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Exploring the Potential of Ulva reticulata for Edible and Eco-friendly Food Wrapper

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Abstract: **Developing an edible food wrapper sheet using *Ulva reticulata*, green seaweed, has gained attention due to its biodegradable and non-toxic properties. This study explores *Ulva reticulata* potential as a raw material for creating an environmentally friendly alternative to traditional plastic food wrappers. The sheet formulation process involves extracting the bioactive components from the seaweed, optimizing various parameters such as the ratio of seaweed to water, drying techniques and incorporating natural additives to improve texture, elasticity and shelf life. The resulting edible sheets are assessed for their mechanical properties, biodegradability and food compatibility. The result suggests that these are effective in preserving food, offering a safe and sustainable packaging option. The development of *Ulva reticulata*-based edible wrappers could significantly reduce plastic and promote eco-friendly packaging solutions in the food industry.**

Index Terms: **Eco-friendly, Edible wrapper, Natural polymer, Sheet formulation, *Ulva reticulata*.**

I. Introduction

Plastic pollution is a critical global issue, exacerbated by the widespread use of single-use plastics, particularly in packaging. These plastics may take several decades to hundreds of years to decompose, accumulating in marine ecosystems and breaking down into microplastics (Yan *et al*., 2024). These particles enter the food chain, causing toxic bioaccumulation and exposing humans to harmful substances such as plasticizers and heavy metals (Auta *et al*., 2017). The COVID-19 pandemic worsened the crisis, increasing plastic consumption by 250-300% (Prata *et al*., 2020). Currently, 4.4 to 12.7 million tonnes of plastic waste enter the oceans annually, with global plastic production projected to reach 2600 million tonnes by 2050. To combat plastic pollution, biodegradable alternatives such as edible food packaging have gained attention (Rhim *et al*., 2013). Food wrappers, made from biopolymers, act as protective barriers, preventing moisture loss, oxidation and microbial contamination while maintaining food quality. Seaweed biopolymers, including polysaccharides like alginate and carrageenan enhance mechanical and barrier properties. Unlike conventional paper-based packaging, which often requires synthetic coatings, seaweed-based biopolymers decompose naturally without leaving harmful residues (Azeredo *et al*., 2016). *Ulva reticulata*, a green macroalga, is rich in polysaccharides, making it ideal for biodegradable food packaging. It improves film flexibility, strength, and thermal stability while exhibiting antimicrobial and antioxidant properties. When incorporated into biopolymer matrices, *Ulva reticulata* enhances durability, moisture resistance and biodegradability (Lahaye, M., & Robic, A. 2007). Although several edible films derived from plant and marine resources have been investigated, limited studies have focused on the application of *Ulva reticulata* in the development of edible food wrapper sheets. The novelty of the present study lies in exploring the utilization of *Ulva reticulata* as sustainable raw material for the formulation of biodegradable food wrappers and evaluating their phytochemical composition, antioxidant activity, antimicrobial activity and physicochemical characteristics. The development of such seaweed-based packaging materials may contribute towards reducing plastic pollution while promoting environmentally responsible food packaging practices.

II. Materials And Methods

A. Sample Collection and Extraction of Bioactive Compounds

Fresh *Ulva reticulata* samples were collected from the coastal waters of Rameshwaram (Latitude 9.2881°N and Longitude 79.3129°E), Tamil Nadu, India (Fig. 3). The collected samples were washed thoroughly with distilled water to remove sand, salts and other adhering impurities. The samples were shade-dried at room temperature for 5-7 days. The dried samples were pulverized into a fine powder using a laboratory mixer grinder and stored in an airtight container until extraction. The powdered sample was subjected to aqueous Soxhlet extraction using distilled water under controlled temperature conditions for 7-8 hours. The extract was filtered through Whatman No. 1 filter paper and stored at 4°C for further analysis (Holdt & Kraan, 2011; Lahaye & Robic, 2007).

B. Qualitative Phytochemical Screening of Ulva reticulata

A qualitative phytochemical screening of the *Ulva reticulata* was carried out to determine the presence of major bioactive constituents including alkaloids, tannins, saponins, steroids, terpenoids, glycosides, phenols, quinones, proteins, carbohydrates and flavonoids. The observations were recorded based on the characteristic colour change or precipitate formation produced during each qualitative test (Harborne, 1998).

C. Fourier Transform Infrared Spectroscopy (FTIR) Analysis

Fourier Transform Infrared Spectroscopy (FTIR) analysis was performed to identify the functional groups present in the aqueous extract of *Ulva reticulata.*The analysis was carried out using an FT/IR-4600 Type A Fourier Transform Infrared Spectrophotometer (JASCO Corporation, Japan) equipped with an ATR PRO ONE accessory. The spectra were recorded over the wavenumber range of 4000-600 cm^{-1} using a TGS detector at a spectral resolution of 4 cm^{-1} with 32 scans. The characteristic absorption peaks were analysed to identify the functional groups present in the extract (Kidgell *et al*., 2019; Lahaye & Robic, 2007).

D. Antioxidant Activity by DPPH Radical Scavenging Assay

The antioxidant activity of the aqueous extract of *Ulva reticulata* was determined by 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical scavenging assay following a modified Brand-Williams method. Different concentrations of the extract (100, 200, 300, 400 and 500μL) were prepared and mixed with the DPPH solution. The reaction mixtures were incubated at room temperature in the dark for 30 minutes. The absorbance was measured at 517 nm using a UV-Visible spectrophotometer. The percentage of radical scavenging activity (%RSA) was calculated using the following equation (Brand-Williams *et al*., 1995):

$$\frac{Radical\ Scavenging\ Activity}{Inhibition\ \%} = \frac{Ab - As}{Ab \times 100}$$

where : Ab - absorbance of blank
As - absorbance of the sample

E. Formulation of Edible Food Wrapper Sheet

The edible food wrapper sheet was prepared by blending the aqueous extract of *Ulva reticulata* with Polyvinyl alcohol (PVA), gelatin and Polyethylene glycol (PEG). The mixture was stirred continuously using a magnetic stirrer under controlled temperature until a homogeneous solution was obtained. Trial II formulation was selected for further characterization based on their integrity and flexibility. The prepared solution was poured onto clean glass plates and dried under controlled conditions to obtain uniform edible wrapper sheets (Han & Scanlon, 2014; Rhim *et al*., 2013).

F. Physico-chemical Characterization of the Edible Food Wrapper Sheet

1) Overall Migration Test

The overall migration test was carried out at Microbiotek Laboratory, Coimbatore, following standard laboratory procedures for food-contact materials. Defect-free wrapper sheets ($5\ cm \times 5\ cm$) were immersed separately in food stimulants comprising 10% ethanol, 50% ethanol and food oil under controlled temperature and exposure conditions. After the specified exposure period, the samples were removed, drained carefully using blotting paper and analysed to determine the migration values.

2) Solubility Test

The water solubility of the edible wrapper sheet was determined by immersing a pre-weighed ($5\ cm \times 5\ cm$) sample in distilled water at 25°C for a specified duration. After immersion, the sample was removed carefully, dried and weighed. The percentage solubility was calculated based on the weight loss after immersion (Rhim *et al*., 2013).

3) Water Absorption Test

The water absorption capacity of the edible wrapper sheet was determined using pre-weighed samples ($5\ cm \times 5\ cm$). The samples were immersed in distilled water for a fixed period, after which excess surface water was removed using blotting paper. The wet weight was recorded and the percentage of water absorption was calculated using the difference between the wet and dry weight (Rhim *et al*., 2013).

4) Thermal Stability Test

The thermal stability of the edible wrapper sheet was evaluated by exposing the sample to low temperature (-20°C and 4°C) and elevated temperature (40°C to 60°C) under controlled laboratory conditions. After exposure, the samples were examined for changes in appearance, flexibility, deformation, cracking, melting and dimensional stability (Shen *et al*., 2021).

5) Thickness Measurement

The thickness of the edible wrapper sheet was measured using a digital Vernier caliper. Measurements were taken at different positions of the sheet and the average thickness was recorded (Han & Scanlon, 2014).

G. Antimicrobial Activity Test for Ulva reticulata and Food Wrapper Sheet

The antimicrobial activity of the aqueous extract of *Ulva reticulata* and the formulated food wrapper sheet was evaluated using the agar well diffusion method and disc diffusion. Test microorganisms including *Escherichia coli, Pseudomonas* sp., *Staphylococcus aureus, Candida albicans, Aspergillus niger, Klebsiella* sp. were cultured overnight in nutrient broth. Sterile nutrient agar plates were prepared and inoculated with the respective test organisms.

For the aqueous extract of *Ulva reticulata, wells* (6mm diameter) were made in the inoculated agar plates using a sterile cork borer (Bauer *et al*., 1966). Different volumes of the extract (25, 50, 75 and 100µl) were added into wells. The plates were incubated at 37°C for 24 hours and the antimicrobial activity was determined by measuring the diameter of the zone of inhibition.

For the edible food wrapper sheet, sterile 6mm diameter discs prepared from the wrapper sheet were aseptically placed on the surface of the inoculated agar plates. The plates were incubated at 37°C for 24 hours and the antimicrobial activity was assessed by measuring the zone of inhibition around the discs.

III. Results And Discussion

A. Qualitative Phytochemical Analysis

The qualitative phytochemical analysis of *Ulva reticulata* revealed the presence of alkaloids, tannins, saponins and proteins, while steroids, terpenoids, glycosides, quinones, carbohydrates and flavonoids were not detected (Table I). The occurrence of these bioactive compounds indicates the *Ulva reticulata* possesses valuable phytochemicals that may contribute to its biological activities, particularly antioxidant and antimicrobial properties.

Among the detected phytochemicals, tannins and saponins are well known for their free radical scavenging and antimicrobial activities, whereas alkaloids have been reported to exhibit diverse pharmacological properties. The presence of proteins also enhances the nutritional value of the seaweed and may contribute to the structural characteristics of edible film formulations.

Table I Qualitative Phytochemical analysis of *Ulva reticulata*

S.No.	Phytochemical Constituents	Results
1.	Tannins	+
2.	Alkaloids	+
3.	Saponins	+
4.	Steroids	-
5.	Terpenoids	-
6.	Glycoside	-
7.	Phenol	-
8.	Quinones	-
9.	Proteins	+
10.	Carbohydrate	-
11.	Flavonoids	-
12.	Alkaloids (Iodine)	-

Similar phytochemical compositions have been reported in several *Ulva* sp, suggesting that marine green algae are a rich source of bioactive metabolites suitable for food, pharmaceutical and biodegradable packaging applications (Senturk Parreidt *et al*., 2018).

B. Fourier Transform Infrared Spectroscopy (FTIR) Analysis

The FTIR spectrum exhibited characteristic absorption peaks at 3315.03 cm^{-1}, 2746.14 cm^{-1} and 1633.41cm^{-1} which were assigned to hydroxyl (-OH), methylene (-CH) and carboxyl (-COOH) functional groups respectively (Fig. 1 and Table II). These functional groups are commonly associated with polysaccharides, proteins and other biologically active constituents present in marine macroalgae.The identification of hydroxyl and carboxyl groups suggests the presence of functional compounds that may contribute to the antioxidant activity and film-forming properties of the extract.

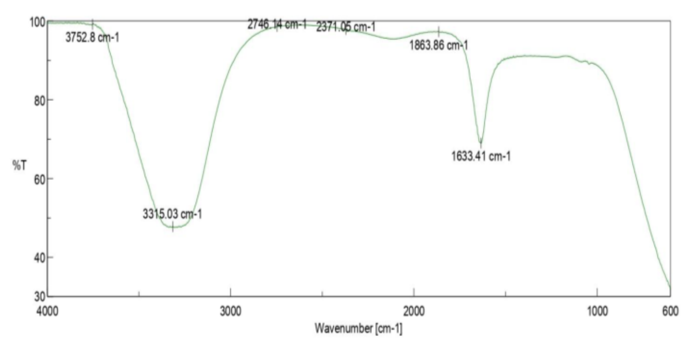

Fig. 1 Graph of FTIR Spectrum analysis of *Ulva reticulata*

Such functional groups are known to play an important role in intermolecular interactions, thereby improving the stability and physicochemical characteristics of biodegradable films. Similar FTIR spectral characteristics have been reported for *Ulva* sp confirming the presence of ulvan and other bioactive polysaccharides responsible for their biological and functional properties (Kidgell *et al*., 2019; Lahaye & Robic, 2007).

Table II FTIR Spectrum analysis of *Ulva reticulata*

PEAK	SAMPLE PEAK	BOND STRENGTH	FUNCTIONAL GROUP	COMPOUND
1	3315.03	Medium to strong	O-H	Alcohols, Phenol
2	2746.14	Weak	-C-H	Methylene group
3	1633.41	Strong	-COOH	Carboxyl group

C. Antioxidant activity

The extract exhibited concentration-dependent radical scavenging activity, with the percentage inhibition increasing progressively with increasing extract concentration (Fig. 2). The IC50 value was determined to be 271.66, indicating moderate antioxidant potential (Table III). The antioxidant activity observed in the present study may be attributed to the presence of phytochemicals such as tannins and other antioxidant constituents identified during phytochemical screening. Marine macroalgae are recognized as natural sources of antioxidant compounds capable of neutralizing free radicals and reducing oxidative stress (Brand-Williams *et al., 1995;* Holdt & Kraan, 2011; Tanna & Mishra, 2018).

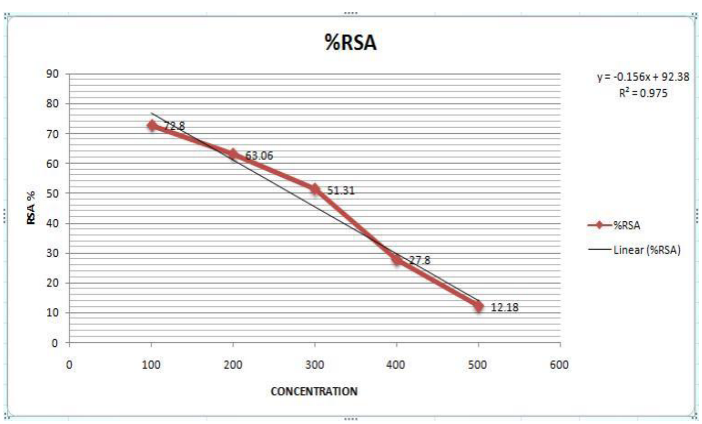

Fig. 2 Graph of Antioxidant activity of *Ulva reticulata*

Table III Antioxidant activity of *Ulva reticulata* by DPPH method

Concentration	Control Absorbance	Sample absorbance at 517 nm	% RSA	IC 50
100	1.022	0.3	72.8	271.66
200	1.022	0.4	63.06	271.66
300	1.022	0.52	51.31	271.66
400	1.022	0.76	27.8	271.66
500	1.022	0.92	12.18	271.66

D. Formulation of Edible Food Wrapper Sheet

Among the two formulations, Trial 2 exhibited superior flexibility, uniformity and structural integrity and was selected for further physicochemical characterization (Table IV). The incorporation of Polyvinyl alcohol (PVA), gelatin and Polyethylene glycol (PEG) contributed to improved film formation and handling properties (Fig. 4).

The combination of natural seaweed extract with biodegradable polymer enhanced the qualities such as film strength, flexibility and biodegradability thereby supporting the application of seaweed-based materials as sustainable alternatives to conventional plastic packaging (Han & Scanlon, 2014; Shanbhag *et al*., 2023).

Table IV Formulation of Edible Food Wrapper Sheet

S.No.	Ingredients	Trial I	Trial II
1	*Ulva* extract	10ml	10ml
2	PVA	10ml	15ml
3	Gelatin	2ml	2ml
4	PEG	2ml	2ml

Fig. 3 Algal Seaweed *Ulva reticulata*

Fig. 4 Edible food wrapper sheet

E. Physico-chemical Testing for Edible Food Wrapper Sheet

1) Overall Migration analysis

$$\text{Overall migration} = M \div A = (Mass\ loss)/(Surface\ area)$$

10% Ethanol = 4.2 mg / 0.5 dm^2 = 8.4 mg/dm^2
50% Ethanol = 4.9 mg/ 0.5 dm^2 = 9.8 mg/dm^2
Food oil = 3.7 mg/ 0.5 dm^2 = 7.4 mg/dm^2

The migration values were 8.4 mg/dm^2 in 10% ethanol, 9.8 mg/dm^2 in 50% ethanol and 7.4 mg/dm^2 in food oil. Among the tested stimulants, the highest migration was observed in 50%

ethanol, while the lowest migration was observed in food oil. Nevertheless, the migration values remain within acceptable limits for food-contact materials, indicating the suitability of the developed wrapper for food packaging applications.

The migration behaviour is influenced by the interaction between the polymer matrix and different food stimulants. The incorporation of *U. reticulata* polysaccharides with PVA and gelatin may have contributed to improved structural stability, thereby minimizing the release of film constituents into the surrounding medium (Han & Scanlon, 2014; Hosseini & Gomez-Estaca, 2020).

2) Solubility Test

Solubility trial $S = (Initial\ weight - Final\ weight)\ /\ (Initial\ weight\ \times 100)$

$$= 0.507g - 0.484g/0.507g \times 100$$
$$= 4.54 \pm 2$$

The water solubility of the edible food wrapper sheet was 4.54$\pm$ 2.00% indicating low solubility under the tested conditions. The low percentage of dissolution suggests that the wrapper retained its structural integrity during water exposure, making it suitable for packaging semi-moist and moderately moist food products.

The reduced solubility may be attributed to the intermolecular interactions between *U. reticulata* polysaccharides, gelatin and polyvinyl alcohol which enhanced the cohesion of the polymer network (Azeredo *et al*., 2016; Rhim *et al*., 2013).

3) Water Absorption Test

$$Absorption = Wet\ weight\ - Dry\ weight \div Dry\ weight\ \times 100$$
$$= 2.260g\ - 1.826g\ \div 1.826g\ \times\ 100$$
$$= 19.22 \pm 0.5$$

The edible food wrapper exhibited a water absorption value of 19.22% demonstrating moderate moisture uptake. Moderate water absorption is considered beneficial because it allows the wrapper to maintain flexibility without undergoing excessive swelling or structural degradation during storage.

The observed moisture absorption behavior may be associated with the hydrophilic nature of ulvan and other polysaccharides present in *Ulva reticulata.* The incorporation of biodegradable polymers helped regulate water uptake and maintain film stability (Lahaye & Robic, 2007; Pari *et al*., 2025).

4) Thermal Stability

The thermal stability evaluation demonstrated that the edible food wrapper sheet remained intact under both low-temperature (-20°C and 4°C) and elevated temperature (40°C-60°C) conditions without noticeable melting, shrinkage, cracking or deformation. Furthermore, the wrapper retained its flexibility after exposure to refrigeration and freezing temperature indicating satisfactory thermal resistance.

The improved thermal stability may be attributed to the interaction between seaweed polysaccharides and the polymeric matrix formed by PVA and gelatin. Such interactions enhance the structural integrity of biodegradable films, making them suitable for food packaging under different storage conditions (Shen *et al*., 2021; Torres *et al*., 2023).

5) Thickness and Density

Weight of the sheet = 1.982gm
Length = 9cm
Thickness = 0.4mm
Breadth = 9cm
GSM = $weight\ \times 10{,}000\ /length\ \times breadth$
GSM = $1.982g\ \times 10{,}000/9cm\ \times 9cm$
= 244.94 g/m^2
Density = GSM / Thickness
= 0.612g/cm^3

The developed edible food wrapper sheet exhibited a thickness of 0.4 mm, GSM of 244.94 g/m^2 and a calculated density of 0.612 g/cm^3. The uniform thickness indicates effective film formation and homogeneous distribution of the film-forming components, while the moderate GSM reflects a suitable balance between flexibility and mechanical strength.

The incorporation of *Ulva reticulata* extract with PVA, gelatin and PEG contributed to the formation of a compact and stable film matrix (Rhim *et al*., 2013; Torres *et al*., 2023).

F. Antimicrobial Activity of Ulva reticulata and Food Wrapper Sheet

The antimicrobial activity of the aqueous extract of *Ulva reticulata* demonstrated effective inhibition against the tested bacterial and fungal pathogens (Table V). Among the tested microorganisms, *Pseudomonas* sp. exhibited the highest sensitivity followed by *Staphylococcus aureus*, *Klebsiella* sp. and *Candida albicans.* In contrast *Aspergillus* sp. exhibited comparatively lower susceptibility with inhibition observed only at higher extract concentrations. The increase in the zone of inhibition with increasing extract concentration indicates a concentration-dependent antimicrobial effect of the seaweed extract.

Table V Antimicrobial Activity of *Ulva reticulata*

S.No.	Organism	25µl	50µl	75µl	100µl

		extract	extract	extract	extract
1	*Klebsiella* sp.	24mm	25mm	28mm	24mm
2	*Pseudomonas* sp.	33mm	31mm	31mm	38mm
3	*Staphylococcus aureus*	27mm	29mm	24mm	24mm
4	*Candida albicans*	20mm	18mm	21mm	25mm
5	*Aspergillus* sp.	No zone	No zone	20mm	20mm

The antimicrobial activity may be attributed to the presence of bioactive phytochemicals including tannins, alkaloids and saponins together with sulfated polysaccharides present in *Ulva reticulata.* These compounds are known to disrupt microbial cell membranes, interfere with cellular metabolism and inhibit microbial proliferation.

The antimicrobial activity was carried out for the *Ulva reticulata* based food wrapper sheet against the organisms *Candida albicans* and *Escherichia coli*.

Table VI Antimicrobial activity of food wrapper sheet

S.No.	Organism	Food wrapper sheet	Silver-incorporated food wrapper sheet
1	*Candida albicans*	No zone formation	15mm
2	*Escherichia coli*	No zone formation	13mm

The antimicrobial activity assessment of the edible food wrapper sheet showed no inhibition against *Candida albicans* and *Escherichia coli* in the absence of silver incorporation. However, the silver-incorporated edible wrapper exhibited distinct zones of inhibition against both microorganisms, indicating enhanced antimicrobial performance following silver incorporation.

The improved antimicrobial activity may be attributed to the synergistic interaction between the bioactive constituents of *Ulva reticulata* and silver, which enhanced the release of antimicrobial agents and increased microbial growth inhibition (Holdt & Kraan, 2011; Kidgell *et al*., 2019; Tanna & Mishra, 2018).

Conclusion

The study demonstrated the successful development of an edible food wrapper using *Ulva reticulata* extract. The developed wrapper exhibited desirable physicochemical characteristics, low solubility, moderate water absorption, good thermal stability together with antioxidant and enhanced antimicrobial activity indicating its sustainability as an active food packaging material. The combined use of seaweed-derived bioactive compounds and biodegradable polymers offers a sustainable strategy for developing eco-friendly packaging systems with potential applications in food preservations. Beyond providing an alternative to conventional plastic packaging, this work highlights the value of marine macroalgae as renewable resources for advanced biomaterial development. The outcome of this study contributes to the growing field of sustainable food packaging and may serve as a foundation for future research aimed at optimizing mechanical properties, extending food shelf life, evaluating biodegradation under practical conditions and facilitating industrial-scale production.

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