Tukey's Honestly Significant Difference Test was used to determine what group was significantly different. The resulting Tukey's Test showed that the *C. racemosa* dried at the various temperature groups were all significantly different.

The operational temperature and drying time are critical factors in retaining seaweed quality. At temperatures greater than 40°C, proteins can denature [45, 46]. Based on the results of our study, the seaweed's protein content at 55°C is higher than the protein content dried at 60°C. Similar observations have been reported for brown seaweeds where protein degrades more with higher temperatures [8]. Also, the protein content of the seaweed in our study dried at 55°C for 240 minutes is higher than that of the seaweed dried at 50°C for 270 minutes. Similar findings have been found for fruits and vegetables where more extended drying periods increase nutritional degradations [47]. According to the study of Buriyo (2018), the protein content has significant differences because of the difference between protein degradation of the seaweed in all temperature ranges [48]. The study of Harrysson (2019), also suggested that the seaweed, while soaked in freshwater during sample preparation, may wash out minerals that can change the mass balance within the composition, which can cause variance in the protein content [49].

Carbohydrate Content. Carbohydrates are a vital biochemical component, as they are the primary energy source in an organism's body. The carbohydrate content of *C. racemosa* varies, ranging from 3.6% to 83.2%, and the carbohydrate content of the acquired fresh *C. racemosa* (19.38%) is in the range of their typical values [50]. As seen in Table 2, the *C. racemosa* dried at 55°C presented the highest carbohydrate content compared to those dried at 50°C and 60°C. Seaweed carbohydrates typically contain perfect amounts of polysaccharides, an essential energy source for living organisms [51]. Hence, the carbohydrate content must be conserved even after drying for seaweed to serve as a significant dietary element. The one-way ANOVA used for the dried *C. racemosa*'s total carbohydrate content resulted in a p-value of 0.09, signifying no significant difference in the total amount of carbohydrates across all temperature groups.

Three studies on seaweed reported that the difference in species, growth, environmental season and origin, temperature, metabolic preference, and photosynthetic activity can produce variance in the total carbohydrates of seaweeds [17, 52, 53]. The species used were consistent throughout the experiment, along with their place of origin. This may explain the insignificant difference of total carbohydrates across the different temperature groups.

4. Conclusion

This study aimed to determine and evaluate the appropriate drying temperature and conditions for *Caulerpa racemosa* using a tray dryer. The process included tray drying *C. racemosa* and analyzing its proximate composition. It was found that less moisture content of *C. racemosa* is retained during equilibrium as the air temperature and drying rate increase. The seaweed's drying process occurred in both the constant and falling rate periods. It was also discovered that the various drying air temperatures impacted the crude ash and crude protein composition of the dried *C. racemosa.* In conclusion, the best drying temperature was observed to be 55°C; resulting in minimum nutritional loss and higher moisture loss, which is crucial for the preservation of *C. racemosa*. It is important to note that this study only determines the drying conditions at three temperature groups. Further studies need to be administered regarding the other methods and sensory analysis to fully determine the appropriate drying temperature and conditions for *C. racemosa*.

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6. Conflict of Interest

The authors declare no conflict of interest.

7. References

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