Egypt. J. Chem. **Vol. 68,** No. 10 pp. 441 - 449 (2025)

Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

Extraction and Characterization of Alginate Biopolymer from Abundant Brown Seaweeds, Hurghada, Red Sea, Egypt

Nourhan A. Ashour[1], Gihan A. El-Shoubaky[1], Marwa M. Saleh[1], Nasser Y. Mostafa*[2]

[1]*Department of Botany and Microbiology, Faculty of Science, Suez Canal University, Ismailia 41522, Egypt.*

[2]*Department of Chemistry, Faculty of Science, Suez Canal University, Ismailia 41522, Egypt.*

Abstract

Brown seaweed is the main source of alginates biopolymer, which has been widely employed in various technological fields. The economic importance of seaweed spans multiple industries, offering sustainable solutions that can enhance food security, health, and environmental sustainability. In our study, five abundant brown macroalgal species were collected from Hurghada, Red Sea (*Padina boergesenii*, *Hormophysa cuneiformis*, *Polycladia myrica*, *Turbinaria turbinata* and *Sargassum aquifolium*) for alginate extraction and characterization. The alginate yield varies across different species. *T. turbinata* produced the highest alginate yield (35.1 ± 1%), while *P. boergesenii* yielded the least (18.3 ± 0.5%). The alginate molecular structure was characterized using FTIR, TGA and viscosity measurement. The average molecular weight of alginates varies from 9.04 × 105 g/mol for *T. turbinata* to 1.2 × 105 g/mol for *P. boergesenii.* There is a direct correlation between the alginate yield and molecular weights. Furthermore, *T. turbinata* and *S. aquifolium* species demonstrate a potential economical source for high quality Na-alginates for various ecofriendly applications.

Keywords: Brown macroalgae; Alginate; Yield; Molecular weight; FTIR; Viscosity

1. Introduction

Seaweed is abundant, versatile in its habitat, cost-effective, easy to cultivate, and grows without the need for fertilizers or pesticides **[1]**. Seaweed has a significant biomass and contains polysaccharides, agarose, ulvan, and fucoidans **[2]**. Agar, alginate, and carrageenan are examples of seaweed-derived hydrocolloids that can be used as biopolymers in bioplastic synthesis **[3].** Polysaccharides are polymers that have triggered significant attention in the packaging sector. A variety of macroalgal divisions produce polysaccharides, including agar, alginate, and carrageenan. In recent years, biopolymers are increasingly being explored for advanced applications in optical thin films **[4]** and electrical devices due to their sustainability, flexibility, and unique material properties. Also, it is used in packaging and encapsulation of pharmaceutical and natural products due to their biodegradability and biocompatibility **[5]**.

Alginophytes are seaweeds that produce alginate and are primarily obtained from wild brown seaweed **[6]**. Alginates are widespread in brown algae such as *Laminaria digitata* and *Laminaria japonica*. Alginate is separated by treating an aqueous alkali solution with NaOH, and the resulting extract is sodium alginate powder, which is only soluble in water. Calcium alginate is insoluble in water and organic solutions, therefore Ca^{2+} is eliminated. The resulting alginate can be used in a variety of other applications **[7].**

Brown seaweed contains alginates in its cell wall and intercellular surrounding substance, which are responsible for its mechanical and flexibility characteristics **[8]**. Alginate also comes in the form of insoluble salts of calcium, magnesium and sodium and there are numerous factors impacting the yield and quality of alginate in brown seaweed, like species, harvest season, and others **[9]**.

Alginates consist of repeated groups of β-D-mannuronic acid (M) and α-L-guluronic acid (G) connected by 1 to 4 glycosidic linkages in a linear structure. Because the grouping of alginate linear polymers is variable, the blend of M and G are depending on the marine macroalgal species, their extraction process, and time **[10]**. The extraction technique is based on the alteration of an insoluble combination of salts of alginic acid to a soluble salt (alginate) that is appropriate for water extraction **[11]**. The proportion of the three forms of blocks, namely MM, GG and MG, specifies the physical qualities of alginates. Alginates with a high proportion of M blocks have an advanced viscosity, whereas those with a high quantity of G blocks have higher gelling capabilities **[12]**. The additive of calcium ions mostly affects the GG blocks, which resulted in improved gel strength due to an increase in their binding ability **[13, 14].**

The species, season, and source of seaweed are essential determinants in influencing the yield of hydrocolloid extraction; however, other stimuli such as temperature and time of extraction, pre-treatment, alkaline concentration, and method of extraction also play vital roles in the hydrocolloid yield **[15].** During the extraction process, as hydrocolloids are in the cell wall, it was firstly interrupted to allow the compound to flow into the extraction media **[16]**. There have been many advanced tools

*Corresponding author e-mail: nmost69@yahoo.com; (Nasser Y. Mostafa).

Receive Date: 19 January 2025, Revise Date: 08 February 2025, Accept Date: 05 March 2025

DOI: 10.21608/ejchem.2025.354002.11191

investigated to increase the extraction yield, efficiency, and sustainability of extraction processes by lowering their time and temperature, leading to reduced consumption of energy **[17].**

Red Sea shores of Egypt is a residence of diverse groups of marine macroalgal species. Studies documented the massive growth of some brown macroalgal species **[18]**. Macroalgae can cause several ecological problems in coastal tourism areas, affecting both the environment and tourism **[19]**. Human activities are thought to have led to a rise in the size, frequency, and spread of macroalgal blooms in marine and estuarine ecosystems. Funding economical use of these macroalgae may help to solve environmental and sociological issues caused by macroalgae blooming **[20]**. Several man-made and ecological factors contribute to the increase in harmful macroalgal blooms, like those caused by *Sargassum* sp. **[21]**. Thes factors include nutrient pollution (Eutrophication) caused by Agricultural runoff containing excess nitrogen and phosphorus from fertilizers. Also, poorly treated sewage discharge contributes to the nitrogen and phosphorus problem **[22]**. Warmer waters create ideal conditions for the proliferation of macroalgae like *Sargassum* **[23]**.

Ocean acidification due to increased CO_2 absorption can favor macroalgae over other marine organisms. In combination, these factors are contributing to the global increase in harmful macroalgal blooms, which have serious ecological and economic implications. While brown seaweed is a well-known source of alginates, there is limited research on the variability in alginate yield, molecular structure, and quality among different species from the Red Sea region. Furthermore, the relationship between alginate yield and molecular weight, as well as the potential of these species for eco-friendly applications, remains underexplored. This study addresses these gaps by characterizing alginates extracted from five abundant brown macroalgal species (Padina boergesenii, Hormophysa cuneiformis, Polycladia myrica, Turbinaria turbinata, and Sargassum aquifolium) collected from Hurghada, Red Sea, and and explores their economic feasibility as sustainable sources of alginates for large-scale commercial production. The yield, viscosity, molecular weight and quality of extracted alginates were also compared.

2. Materials and methods

2.1. Seaweed collection

Abundant brown macroalgal Samples were assembled from the intertidal zone of El-Ahyaa region, Hurghada, on the Red Sea, Egypt (27°17′ N, 33°46′ E) (Fig. 1)

Fig. 1: A map of Egypt displaying the study area

2.2. Identification and preparation of the collected macroalgal samples

Vigorously selected brown macroalgae were collected manually and meticulously cleaned in seawater to remove attached debris. The samples were then completely rinsed with distilled water to remove excess salt. The purified brown macroalgae were air-dried in shade at room temperature. Morphological identification of the samples was performed using taxonomic keys by **[24-27]**. Five abundant marine brown macroalgae species were identified as exhibiting the highest biomass: (*Hormophysa cuneiformis* (J.F.Gmelin) P.C.Silva, *Padina boergesenii* Alender and Kraft, *Polycladia myrica* (S.G.Gmelin), *Sargassum aquifolium* (Turner) C.Agardh and *Turbinaria turbinata* (Linnaeus) Kuntze (Fig. 2). Dried samples were homogenized using an electric mixer and kept at 4°C for successive analysis.

2.3. Extraction of sodium alginate

The extraction method of alginate from the selected brown macroalgal species was done according to **[28]** with some modifications. A sample of 20 g of the dried macroalgal mass were soaked in 1% w/v calcium chloride ($CaCl_2$) for 18 h. After that, the seaweed samples were washed with distilled water before the reaction with 5% v/v hydrochloric acid (HCl) for 1 h. The seaweed samples rinsed again with distilled water, kept in 3% w/v sodium carbonate (Na_2CO_3) for 1 h, before 250 mL of distilled water was used for further reaction (15 h). The alginate extract was separated from the insoluble seaweed residue by

centrifugation at 16,000×g, filtered via muslin fabric, precipitated with absolute isopropyl alcohol then ethanol. The alginate extract obtained was left to dry for 24 hours at 60°C. The yield (%) was calculated as follows:

Yield of sodium alginate (% w/w) = $\frac{Dry\ weight\ of\ alginate}{Initial\ dry\ weught\ of\ seaweeds} \times 100\ \%$

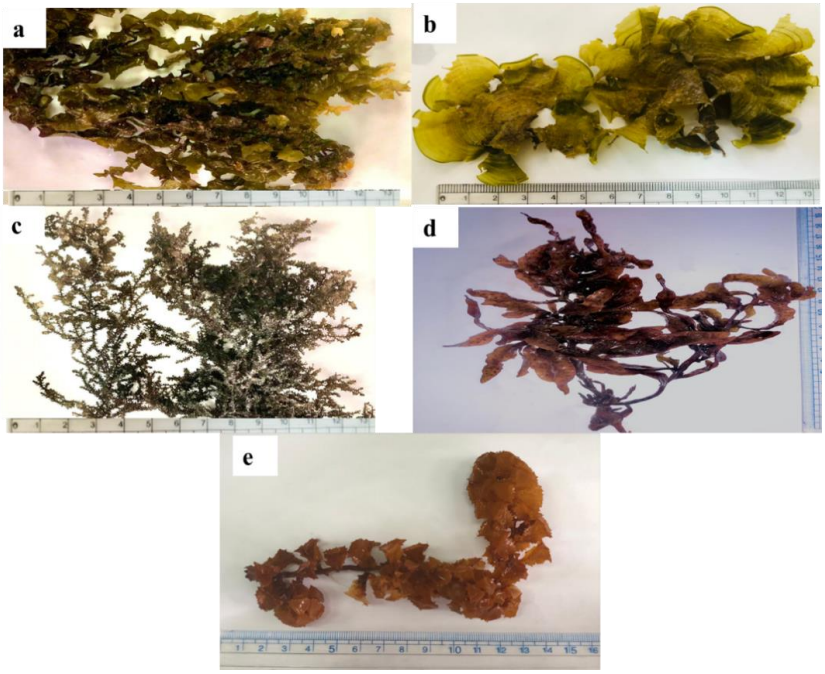

Fig. 2: Images of the selected brown macroalgal species: a: *H. cuneiformis*, b: *P. boergesenii*, c: *P. myrica*, d: *S. aquifolium* and e: *T. turbinata*

2.4. Physiochemical Properties of the extracted Sodium Alginate

One gram of the extracted sodium alginate was dissolved in 100 mL of purified water, and pH was measured using a Jenway portable pH meter (Model 550) at room temperature to assess the Na-alginate quality according to **[29]**. The color was assessed visually against a white and dark lighting background. The moisture content of the extracted sodium alginate was calculated through the loss in mass of sodium alginate after drying at 105 ± 1 ◦C for 24 h **[29]**. Ash content was assessed according to **[30]**, 100 mg of biomass was dried overnight in porcelain crucibles at 105 ◦C. After drying for 30 minutes in a desiccator, the crucibles were measured and heated to 550 ◦C for 3 hours in a furnace. The ash concentration was calculated on a dry weight basis by weighing the biomass after 105 ◦C.

2.5. Functional group analysis using Fourier Transform Infra-Red Spectroscopy (FTIR)

The isolated sodium alginate's functional groups were identified using the Fourier Transform Infra-Red Spectroscopy (FTIR) approach described by **[31]**. The dried sodium alginate was crushed into a fine powder before recording the infrared spectra with a Bruker Alpha ATR-FTIR spectrometer. The spectra were averaged from two independent measurements ranging from 4000 to 400 cm^{-1} with 128 scans at a resolution of 2 cm^{-1}.

2.6. Thermogravimetric analysis

The thermal permanence and composition of the extracted sodium alginate with the highest yield from *T.* turbinata were estimated by measuring weight changes as the temperature increased by using thermogravimetric analysis (TGA) and derivative thermogravimetric analysis (DTG) curves. The thermal properties were estimated using an instantaneous (TG-DTA) thermogravimetry-differential thermal analysis (DTG-60 SHIMADZU). The specimen is heated at a rate of 20 ℃/min. From 10 to 1000◦℃

2.7. Viscosity and molecular weight determination

The intrinsic viscosity of the sodium alginate sample was measured using the method of **[28, 32]**, with slight modifications. A 0.1 M NaCl solution is utilized to alleviate electrostatic interactions among alginate molecules. Sodium alginate is dissolved in this solution to prepare concentrations of 0.2%, 0.1%, 0.05%, and 0.01% w/v. Alginate solutions were added to the Ubbelohde glass viscometer (Cannon, size 1) and dipped in a water bath at 25 ℃. The alginate mixture was introduced into the upper indication line of the viscometer and let to flow naturally under gravity. The flow time of the alginate solution was represented by t, while flow time of pure water recording was designated t_0.

The original alginate solution was diluted at least eight times. The intercept indicates the intrinsic viscosity [η] of the regression lines from graphs demonstrating reduced viscosity. The reduced viscosity (η_{red}) and inherent viscosity (η_{inh}) of the alginate solution were calculated based on its concentration. The average alginate molecular weight was determined using the Mark-Houwink-Sakurada equation (Eq. 1), with k value of 0.023 and a value of 0.984, to establish an empirical link between intrinsic viscosity and average molecular weight. **[32, 33]**

$[\eta] = kM_w^a$ (Eq. 1)

2.8. Carbohydrate content

The carbohydrate content of sodium alginate with the highest yield from *T. turbinaria* was measured using the phenol-sulphuric acid method by **[34]**. The carbohydrate content was estimated using standard D-glucose and reported as mg/g sugar. Different concentrations of polysaccharide solutions were created. 3.2 mL of 80% sulphuric acid was promptly added to each tube of sodium alginate solution of varying concentration. The mixes in the tubes were allowed to achieve their peak reaction temperature for at least one minute. The tubes' temperatures were immediately decreased by placing them into a water bath. After adding 50 µL of phenol, the tubes were left to stand at room temperature for 30 minutes. Finally, absorbance was measured at a wavelength of 480 nm, using UV-vis spectrophotometer **[35].**

2.9. Statistical analysis

The data of physico-chemical parameters were stated as average ± standard deviation (SD). Statistical studies were conducted using SPSS (Version 10.0, SPSS Inc., Richmond, VA, USA). Multivariate analyses and correlation tests were performed using OriginPro (Version 8.1).

3. Results and Discussion

3.1. Extraction Yield

Sodium alginates yield from the chosen brown macroalgal species presents significant implications for both industrial applications and future research **[36]**.

The alginate yield among the different species was significantly different. Among the studied macroalgal species, *T. turbinata* demonstrated the highest yield of sodium alginate (35.1±1%) as shown in Fig.3, establishing it as the most promising candidate for global alginate production. *S. aquifolium*, with a yield of 32.1 ± 0.5%, also represents a highly productive source, followed closely by *Polycladia myrica* with a yield of 28.7 ± 1%. The alginate yield in *T. turbinata* was greater in our study when compared with the study by **[37]** as *Turbinaria triquetra* yielded (22.2 ± 0.56%).

The calculated yields from *H.cuneiformis* (20.2 ± 0.5%) and *P. boergesenii* (18.3 ± 0.5%) suggested that these species might be less efficient for industrial alginate extraction compared to the higher-yielding species. However, the alginate yields obtained in our study were higher than the alginate yields of the alginophytes species analyzed by **[37],** such as *H. cuneiformis* (13.3 ± 0.52%), *P. boergesenii* and *S. aquifolium.* Although, alginate yield from *P. boergesenii* is low, their role should not be overlooked, as they can still contribute to niche markets or specific applications where their alginate properties are desirable. Additionally, understanding the factors influencing alginate yield, such as environmental conditions, seasonal variations, and harvesting techniques, can further enhance the efficiency and output of alginate production **[38]**.

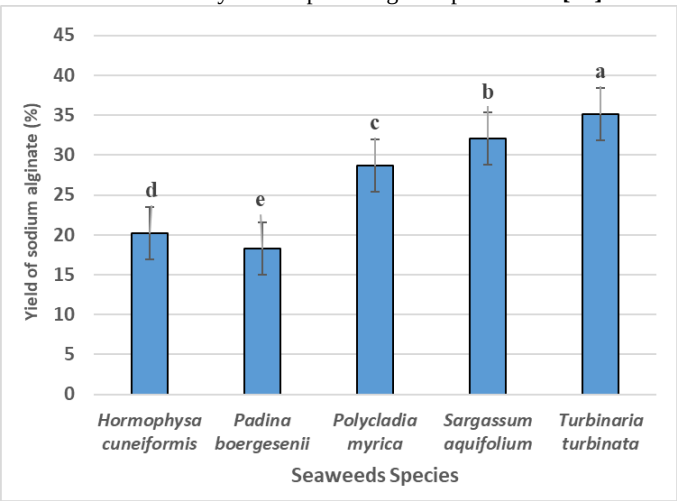

Fig. 3: Differences in sodium alginate yield (% DW) among brown seaweeds species studied. Different letters imply a significant difference at the level of $p < 0.05$.

3.2. Physicochemical properties of the obtained sodium alginate

The physical exploration confirmed that the gained sodium alginate had a yellowish white color to yellowish brown color as shown in Fig. 4 and Table 1. This result demonstrated that these seaweeds' alginate is good, according to the FAO report provided by **[39]**, where it is stated that the color of sodium alginate is white to yellowish-brown.

The pH of the resulting sodium alginate was alkaline, ranging from 9.7 to 10. *H. cuneiformis* has the greatest pH value (10±0.01), whereas *P. myrica* has the lowest (9.7±0.25), **[37]** indicated that sodium alginate is stable at pH levels ranging from 5 to 10; also, the Food Chemical Codex (FCC) has determined that the food quality of sodium alginate in the food sector must be between pH 3.5 and 10. When the extracted sodium alginate findings are compared to these requirements, it is clear that they meet the food industry's quality standards. The moisture content varies from 8.2% to 13.3%, with *H. cuneiformis* having the highest moisture content (13.3 ± 0.1%) and *P. boergesenii* having the lowest moisture content (8.2 ± 0.1%). Which is lower than the moisture level approved by the Food Chemical Codex (FCC) of less than 15% **[40].**

P. boergesenii had the highest ash content (11 ± 0.1%), while *S. aquifolium* had the lowest ash content (6.3 ± 0.3). Mineral salt could be found on the surface or in the thallus, depending on the hydrology and hydrochemistry of the habitat and this agreed with **[41, 42].** Padina, which lived on the shore's bottom, had a higher ash content than Sargassum, which lived

elsewhere. It was discovered that there was a lot of mineral salt on the surface of their leaves. Padina has more calcium salt than the other varieties. This was readily visible on the surface after drying, appearing as white blotches. Padina also had a softer and thinner body, so it's more easily destroyed during extraction. This state could lead to difficulties during the separation and purification of alginate, which results in the presence of some contaminants **[42]**. In general, mineral salt is high in halogen compounds (Br and I) but low in sodium and chlorine. Leaching in 1% CaCl2 and soaking in 5% HCl may decrease the amount of mineral salt **[43]**.

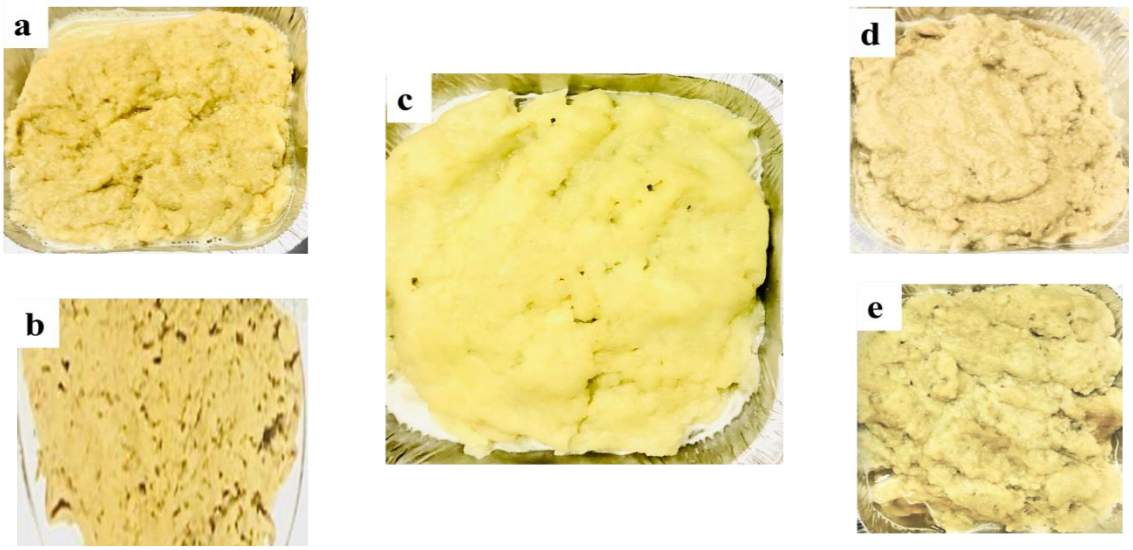

Fig. 4: Sodium alginate extracted from brown macroalgal species a) *H. cuneiformis*, b) *P. boergesenii*, c) *S. aquifolium*, d) *P. myrica)* and e*) T. turbinata*

Table 1. Physicochemical parameters of the obtained sodium alginate from the selected brown macroalgal species

Species	Color	pH	Moisture (%)	Ash content (%)
H. cuneiformis	**YW***	**10± 0.01**	**13.3 ± 0.1**	**10.2 ± 0.1**
P. boergesenii	**YW**	**9.85 ± 0.03**	**8.2 ± 0.1**	**11 ± 0.1**
P. myrica	**YW**	**9.7 ± 0.25**	**12.30 ± 0.3**	**10.5 ± 0.4**
S. aquifolium	**YW**	**9.8 ± 0.10**	**11.4 ± 0.5**	**6.3 ± 0.3**
T. turbinata	**YW**	**9.9 ± 0.06**	**10.9 ± 0.3**	**9.7 ± 0.2**

Where, * YW=Yellowish white and the data were stated as average ± standard deviation

3.3. Fourier Transform Infrared (FTIR) spectroscopy

Functional groups of the extracted sodium alginate were investigated using Fourier transform infrared (FTIR) spectroscopy. The FTIR spectra of the extracted alginate are shown in Fig. 5. The sharp peaks at 3840 cm^{-1}, 3737 cm^{-1}, 3673 cm^{-1}, and 3613 cm^{-1} for *P. myrica, T. trurbinata, P. boergesenii, H. cuneiformis,* and *S. aquifolium* correspond to the O-H stretching vibration of hydroxyl groups (-OH) of sodium alginate [44]. These are characteristic bands associated with different free or weakly hydrogen-bonded hydroxyl groups, which are present in the alginate polymer [44]. In general, the stretching bands of hydroxyl groups in biological macromolecules like polysaccharides and proteins occur in a broad range due to involvement in hydrogen bonding **[45].** In sodium alginate, hydroxyl groups are abundant due to the polysaccharide structure, which contains α-L-guluronic acid (G) and β-D-mannuronic acid (M) units. The O-H stretching typically appears in this region in various ways according to the hydrogen bonding environment. The band at low wavelength indicates that some hydroxyl groups are not strongly hydrogen bonded. The peak at 1534 cm^{-1} is often credited to the asymmetric stretching of the carboxylate (COO^-) groups; the presence of this peak supports the polysaccharide structure of alginate, which contains numerous carboxylate groups throughout its backbone **[46]**.

In FTIR spectroscopy of carbohydrates, the anomeric region refers to the bands in the wavenumber range between 950 and 750 cm^{-1}. This region is significant because it contains absorption bands connected with the C-O stretching and C-H bending vibrations of the anomeric carbon. The anomeric carbon is the carbon atom connected to the oxygen atom in the ring structure of carbohydrates, which becomes a stereocenter when the ring form (cyclic) of the sugar is formed. The peak at 846 cm^{-1} corresponds to the bending vibrations of the C-H bond in the structure of guluronic and mannuronic acid units. The peak at 512 cm^{-1} corresponds to the bending vibration of C-O and C-C bonds in the polysaccharide backbone **[46]**. The C-H stretching band appears at 2910 cm^{-1}. The band at 1012 cm^{-1} is due to the stretching vibrations of C-O-C and C-O groups in the glycosidic bonds linking the monomer units of alginate (mannuronic and guluronic acid).

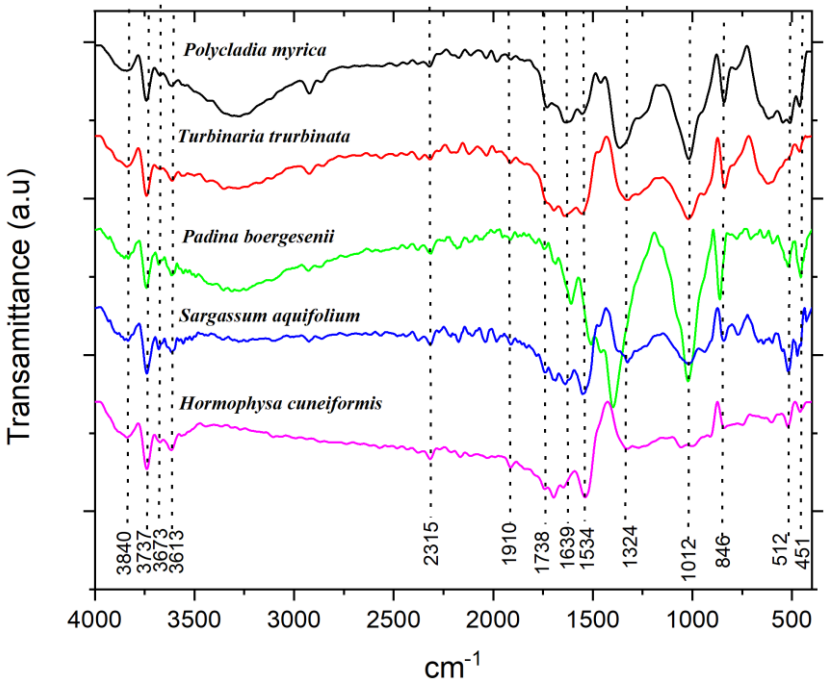

Fig. 5: FTIR spectra of sodium alginate obtained from different macroalgal species

3.4. Thermogravimetric analysis

Thermogravimetric analysis (TGA) is operated to measure the change in mass of a substance as it is heated, providing insights into its thermal stability and decomposition characteristics. The sample with the highest sodium alginate yields from *T. turbinata* was selected for thermal stability analysis. TGA of sodium alginate extracted from *T. turbinata*, is shown in Fig. 6. The TGA curve shows three characteristic thermal decomposition steps typical of alginates, with moisture loss, significant polymer degradation, and residual ash formation. The initial weight loss due to moisture loss appears in the temperature go from 30°C to 160°C with 8.8 % weight loss. This weight loss corresponds to the release of actually adsorbed water molecules **[47].**

The second weight loss (29.7%) in the temperature variety from 210°C to 350°C, is due to the degradation of the polysaccharide structure itself, primarily due to the interruption of glycosidic bonds within the alginate and the formation of gases like CO_2, water vapor, and other degradation products **[47]**. The third decomposition stage with weight loss 12.8% occurs at temperature range from 525°C to 630°C and represents the continued breakdown of more thermally stable residues and formation of char or carbonaceous materials.

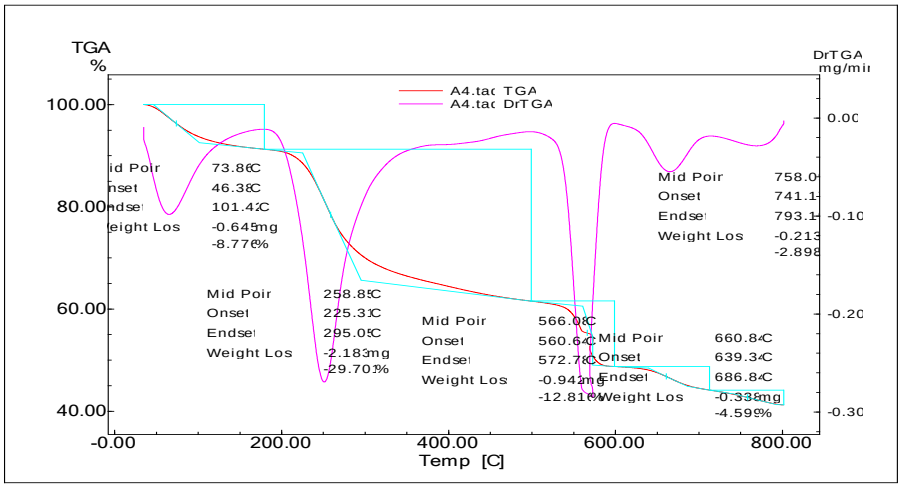

Fig. 6: TGA of sodium alginate obtained from *T. turbinata*

3.5. Viscosity and molecular weight

The molecular weight of alginate has a crucial role in determining its physical and chemical properties, thereby influencing its functionality in different applications. Molecular weight of biopolymers significantly affects their properties such as viscosity, rheological properties, solubility and gelling ability. Higher molecular weight alginates generally exhibit higher viscosity. The intrinsic viscosity and molecular weight vary from species to species within the same division **[20]**. *T. turbinata*

had the highest molecular weight (9.04 × 10^5 g/mol), followed by *S. aquifolium* (5.8 × 10^5 g/mol), *P. myrica* (2.8× 10^5 g/mol) then *H. cuneiformis* (2.2 × 10^5 g/mol), where *P. boergesenii* were have the lowest molecular weight (1.2 × 10^5 g/mol) as shown in Table (2). The molecular weight of the sodium alginate attained from *T. turbinata* were higher than *Turbinaria conoides* **(**8.06×10^5 g mol^{-1} **)** reported by **[48]**. The intrinsic viscosity is greatly dependent on the extraction process applied **[49]**. According to **[48]**, there is a significant difference in the average molecular weight (Mw) of the alginate extracted from *T. conoides* depending on the extraction temperature. Its Mw decreased by more than 83% when the extraction temperature was increased **[48].** The molecular weight of alginate extracted from *S. aquifolium* (5.8 × 10^5 g/mol) was higher than the molecular weight of the extracted alginate of *Sargassum latifolium* **(**4.16×10^5 g mol^{-1} **)** as repoterd by **[32].** Accordingly, the sodium alginate that was isolated from the Egyptian species, particularly *T. turbinata* and *S. aquifolium*, had the potential to be applied in a variety of industries based on their ranges of viscosity.

.

Table 2: The Yield, viscosity and molecular weight of alginates from the selected brown macroalgal species

Alginate source	Viscosity [η_{sp}] dL/g	Molecular weight M_w × 10^5 (g/mol)	Yield (%)
H. cuneiformis	**1.12**	**2.2**	**18.3**
P. boergesenii	**1.1**	**1.2**	**20.2**
P. myrica	**1.4**	**2.8**	**28.7**
S. aquifolium	**1.77**	**5.8**	**32.1**
T. turbinata	**1.8**	**9.04**	**35.1**

Viscosity and molecular weight are important for applications such as food thickening and stabilization, where a thicker consistency is desired. The alginate's gelling properties are also influenced by its molecular weight. Higher molecular weight alginates tend to form stronger and more stable gels, which are useful in food products, pharmaceuticals, and biomedicine. However, Low molecular weight alginates are frequently more soluble in water, which can be advantageous in applications where rapid dissolution is needed. High molecular weight alginates produce strong and flexible films, which are useful in packaging and coating applications, as bioplastics **[20].**

Inspecting the molecular weight data and yield data in Table 2, it appears that there is a direct correlation between molecular weight and yield. Figure 7 depicts the link between molecular weight and yield. The statistical analysis results show a high positive connection (r = 0.899), as the yield increases the molecular weight increases.

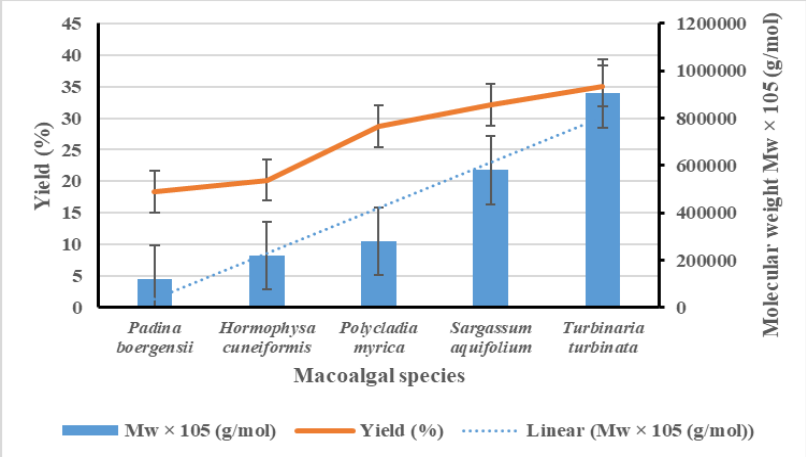

Fig. 7: The Correlation between molecular weight and extraction yield of sodium alginate

3.6. Carbohydrate content

The carbohydrate content of sodium alginate with the highest yield from *T. turbinaria* was 99.7%. This is higher than the alginate carbohydrate's content reported by **[50],** who estimated the carbohydrate content in *S. tenerrium* as 90.67%. High carbohydrate content in the *Saccharina longicruris*, with 99.1% was also reported by [51]. This biochemical composition shows their suitability to be an appropriate source of food for human consumption.

4. Conclusions

Brown macroalgae species yield sodium alginate, a valuable polysaccharide. Factors such as species, environmental conditions, and age influence Na-alginate yield. *T. turbinata* has the highest extraction yield and molecular weight, making it a superior source for alginate extraction. Other species like *S. aquifolium* and *P. myrica* also show promising extraction yields

and functional properties. Alginates from brown macroalgae have potential applications in food thickeners, stabilizers, and biomedical uses, with higher molecular weight alginates being particularly valuable. The molecular weight and extraction yield of sodium alginate from different brown macroalgal species exhibit a strong direct correlation, with a correlation coefficient of r = 0.899. This suggests that species yielding higher amounts of alginate tend to have alginates with higher molecular weights, when the extraction conditions are the same for all investigated species. Such a relationship indicates that higher-yielding species, like *T. turbinata*, not only produce more alginate but also offer superior molecular weight characteristics, making them more suitable for applications requiring higher viscosity and stronger gelling properties. The study highlights the varying characteristics of alginates from different brown seaweeds, influencing their suitability for specific functional uses.

5. Conflicts of interest

There are no conflicts of interest to declare.

6. Formatting of funding sources

The authors state that they have no known competing financial interests or personal relationships that could have influenced the work presented in this study.

7. Data availability

The article describes a study that used no data.

8. References and Bibliography

[1] A. Kumar, P. Hart, V. Thakur, Seaweed Based Hydrogels: Extraction, Gelling Characteristics, and Applications in the Agriculture Sector, ACS Sustainable Resource Management 1(9) (2024) 1876-1905.
[2] P. Sarkar, T.K. Bandyopadhyay, K. Gopikrishna, O.N. Tiwari, B. Bhunia, M. Muthuraj, Algal carbohydrates: Sources, biosynthetic pathway, production, and applications, Bioresource Technology (2024) 131489.
[3] H. Abdul Khalil, W. Suk, F. Owolabi, M. Haafiz, M. Fazita, G. Deepu, M. Hasan, R. Samsul, Techno-functional properties of edible packaging films at different polysaccharide blends, J. Phys. Sci 30 (2019) 23-41.
[4] A. Badawi, E.M. Ahmed, N.Y. Mostafa, F. Abdel-Wahab, S.E. Alomairy, Enhancement of the optical and mechanical properties of chitosan using Fe2O3 nanoparticles, Journal of Materials Science: Materials in Electronics 28(15) (2017) 10877-10884.
[5] F.A.S. Hassan, E.F. Ali, N.Y. Mostafa, R. Mazrou, Shelf-life extension of sweet basil leaves by edible coating with thyme volatile oil encapsulated chitosan nanoparticles, International Journal of Biological Macromolecules 177 (2021) 517-525.
[6] M. Beata Łabowska, I. Michalak, J. Detyna, Methods of extraction, physicochemical properties of alginates and their applications in biomedical field–a review, Open Chemistry 17(1) (2019) 738-762.
[7] I. Parveen, K.M. Maraz, M.I. Mahmud, R.A. Khan, Seaweed based bio polymeric film and their application: A review on hydrocolloid polysaccharides, Scientific Review 5(5) (2019) 93-102.
[8] I. Cruz, Y. Bashan, G. Hernàndez-Carmona, L.E. De-Bashan, Biological deterioration of alginate beads containing immobilized microalgae and bacteria during tertiary wastewater treatment, Applied microbiology and biotechnology 97 (2013) 9847-9858.
[9] M. Rinaudo, Biomaterials based on a natural polysaccharide: alginate, TIP. Revista especializada en ciencias químico-biológicas 17(1) (2014) 92-96.
[10] N. Rhein-Knudsen, M.T. Ale, F. Ajalloueian, A.S. Meyer, Characterization of alginates from Ghanaian brown seaweeds: Sargassum spp. and Padina spp, Food Hydrocolloids 71 (2017) 236-244.
[11] L. Pereira, S.F. Gheda, P.J. Ribeiro-Claro, Analysis by vibrational spectroscopy of seaweed polysaccharides with potential use in food, pharmaceutical, and cosmetic industries, International Journal of Carbohydrate Chemistry 2013(1) (2013) 537202.
[12] M. Fertah, A. Belfkira, M. Taourirte, F. Brouillette, Extraction and characterization of sodium alginate from Moroccan Laminaria digitata brown seaweed, Arabian Journal of Chemistry 10 (2017) S3707-S3714.
[13] R. Abka-Khajouei, L. Tounsi, N. Shahabi, A.K. Patel, S. Abdelkafi, P. Michaud, Structures, properties and applications of alginates, Marine drugs 20(6) (2022) 364.
[14] Y. Wang, Z. Shen, H. Wang, Z. Song, D. Yu, G. Li, X. Liu, W. Liu, Progress in Research on Metal Ion Crosslinking Alginate-Based Gels, Gels 11(1) (2024) 16.
[15] A.D. Premarathna, T.A. Ahmed, G. Kulshreshtha, S. Humayun, C.N.S. Darko, V. Rjabovs, R. Hammami, A.T. Critchley, R. Tuvikene, M.T. Hincke, Polysaccharides from red seaweeds: Effect of extraction methods on physicochemical characteristics and antioxidant activities, Food Hydrocolloids 147 (2024) 109307.
[16] L. Gomez, C. Alvarez, M. Zhao, U. Tiwari, J. Curtin, M. Garcia-Vaquero, B. Tiwari, Innovative processing strategies and technologies to obtain hydrocolloids from macroalgae for food applications, Carbohydrate polymers 248 (2020) 116784.
[17] H. Khalil, T. Lai, Y. Tye, S. Rizal, E. Chong, S. Yap, A. Hamzah, M. Fazita, M.T. Paridah, A review of extractions of seaweed hydrocolloids: Properties and applications, Express Polymer Letters 12(4) (2018).
[18] M.F. Azzazy, A.S. M, A.M. Nofal, I.Z. Abdelsalam, M.S. Abousekken, O.A.S. Tammam, Ecological and Phytochemical Studies on Brown Algae Sargassum muticum from Marsa Alam at Red Sea Coast, Egypt, Alexandria Science Exchange Journal 40(4) (2019) 743-753.
[19] D.A. Lyons, R.C. Mant, F. Bulleri, J. Kotta, G. Rilov, T.P. Crowe, What are the effects of macroalgal blooms on the structure and functioning of marine ecosystems? A systematic review protocol, Environmental Evidence 1(1) (2012) 7.

[20] K.Y. Lee, D.J. Mooney, Alginate: properties and biomedical applications, Progress in polymer science 37(1) (2012) 106-126.
[21] J. Xiao, Z. Wang, H. Song, S. Fan, C. Yuan, M. Fu, X. Miao, X. Zhang, R. Su, C. Hu, An anomalous bi-macroalgal bloom caused by Ulva and Sargassum seaweeds during spring to summer of 2017 in the western Yellow Sea, China, Harmful Algae 93 (2020) 101760.
[22] N. Rosic, C. Thornber, Biotechnological Potential of Macroalgae during Seasonal Blooms for Sustainable Production of UV-Absorbing Compounds, Marine drugs 21(12) (2023) 633.
[23] Y. Ji, K. Gao, Effects of climate change factors on marine macroalgae: A review, Advances in marine biology 88 (2021) 91-136.
[24] A. Gribb, Marine algae of the southern Great Barrier Reef, Part I. Rhodophyta. Australia Coral Reef Society (1983).
[25] H.B.S. Womersley, The marine benthic flora of southern Australia, (2004).
[26] E. Coppejans, T. Beeckman, Caulerpa (Chlorophyta, Caulerpales) from the Kenyan coast, Nova Hedwigia 50(1-2) (1990) 111-125.
[27] A.A. Aleem, The marine algae of Alexandria, Egypt, 1993.
[28] S.-Y. Chee, P.-K. Wong, C.-L. Wong, Extraction and characterisation of alginate from brown seaweeds (Fucales, Phaeophyceae) collected from Port Dickson, Peninsular Malaysia, Journal of applied phycology 23 (2011) 191-196.
[29] B. Ben-Gigirey, M.L. Rodríguez-Velasco, A. Gago-Martínez, Extension of the validation of AOAC official method SM 2005.06 for dc-GTX2, 3: Interlaboratory study, Journal of AOAC International 95(1) (2012) 111-121.
[30] J. Olsson, G.B. Toth, E. Albers, Biochemical composition of red, green and brown seaweeds on the Swedish west coast, Journal of Applied Phycology 32(5) (2020) 3305-3317.
[31] W. Kemp, Organic spectroscopy, Bloomsbury Publishing2017.
[32] M.R. Torres, A.P. Sousa, E.A. Silva Filho, D.F. Melo, J.P. Feitosa, R.C. de Paula, M.G. Lima, Extraction and physicochemical characterization of Sargassum vulgare alginate from Brazil, Carbohydrate research 342(14) (2007) 2067-2074.
[33] F. Clementi, M. Mancini, M. Moresi, Rheology of alginate from Azotobacter vinelandii in aqueous dispersions, Journal of food engineering 36(1) (1998) 51-62.
[34] T. Masuko, A. Minami, N. Iwasaki, T. Majima, S.-I. Nishimura, Y.C. Lee, Carbohydrate analysis by a phenol–sulfuric acid method in microplate format, Analytical biochemistry 339(1) (2005) 69-72.
[35] A.K. Min, T.A. Kyaw, W.W.M. Zin, S. San Aye, C.C. Than, Determination of Nutritional Values and Evaluation of Cytotoxicity Bioassay of Oroxylum indicum (L.) Benth (Kyaung-sha) Fruits.
[36] K. Anjana, K. Arunkumar, Brown algae biomass for fucoxanthin, fucoidan and alginate; update review on structure, biosynthesis, biological activities and extraction valorisation, International Journal of Biological Macromolecules (2024) 135632.
[37] S.H. Rashedy, M.S. Abd El Hafez, M.A. Dar, J. Cotas, L. Pereira, Evaluation and characterization of alginate extracted from brown seaweed collected in the Red Sea, Applied Sciences 11(14) (2021) 6290.
[38] D.J. McHugh, A guide to the seaweed industry, (2003).
[39] J.J. Coppen, Gums, resins and latexes of plant origin, (1995).
[40] W. Mushollaeni, The physicochemical characteristics of sodium alginate from Indonesian brown seaweeds, Afr J Food Sci 5(6) (2011) 349-352.
[41] F. Salasa, Seaweeds and Fish Processing Technology, Fisheries Department of Indonesia. Jakarta (2002) 12.
[42] K. Truus, M. Vaher, I. Taure, Algal biomass from Fucus vesiculosus (Phaeophyta): Investigation of the mineral and alginate components, Proc. Estonian Acad. Sci. Chem 50(2) (2001) 95-103.
[43] W. Mushollaeni, Extraction of Alginate from Brown Seaweeds Sargassum, and Turbinaria, Young Lecturer Experiment Paper (2007) 20-33.
[44] M.Z.I. Mollah, M.R.I. Faruque, D.A. Bradley, M.U. Khandaker, S.A. Assaf, FTIR and rheology study of alginate samples: Effect of radiation, Radiation Physics and Chemistry 202 (2023) 110500.
[45] M.A. Rizk, N.Y. Mostafa, Extraction and characterization of collagen from buffalo skin for biomedical applications, Oriental Journal of Chemistry 32(3) (2016) 1601-1609.
[46] W. Jiao, W. Chen, Y. Mei, Y. Yun, B. Wang, Q. Zhong, H. Chen, W. Chen, Effects of Molecular Weight and Guluronic Acid/Mannuronic Acid Ratio on the Rheological Behavior and Stabilizing Property of Sodium Alginate, Molecules, 2019.
[47] J.P.K. John Kennedy, J.B. Muthuramalingam, V.K. Balasubramanian, M. Balakrishnan, K. Murugan, S. Soorangkattan, K.D. Nalluchamy, S. Muniyasamy, S. Murugan, M.V. Khumalo, P.K. Sarangi, The Production and characterization of alginate from Sargassum wightii Greville ex J. Agardh.: Exploring diverse acid treatments and analytical techniques, Process Safety and Environmental Protection 185 (2024) 557-565.
[48] S.-Y. Chee, P.-K. Wong, C.-L. Wong, Extraction and characterisation of alginate from brown seaweeds (Fucales, Phaeophyceae) collected from Port Dickson, Peninsular Malaysia, Journal of Applied Phycology 23(2) (2011) 191-196.
[49] T.A. Davis, F. Llanes, B. Volesky, G. Diaz-Pulido, L. McCook, A. Mucci, 1 H-NMR study of Na alginates extracted from Sargassum spp. in relation to metal biosorption, Applied biochemistry and biotechnology 110 (2003) 75-90.
[50] S. Viswanathan, T. Nallamuthu, Extraction of sodium alginate from selected seaweeds and their physiochemical and biochemical properties, Extraction 3(4) (2014).
[51] A. Singh, B. Pal, K.S. Singh, Carbohydrate and pigment composition of macroalgae in a kelp-dominated Arctic fjord, Regional Studies in Marine Science 77 (2024) 103644.