Ulva spp (*Ulva intestinalis, U. fasciata, U. lactuca, and U. rigida*) composition and abiotic environmental factors

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Abstract. Seaweed, including various species of *Ulva* (e.g., *Ulva intestinalis, U. fasciata, U. lactuca,* and *U. rigida*), is essential for maintaining the balance of aquatic ecosystems. These algae are found worldwide and have a high growth rate in diverse habitats. This article analyzes the composition of these *Ulva spp* (including carbohydrates, proteins, lipids, and ash). It also investigates the environmental factors that affect their growth and composition, such as pH, temperature, water depth, salinity, and nutrient availability. Understanding the variations in composition and environmental influences among *Ulva spp* highlights the importance of studying their ecological impact and genetic diversity.

1. Introduction

Seaweed, encompassing a diverse range of macroalgae, plays a pivotal role in marine ecosystems, acting as a cornerstone for food provision, reproduction facilitation, and habitat creation for myriad marine organisms. Esteemed studies by Alavian et al. (2018), Schutt [1] et al. (2023), and van den Burg [2] et al. (2022) have underscored the indispensable ecological and biological significance of seaweed, highlighting its vital contribution to the overall stability and sustainability of marine ecosystems [3-8]. As a prolific source of dissolved organic carbon, seaweed significantly enriches coastal waters with essential nutrients, including carbohydrates, polysaccharides, nitrogen, and polyphenolic compounds. This nutrient-rich environment fosters a thriving biodiversity essential for ecological balance.

Beyond their ecological contributions, seaweeds are heralded for their rich composition of bioactive compounds. Carotenoids, fiber, proteins, essential fatty acids, vitamins, and minerals found in seaweeds not only bolster marine life but also offer promising benefits for human health and industry. Pioneering research by Al-Juthery et al. (2020), Dere et al. (2003), Fleurence (1999), and Polat et al. (2023) has illuminated the multifaceted applications of seaweeds, ranging from their use in pharmaceuticals to their role as sustainable fertilizers [9-15].

Recent scholarly interest has particularly focused on the *Ulva* species, known for their exceptional nutritional profile and ecological value. *Ulva spp*., such as *Ulva intestinalis, Ulva fasciata, Ulva lactuca,* and *Ulva rigida*, are celebrated for their dense concentrations of proteins, lipids, minerals, and vitamins—nutrients crucial for human well-being. Ananthi and Bagyalakshmi (2024), Elmosallamy et al. (2021), and Rasyid (2017) have contributed significantly to our understanding of the nutritional potential of *Ulva spp*., positing these algae as a sustainable food source amidst growing global food security concerns [16-32].

This article aims to comprehensively explore the compositional diversity of various *Ulva species*, scrutinizing the myriad factors influencing their growth and biochemical makeup. Through a detailed examination, we endeavor to shed light on the untapped potential of *Ulva spp*., advocating for their integrated management and conservation as a strategy to harness their ecological and nutritional benefits.

2. *Ulva* Biomass Composition and Nutrient Removal

The provided table presents a comprehensive overview of the biochemical composition of several *Ulva spp*. macroalgae. *Ulva intestinalis* exhibits a protein content ranging from 10.4% to 26%, carbohydrates ranging from 51.79% to 55.43%, and varying lipid levels, with ashes accounting for 18.81% to 19.95% of its dry weight. Similarly, *Ulva fasciata* displays protein concentrations between 13.13% and 27.09%, carbohydrates ranging from 30.82% to 65.19%, lipid content varying from 0.34% to 12.12%, and ash content spanning from 2.18% to 34.15%. Ulva lactuca demonstrates protein levels from 8.46% to 23.2%, carbohydrate content ranging from 17.2% to 58.4%, lipid concentrations varying between 0.19% and 4.05%, and ash percentages ranging from 11.2% to 30.9%. Additionally, *Ulva rigida* displays protein levels between 6.64% and 17.8%, carbohydrate content spanning from 22% to 54.5%, lipid concentrations varying from 0.09% to 12%, and ash percentages ranging from 24% to 30.1%. These values highlight significant variations in protein, carbohydrate, lipid, and ash content among different *Ulva spp*., indicating the influence of various factors such as geographic location, seasonal variation, and physiological state on their biochemical composition.

Table 1. Composition of *Ulva* biomass and nutrient removal [17, 33-49].

		Sampling		**Content % Dry weight**			
Species	References	Date	Location	Proteins	Carbohydrates	Lipids	Ashes
Ulva intestinalis	(Peasura et al., 2015)	July 2010	Pattani Bay. Thailand	16.95	55.43	low	19.95
	(Akter Tubril et al., 2023) (Tabarsa et al., 2018)	-	St. Martine Island Bangladesh	15.41	51.79	1.21	18.81
	(Bodin et al., 2020) (Peasura et al., 2015)	-	The coast Noor. Iran	10.4	-	-	-
	(Akter Tubril et al., 2023)	-	-	26	-	-	-
Ulva fasciata	(Mofeed et al., 2019)	October 2016	Alexandria. Egypte	17.35	30.82	2.4	34.15
	(El-Gendy et al., 2023)	August and October 2022	Alexandria Egypte	13.13	44.85	3.27	21
	(Rao P et al. 2015)	Summer 2006	Visakhapatnam India	24.75	55.58	7.14	12.53
		Monsoon 2006		24.01	65.19	7.87	2.79
		Post-Monsoon 2006-2007		25.91	62.45	9.46	2.18
		Summer 2007		27.09	62.20	7.95	2.77

		Monsoon 2007		25.36	60.06	10.42	4.17
		Post-Monsoon 2007-2008		23.69	56.02	12.12	8.17
	(Pádua et al., 2004)	December 1995	Ilha do Mel Brazil	13.30	53.31	1.94	20.61
		February 1996		16.13	56.47	0.34	17.75
Ulva lactuca	(Mofeed et al., 2019)	October 2016	Damietta. Egypte	21.38	35.48	11.6	21.08
	(Elmosallamy et al., 2021) (Pádua et al., 2004)	Aquaculture 2017	Alexandria Egypte	22	-	-	-
	(Elmosallamy et al., 2021)	oct-95	Guaraqueçaba Brazil	15.23	58.40	1.22	13.23
		February 1996		18.35	57.67	1.79	12.54
	(Pádua et al., 2004)	July 2007	Monastir Tunisia	8.46	-	7.87	19.59
	(Mohy El-Din, 2019)	Summer 2016/2017	Alexandria Egypte	20.3	19.5	3.76	24.5
		Autumn 2016/2017		18.2	18.4	3.2	21.5
		Winter 2016/2017		15.65	17.2	2.82	28.9
		Spring 2016/2017		23.2	18.9	4.05	28.33
	(Castro-González et al., 1996)	Summer 1994	La Paz, BCS Mexico	10.7	30.9	0.25	30.9
	(Tabarsa et al., 2012)	April 2008	Qheshm island Iran	10.69	-	0.99	18.03
	(Rasyid, 2017)	-	Pameungpeuk Indonesia	13.6	58.1	0.19	11.2
Ulva rigida	(Taboada et al., 2010)	-	La Coruna Spain	17.8	54.5	0.09	28.6
	(Satpati and Pal, 2011)	-	Chilka Lake India	6.64	22	12	24
	(Cañedo-Castro et al., 2019)	-	Baja California Sur (BCS) Mexico	8.7	-	-	30.1
	(Paiva et al., 2017)	April 2013	Sao Miguel Island, Portugal	15.78	16.74	1.02	20.60

	(Latique et al., 2021)	Ocrobre 2019	Laâyoune city Morocco	9.3	-	2.83	-
	(Balar et al., 2019)	November 2014 to August 2016	109 samples India	4.14-26	16.63-65.93	0.8-3.1	-
	(Moreira et al., 2021)	May 2017	Ria Formosa Portugal	11.13 - 15.59	55.23	1.14	32.50

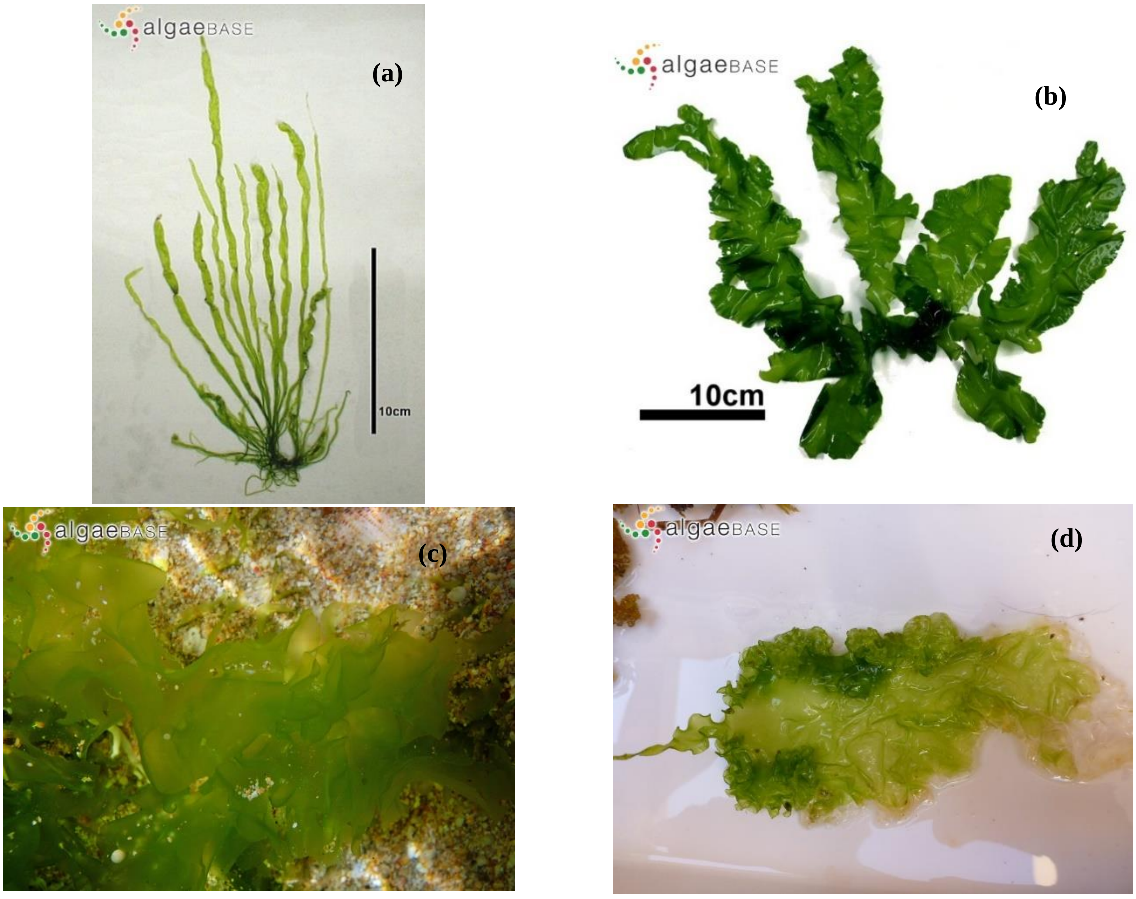

Fig. 1. Representative Images of *Ulva Species*: *Ulva intestinalis* (a), *Ulva fasciata* (b), *Ulva lactuca* (c) and *Ulva rigida* (d) (Source: AlgaeBase)

3. Abiotic environmental factors affecting *Ulva spp* growth

Abiotic environmental factors profoundly influence the growth and physiology of *Ulva spp*., shaping their ecological dynamics and productivity. These factors include pH, temperature, water depth, salinity, and nutrient availability, each playing a vital role in determining the success of *Ulva* populations in marine environments. Understanding the interplay between these abiotic factors and *Ulva spp*. responses is essential for effective management and conservation efforts in coastal ecosystems.

– pH: The growth and composition of *Ulva spp*. are significantly influenced by the water's acidity, as shown by pH. Variations in pH can affect *Ulva spp*. growth and chemical production rates, among other functions. The ideal pH range for *Ulva spp*. growth is generally between 7.5 and 9.5 [50, 51].

Frost-Christensen and Sand-Jensen (1990) demonstrate that pH significantly affects *Ulva lactuca*, with growth remaining stable between pH 7.5 and 9, but sharply declining above pH 9 and approaching zero just above pH 10. This decline is attributed to direct pH effects on cell pH, reduced bicarbonate availability, and impaired carbon uptake. Overall, high pH levels inhibit *Ulva lactuca* growth due to physiological and carbon uptake mechanisms [50].

- Temperature: Temperature tolerance studies suggest a range of 6°C to 25°C for *Ulva spp*. [52]. Temperature exerts a significant influence on *Ulva species*, impacting various aspects of their physiology and growth. Optimal temperatures are crucial for promoting higher rates of photosynthesis, with *Ulva prolifera* showing peak photosynthetic activity at 23°C, while extreme temperatures can adversely affect this process [53]. Additionally, temperature plays a pivotal role in the growth rate of *Ulva spp*, with *Ulva curvata* exhibiting an optimum growth temperature of 23°C, and growth rates varying with temperature changes and nitrogen limitation interactions [54]. Physiological responses such as metabolic processes and adaptation mechanisms are also affected by temperature variations, with *Ulva fasciata* exhibiting adaptations like developing heat-resistant cells in response to temperature changes [55]. Moreover, temperature fluctuations can impact seasonal growth patterns and acclimation processes, with *Ulva lactuca* showing maximum growth rates between 12°C to 18°C, and differences observed in growth responses based on locality and seasonal changes [52]. Understanding these temperature-mediated impacts on *Ulva spp* is vital for predicting their ecological dynamics and responses to environmental changes.

- Water depth: Water depth exerts a profound influence on the physiology, adaptability, and growth dynamics of *Ulva spp*., as elucidated by various studies. One study [56] delved into the physiological characteristics of *Ulva* mats at different depths, revealing a notable gradient in tissue nitrogen content, with lower layers harboring higher nitrogen levels attributed to light limitation and slower dilution of internal nitrogen resources. In addition, decomposition and anoxia at the bottom of the mats were identified as factors contributing to an upward nutrient flux. Surprisingly, despite challenges posed by reduced light availability in deeper subtidal zones (2-20 meters), *Ulva spp*. demonstrate remarkable adaptability, showcasing mobility and gentle drift due to turbulence [57]. This adaptability is complemented by nutrient delivery from sediment, which supports their growth in such environments. In freshwater ecosystems, water depth emerges as a pivotal factor influencing *Ulva* mat development, with greater depths correlating positively with larger surface area and higher thalli density [58]. Moreover, a specific focus on *Ulva lactuca* underscored the significance of water depth in regulating tissue nitrogen content and growth dynamics (Pérez-Mayorga et al., 2011). Deeper deployments were found to exhibit substantially higher tissue nitrogen content, particularly on cooler days, indicative of the intricate interplay between environmental factors and *Ulva* physiology. These results emphasize the various ways that water depth affects *Ulva* species, highlighting how they survive and adapt in different water environments.

- Salinity: Salinity is crucial for the physiological responses and growth patterns of *Ulva spp* [59]. Different types of *Ulva* have different salinity preferences, with some even thriving in freshwater (like *U. limnetica*) [59]. Too much or too little salinity can induce oxidative stress due to the accumulation of reactive oxygen species (ROS) [59, 60]. These substances can affect the photosynthetic efficiency and growth rates of Ulva. Low salinity (5-15 psu) can slow down metabolism and photosynthesis [53, 61], while high saltiness (26-32 psu) can boost photosynthesis but also cause stress and reduce growth [53, 60, 62]. Overall, maintaining suitable salinity levels within the range of 15-25 psu promotes optimal growth and productivity in *Ulva spp*.

- Nutrient availability: Nutrient availability, particularly nitrogen (N) and phosphorus (P), profoundly influences the growth and physiological responses of *Ulva spp*., as demonstrated in a study conducted by Buapet et al. 2008 [63]. *Ulva reticulate*, for instance, demonstrates a strong preference for nitrogen uptake, leading to rapid growth and increased biomass in response to elevated nitrogen levels [63]. Similarly, *Ulva lactuca* exhibits stimulation from ammonia (NH_3) and phosphate (MPO_4) additions, although excessive ammonia (NH_3) concentrations can inhibit productivity [64]. Nutrient availability also impacts *Ulva prolifera*, with saturated nitrate (NO_3^-) uptake and escalating phosphorus uptake influencing its growth and photosynthetic performance [65]. Moreover, *Ulva spp* possess a remarkable capacity to store nitrogen and phosphorus, with tissue concentrations reflecting surrounding water nutrient levels [66]. The biochemical composition and productivity of *Ulva spp*. are directly influenced by nutrient levels, particularly nitrate, which positively impacts protein content and phenolic composition [67]. To sum up, maintaining the balance of optimal nutrient conditions is crucial for maximizing the growth, biochemical properties, and productivity of *Ulva spp* in coastal environments.

4. Conclusion

In summation, the analysis of biochemical composition across different *Ulva species* has elucidated notable disparities, underscored by an intricate interplay of geographic locale, temporal dynamics, and inherent physiological attributes. The data presented herein vividly highlight how environmental contingencies—ranging from pH levels and thermal conditions to aquatic depth, salinity gradients, and the availability of nutritive elements—exert profound influences on the phenotypic and genotypic expressions of *Ulva spp*. Such insights are indispensable for the informed management and exploitation of these algae, whose applications span the gamut from aquaculture innovations to the vanguard of environmental remediation strategies.

The critical examination of environmental factors affecting *Ulva spp*. underscores the necessity for a nuanced understanding of these complex biological and ecological matrices. It is evident that the stewardship of *Ulva spp*., whether for the enhancement of marine biodiversity, the bolstering of aquaculture yields, or the advancement of green technologies, requires a holistic appreciation of their ecological roles and physiological demands.

Future research endeavors should, therefore, pivot towards a more granular investigation of the symbiotic relationships between *Ulva spp*. and their habitats. This entails not only the refinement of current methodologies to assess environmental impacts on their growth and nutritional profiles but also the exploration of innovative biotechnological applications that leverage their unique properties. The sustainability and conservation of these pivotal marine assets hinge upon our capacity to elucidate and harness the dynamic interdependencies that define their existence within the broader marine ecosystem.

Conflict of interest

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

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