

GROWTH-PROMOTING AND CLIMATE-RESILIENT NATURE OF *Sargassum wightii* Greville SEAWEED IN *Vigna radiata* (L.) R. Wilczek, THE GREEN GRAM

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ABSTRACT. Seaweed-based bioproducts have been increasingly used in crop production systems due to their distinct bioactive components and effects. The phytostimulatory qualities cause several significant agricultural plants to grow and yield more. Significant changes in the soil and plant microbiome components are also brought about by treatment with seaweed extracts and products, which promote sustainable plant growth. The bioactive property of market-available seaweed *Sargassum wightii* is evaluated in the current study for its effective dose for treatment in green gram. A 20 % extract of *Sargassum wightii* was found promising for seed treatment of green gram to get an increase in germination efficiency and early biomass development by mobilizing the availability of phosphorus. The same concentration was observed to be stress-tolerant for temperature, also. Seaweed extracts are perfect for ecologically sensitive crop cultivation and organic farming because they are very organic. Although the majority of the compounds found in *Sargassum wightii* seaweed extracts are organic, there are also tiny amounts of inorganic nutritional components. They work well with other crop inputs, opening the door for a sustainable integrated management strategy.

Keywords Bioactive, biomass stimulant, stress-tolerant, seaweed extract, sustainable agriculture

INTRODUCTION

Seaweed extract is a natural fertilizer and plant growth enhancer derived from seaweeds, used in agriculture as a biostimulant. There are various benefits of seaweed extract, viz, it improves crop yield and quality, enhances nutrient uptake, improves soil health, helps crops to withstand stress (biotic as well as abiotic), improves disease resistance, increases foliage & flowering and acts as a natural, suitable substitute for chemical fertilizer [1-6]. Table 1 summarises its effect on different crops and concentrations used in various applications. Seaweed extracts are prepared from Red (Rhodophyceae), brown (Phaeophyceae), and green (Chlorophyceae) algae grown in marine and coastal ecosystems. Some of the common seaweed species used for the preparation of seaweed extracts are listed in Table 2.

Table 1 Types of Seaweed extract, doses with method of application, along with crops showing their increasing application in crop improvements.

Serial Number	Name of The Algae/Seaweed	Concentration applied / Effective concentration	Name of Crop	Year	Reference	Remarks
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1	Seaweed extract with Boron	B-deficiency (0.32 mg B kg ⁻¹ soil) and potentially B-deficient conditions (0.69 mg B kg ⁻¹ soil)	Sugar beet	2025	Yang et al. [7]	Nutrient Mobilizer, Improve photosynthetic performance
2	Sargassum angustifolium	0.5, 1.0, and 1.5%	<i>Calotropis pracera</i>	2023	Bahmani et al. [8]	Biostimulant for the amelioration of salt stress
3	Seaweed fertilizer	Long-term application	Okra	2023	Qiqin et al. [9]	Improvement of Soil Structure and Bacterial Composition
4	Seaweed <i>Ulva lactuca</i> extract	8.00%	<i>Citrullus lanatus</i> var. Colocynthoides "Gurum"	2023	Radwan et al. [10]	Seed priming improved germination
5	Syngenta's Quantis and Epivio energy (Seaweed & Vinasse)	Black gram 2.5 to 10 ml L ⁻¹ ; Soybean 0.5 ml to 4.0 ml kg ⁻¹	Blackgram (TAU-1) and Soybean (JS-335)	2022	Vishwanath et al. [11]	Growth and Yield
6	Seaweed Extract (<i>Ascophyllum nodosum</i>)	2.00%	Kabuli Chickpea	2021	Kurakula and Rai [12]	Growth and Yield
7	Seaweed extract (<i>Kappaphycus alvarezii</i>)	0%, 5% and 7.5%	Wheat	2021	Kumar et al. [13]	Yield
8	Seaweed extract	12.5kg/ha, 25kg/ha, 37.5kg/ha, foliar spraying of gel & liquid @ 0.5% twice at tillering and panicle initiation stages	Rice var. ADT53	2021	Deepana et al. [14]	Productivity and Soil Fertility
9	Seaweed extract	2ml/L was applied as a foliar spray thrice at 30, 45 and 60 DAS	French bean	2021	Rai et al. [15]	Growth and Yield
10	IFFCO 'Sagarika' - Seaweed extract (<i>Kappaphycus</i> spp.) and <i>Sargassum</i> spp.)	2ml litre ⁻¹ and 4ml litre ⁻¹ Applied each at the tillering and heading stage	Wheat HD 2967	2021	Sarita et al. [16]	Yield performance
11	Seaweed extracts (<i>Kappaphycus alvarezii</i> and <i>Gracilaria edulis</i>)	5% and 10%	Potato	2021	Garai et al. [17]	Growth, Yield and Tuber Quality
12	Seaweed extracts (<i>Kappaphycus alvarezii</i> & <i>Gracilaria crassa</i>)	0, 5.0, 7.5, 10.0 and 15.0% v/v	Maize	2020	Ghosh et al. [18]	Growth, Yield and nutrient uptake

13	Seaweed Extract (<i>Ascophyllum nodosum</i>)	0% , 0.5%, 1%, 2% and 3%	Onion	2020	Abbas et al. [19]	Productivity and Quality
14	Seaweed - <i>Ascophyllum nodosum</i> -fermented	Short-term application	Maize	2020	Chen et al. [20]	Growth, bacterial diversity and soil nitrogen
15	Seaweed extract	6.00 ml/litre	Broccoli	2018	Manea and Abbas [21]	Growth and Yield
16	Seaweed extract (<i>Kappaphycus alvarezii</i> and <i>Gracilaria edulis</i>)	2.5, 5.0, 7.5, 10, and 15.0% (v/v)	Hybrid Maize NAH 1137	2018	Basavaraja et al. [22]	Growth and Yield
17	Seaweed saps (<i>Gracilaria edulis</i> and <i>Kappaphycus alvarezii</i>)	5% to 15%	Hybrid Maize	2017	Dilavarnaik et al. [23]	Growth and Yield
18	Seaweed extract	500 ml ha ⁻¹	Soybean	2017	Guerreiro et al. [24]	Productivity
19	<i>Sargassum myricocystum</i> (Brown algae), <i>Caulerpa racemosa</i> (Green algae) and <i>Gracilaria edulis</i> (Red algae)	1.0% for 3 hrs Nano Seaweed powder	Pigeon pea	2016	Ambika and Sujatha [25]	Physiological quality
20	Seaweed extract (<i>Ascophyllum nodosum</i>)	0, 0.25, 0.50, 0.75 and 1.00 ml / L	Chickpea	2016	Boghdady et al.[26]	Growth and Yield
21	Seaweed and Fish Waste Compost	40 t ha ⁻¹ , 50 t ha ⁻¹ and 66 t ha ⁻¹	Tomato, Lettuce	2015	Illera-Vives et al. [27]	As a Fertiliser for Horticulture
22	Seaweed extracts (<i>Kappaphycus</i> and <i>Gracilaria</i>)	0, 2.5, 5.0, 7.5, 10 and 15% v/v	Blackgram	2014	Dwivedi et al. [28]	Productivity and Nutrient Status
23	Seaweed extract (<i>Sargassum crassifolium</i>)	10% , 20% , 50%, 100% (v/v) and distilled water spray 0 %	Tomato	2014	Sutharsan et al. [29]	Growth, Yield and Fruit Quality
24	Seaweed extracts (<i>Kappaphycus</i> and <i>Gracilaria</i>)	0, 2.5, 5.0, 7.5, 10.0 and 15.0% v/v	Green gram	2013	Pramanick et al. [30]	Growth and Yield
25	<i>Sargassum wightii</i> Grev	1.00 %	Green gram	2012	Ashok et al. [31]	Growth

26	Seaweed extract (<i>Ulva lactuca</i> , <i>Caulerpa scalpelliformis</i> , <i>Sargassum plagiophyllum</i> , <i>Turbinaria conoides</i> , <i>Padina tetrastromatica</i> , <i>Dictyota dichotama</i>)	0.1%, 0.2%, 0.3%, 0.4%, and 0.5%.	Green gram	2011	Kavipriya et al. [32]	Biostimulant
27	<i>Sargassum wightii</i> , <i>Chaetomorpha linum</i>	20.00 %, 30 %	<i>Cajanus cajan mill sp</i>	2010	Sathya et al. [33]	Growth
28	Seaweed Extract and Chemical Fertiliser	1.00 % Seaweed extract with 50% dose of chemical fertiliser	<i>Tagetes erecta</i>	2010	Sridhar and Rengasmy [34]	Growth and Yield
29	<i>Rosenvigea intricata</i>	20.00 %	<i>Cyamopsis tetragonolo ba (L) Taub</i>	2009	Thirumaran et al. [35]	Seed germination, Growth and Yield,
30	Seaweed extract (<i>Kappaphycus alvarezii</i>)	15%	Soybean	2009	Rathore et al. [36]	Growth, Yield and Nutrient Uptake
31	Green seaweeds extract (<i>Cladophora dalmatica</i> , <i>Enteromorpha intestinalis</i> , <i>Ulva lactuca</i>) and the three red algae extract (<i>Corallina mediterranea</i> , <i>Jania rubens</i> , <i>Pterocladia pinnate</i>)		<i>Vicia faba</i>	2000	El-Sheekh and El- Saied [37]	Seed Germination and Growth

Table 2 Common macro algae used in the preparation of Seaweed extract

Phaeophyceae	Rhodophyceae	Chlorophyceae
Ascophyllum nodosum	Macrocystis pyrifera	Ulva lactuca
Ecklonia maxima	Porphyra perforate	Enteromorpha prolifera
Durvillea antarctica	Nereocystis spp.	Caulerpa paspaloides
Durvillea protatorum	Cyanidium caldarium	Ulva armoricana
Fucus vesiculosus	Gelidium serrulatum	Codium liyengarii
Sargassum spp.	Acanthophora spicifera	Codium tomentosum
Hydroclathrus spp.	Kappaphycus alvarezii	Caulerpa sertularioides
Ralfsia spp.	Gracilaria edulis	
Laminaria digitata	Gracilaria dura	
Cystoseira myriophylloides	Laurencia johnstonii	
Fucus spiralis		
Padina pavonica		
Fucus gardneri		

In the preparation of seaweed extract, both physical (heat, pressure, and microwaves) and chemical (solvents, acids, and alkali) methods are employed. Seaweed extracts consist of a wide group of bioactive compounds such as polysaccharides, plant hormones, fatty acids, sterols, carotenoids, oxylipins, minerals, peptides, amino acids, proteins, lipids, polyphenolics, phlorotannins, etc. Of these, approximately 60% are polysaccharides, 15% are proteins, 2% each are lipids, minerals, and plant hormones, and the remainder are other compounds [38], [39-41]. Wally et al. [42] proposed a shift in thinking by suggesting that components within seaweed extract (SWE) may modulate innate plant pathways involved in the biosynthesis of phytohormones, such as auxins, cytokinins, and abscisic acid. A recent European industry review of the science on the mode of action of seaweed-based plant bio stimulants highlighted that plant hormones are not responsible for the plant bio stimulant effects observed in crops when applying seaweed-based extracts and endorsed molecular-level studies for insights [43].

An action that is emerging for SWE is based on the stimulation of a combination of intrinsic and systemic plant responses to achieve plant priming-like effects. Plant priming is an adaptive mechanism that enables plants to improve their defensive capacity and results in plant conditioning. The effect is manifested as a physiological state of alertness where plants respond more rapidly and intensely to different types of biotic and abiotic stresses. An intrinsic feature of the mechanism is inducibility, which bears a minimal fitness cost (relative to a constitutive mechanism) and enables a balanced trade-off between plant growth and defence responses [44,45]. Many reviews address the topic of plant priming and describe the molecular mechanisms [46-51].

Priming is a plant conditioning strategy that has untapped potential for improving agricultural productivity and protection against yield loss due to environmental stress [52]. In the field, the plant priming mechanism can be stimulated by biotic and abiotic challenges, and the chemical priming stimuli can be applied exogenously [53,54]. The field research has demonstrated that SWE significantly increased commercial cane yield and commercial sugar yield, each by 17%, and increased grower returns by 18% [55,56]. Chen et al [20] reported that the relative abundance of the dominant phyla varied regularly with fertilisation, and bacterial α -diversity was influenced by seaweed fertiliser amendment. The total nitrogen (TN) contents of all soil samples decreased gradually, and the NO_3^- -N and NH_4^+ -N contents of the soils treated with seaweed fertiliser were much higher than those of the control soils. Similarly, the enzymatic activities of dehydrogenase, nitrite reductase, urease, and cellulase in the soil were significantly increased on day 3, day 8, and day 13 after the application of seaweed fertiliser to the maize rhizosphere soil.

Seaweeds are rich in bioactive compounds such as terpenoids, polyphenols, and sulphated polysaccharides. These compounds exhibit potent pesticide properties, offering environmentally friendly alternatives to conventional chemical pesticides. Synergistic effects of different seaweed compounds will enhance the efficacy and commercial viability of seaweed-derived biopesticides [57]. *Sargassum wightii* is a large, brown alga found in tropical and temperate oceans. It thrives in Indian coastal areas with significant populations in Tamil Nadu, Gujarat, Andhra Pradesh, Maharashtra, and the Andaman & Nicobar Islands. It's abundant in the southern and western regions, including the Gulf of Mannar, Visakhapatnam, Nagapattinam, Thiruchendur, Tuticorin, and Kerala. The Gulf of Mannar Biosphere Reserve is a particularly rich area for this seaweed. It is considered an economically important species because it can be used as animal feed, food ingredients, and fertilizer. It has a wide range of bioactive properties. It is found in dark brown colour, 20-30 cm (about 11.81 inch) height with well-marked holdfast, leaves are 5-8 cm (about 3.15 inch) long and 2-9 mm (about 0.35 inch) broad, 5-7 mm (about 0.28 inch) long seldom ending in a long tip.

A systematic review from 2000 to 2025 as mentioned in Table 1, shows that there is no consistency in doses of seaweed extract for its application in different crops. In the current study, market available *Sargassum wightii* Grev. was evaluated to test its effect on seed germination and biomass in Green gram in different doses (lower to higher concentration) for its potential field application.

MATERIALS AND METHODS

Aqueous extraction of the local market procured *Sargassum wightii* seaweed powder was performed in a water bath. 40 g *Sargassum wightii* seaweed powder and 400 ml of distilled water were placed in the 500 ml Erlenmeyer flask, and it was kept in a water bath for 45 minutes at 60°C, the volume remains constant. The extract was filtered using Whatman filter paper no. 1. The extract was kept in a refrigerator at 4°C before use. Different concentrations of these extracts were used to treat the seeds of green gram before sowing into the poly grow bags (16" x 16"), having sterile garden soil and sand in the ratio of 3:1 as potting mixture.

Four replicates (R1–R4) were employed for each of the four treatments (T1–T4), which included 0, 20, 50, and 100 percent extracts (v/v) for T1, T2, T3, and T4, respectively. In each treatment, 100 green gram seeds were steeped in these *Sargassum wightii* seaweed extract concentrations for two hours and overnight, respectively. In a poly grow bag, 25 seeds were planted for each treatment. On average, 25 green gram seeds weighed 0.785 grams.

The percentage of seed germination, plants root & shoot length, leaf number, stress tolerance ability, and phosphorus content of potting mixture after 21 days of growth were evaluated to test the potential of *Sargassum wightii* seaweed extract to be used as an organic input for crop production. pH and EC were determined by a digital pH and EC meter from Digitronics. The methods of Olsen et al 1954 [58] and 1965 [59] were followed for the determination of soil phosphorus. The collected data were analysed statistically using analysis of variance (ANOVA) at online available software [60].

RESULTS AND DISCUSSION

The absorption capacity of Green gram was observed to be different in different concentrations of *Sargassum wightii* seaweed extract T1, T2, T3, and T4. Fig. 1 shows the morphology of seeds after treatment of Green gram for 2 hrs and overnight in T1, T2, T3, and T4, respectively, whereas Fig. 2 shows the percentage increase or decrease in the rate of absorption in different treatments. Untreated T1 containing distilled water only showed a maximum absorption greater than any of the treatments, T2, T3, and T4, in both conditions, 2 hrs and overnight. There is a sharp decrease in the rate of absorption with the increase in concentration of *Sargassum wightii* seaweed extract. T2, that is 20% concentration of *Sargassum wightii* seaweed extract, showed maximum absorption 61.78% in 2 hrs and 153.50% overnight, whereas T3 (50 %), T4 (100%) showed 51.59% & 139.49 % and 47.77% & 121.66% respectively.

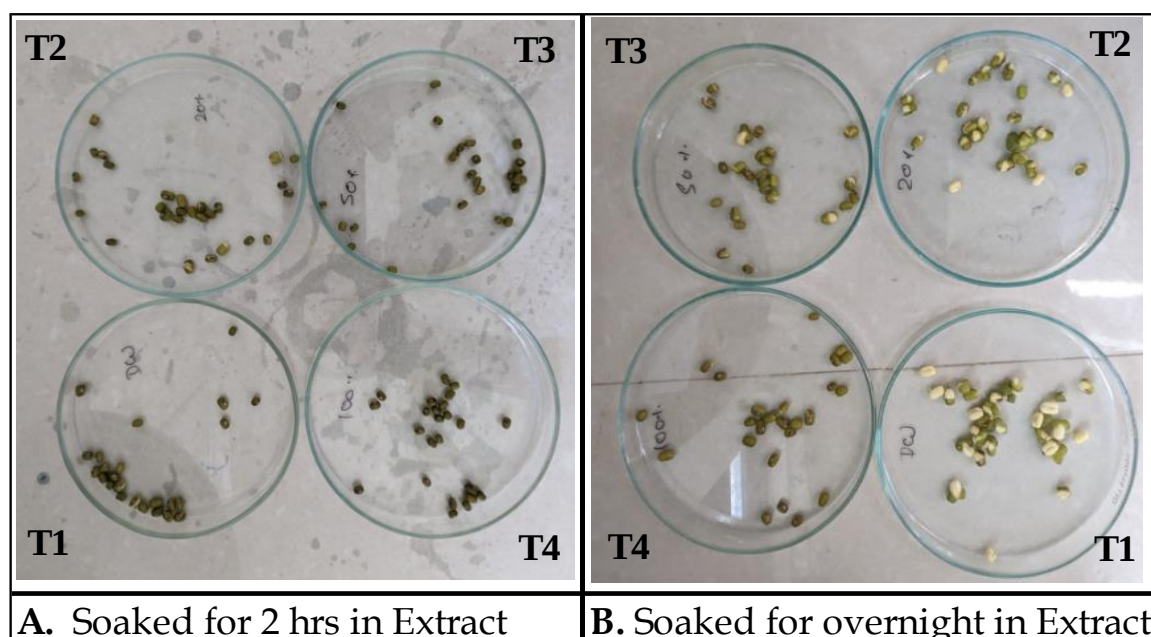


Fig. 1 Seeds of Green gram soaked for different periods: A. 2 hrs and B. Overnight, in different treatments of *Sargassum wightii* seaweed extract; T1 (Control), T2 (20%), T3 (50%) and T4 (100%).

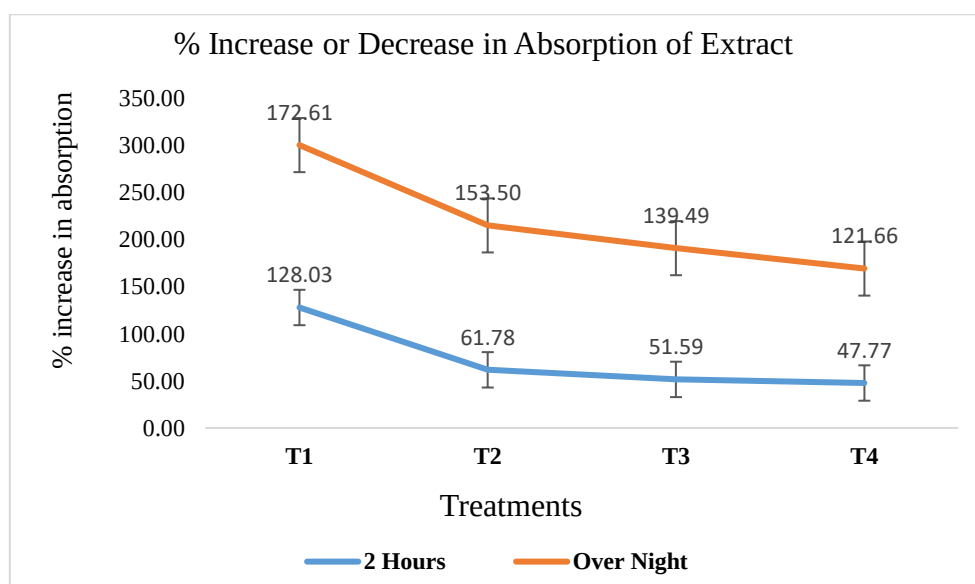


Fig. 2 The graph shows the percent increase or decrease in absorption of extract in different treatments: T1 (Control), T2 (20%), T3 (50%) and T4 (100%) in both the conditions of absorption for 2 hrs and overnight.

Green gram seeds of different treatments (T1, T2, T3, and T4, 2 hours as well as overnight soaked) were sown in the pot to see the effect of different treatments on germination. T2 treatment showed early and 100% (25 out of 25) germination in both the conditions 2 hrs & overnight after 9 & 8 days respectively, whereas in T1 100% (25 out of 25) was observed after 10 days in 2 hrs treatment, T3 and T4 had not shown 100% (25 out of 25) germination in both the conditions 2 hrs & overnight seed soaking. Maximum germination observed in T3 and T4 after 10 days of sowing was 92% (23 out of 25) & 76% (19 out of 25) and 76% (19 out of 25) & 52% (13 out of 25) in both conditions, respectively. Fig. 3 shows the effect of *Sargassum*

wightii seaweed extract on Green gram seed germination after 10 days of sowing in different treatments.

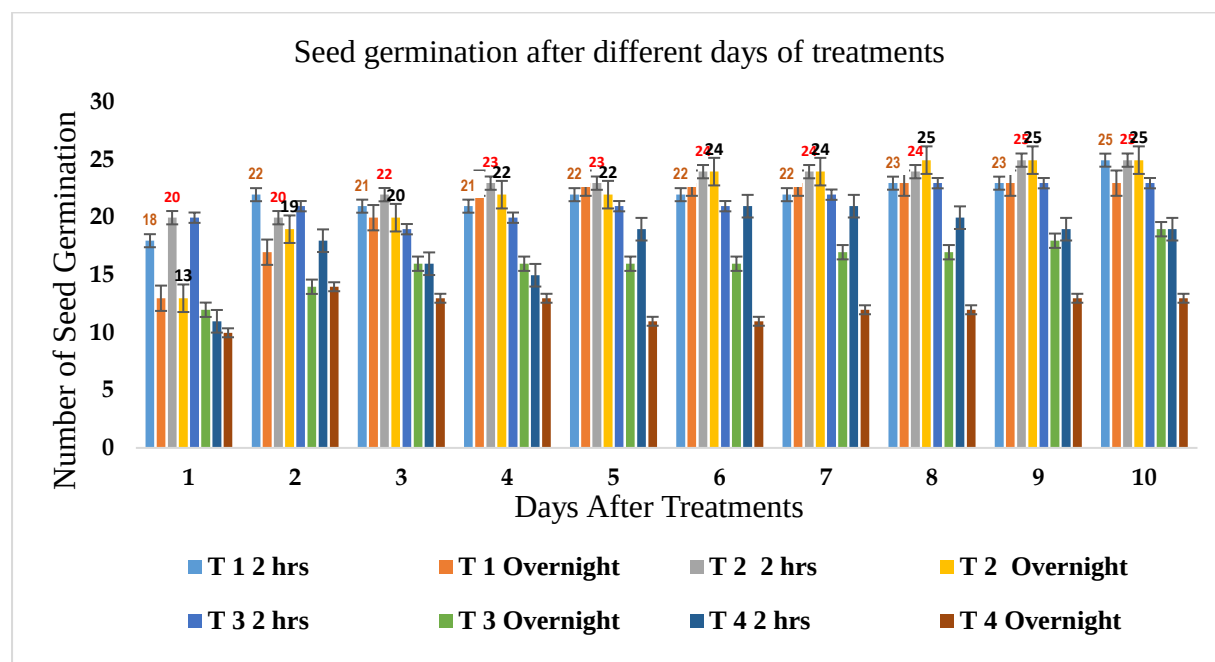


Fig. 3 The bar diagram shows the seed germination in different treatments of *Sargassum wightii* seaweed extract: T1 (Control), T2 (20%), T3 (50%), and T4 (100%) in both the conditions of absorption for 2 hrs and overnight. T2 treatment showed early and 100% (25 out of 25) germination in both conditions, 2 hrs & overnight after 9 & 8 days of sowing.

Several workers [11,31,61-68] have studied the effect of seaweed extract on the germination of seed but the results obtained were not common though the lower concentration promotes seed germination and higher concentration inhibits it but it varies from crop to crop and the nature of seaweed genus & species. Our results are similar to the results obtained by Ashok et al. [31], but there is a remarkable difference in concentrations, though the crop and nature of seaweed are the same (*Green gram* and *Sargassum wightii*). This may be due to the difference in the extraction process of seaweed. The effect of seaweed *Sargassum wightii* extract on plant biomass after 21 days of sowing in polybag pots is shown in Fig. 4. There was an apparent increase in biomass (root length & shoot length) of the plant in T2 in comparison with T1, T3 and T4 as shown in Fig. 5, however there were no remarkable change in number of leaf in any of the treatments. One-way ANOVA for independent measures, viz root length, shoot length, and leaf numbers, shows that the results are statistically significant at $p < 0.05$. The p-value is < 0.00001 .



Fig. 4 Growth of green gram plants after 21 days of treatments of *Sargassum wightii* seaweed extract: T1 (Control), T2 (20%), T3 (50%), and T4 (100%) in both the conditions of absorption for 2 hrs and overnight (Ov. N.). T4 and T3 have lesser number of plants than T2 and T1. Higher concentrations of *Sargassum wightii* seaweed extract (T4 and T3) are more susceptible to temperature burning & death of plants due to scorching summer than lower concentrations of seaweed extract (T2 and T1).

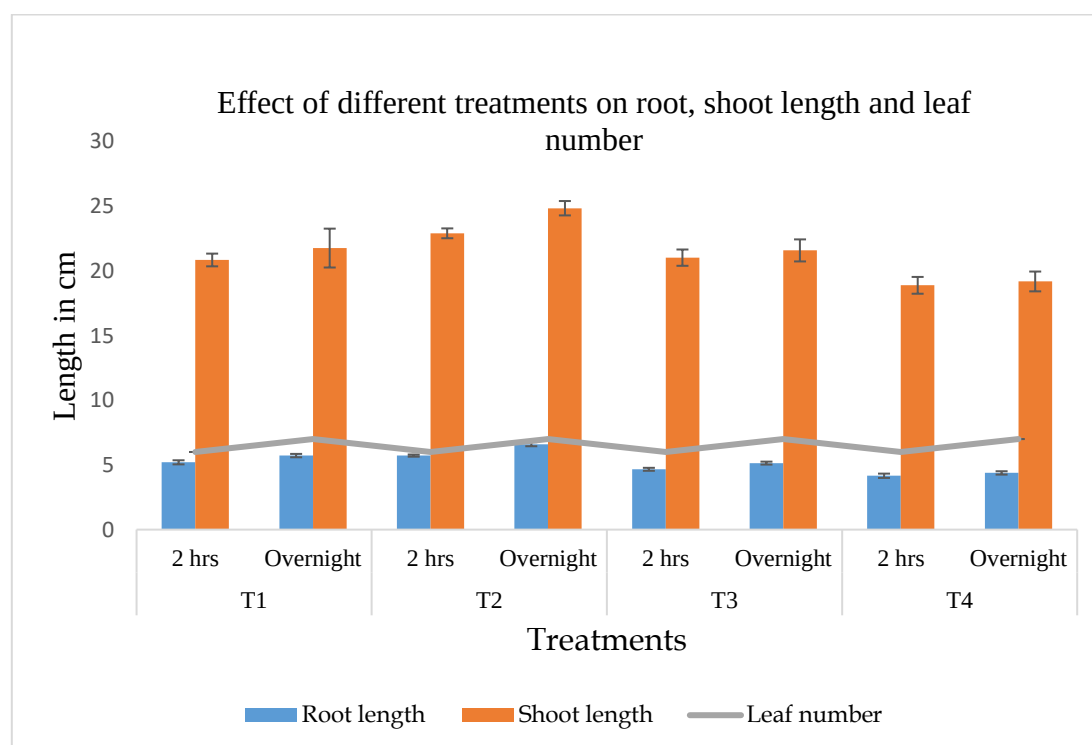


Fig. 5 The bar diagram is showing the change in biomass (root, shoot length and leaf number) in green gram plants after 21 days of treatments of *Sargassum wightii* seaweed extract: T1 (Control), T2 (20%), T3 (50%), and T4 (100%) in both the conditions of absorption for 2 hrs and overnight.

A similar observation was made by Jayachandran et al. [64] when they treated *Arachis hypogea* with different concentrations of liquid seaweed fertiliser obtained from *Hypnea musciformis*, where the length of root and shoot became progressively decreased with

increasing concentration of the extract. Sekar et al. [69] also reported a similar observation in *Vigna unguiculata* when treated with *Ulva lactuca* liquid seaweed fertiliser [good growth at low concentration (0.25%)]. Sylvia et al. [70] reported that higher dilutions of liquid seaweed fertiliser are more effective than lower dilutions. Ashok et al. [31] reported in green gram that when treated with *Sargassum wightii* Grev., the number of leaves was more only at 1.0% concentration in both foliar-treated and root-treated plants, whereas at 2.0% concentration, the number of leaves was reduced.

A slight increase in soil pH was observed as shown in Fig. 6 with increasing concentration of seaweed extract; however, there was no significant change in soil electrical conductivity (EC) as shown in Fig. 7 in different treatments. One-way ANOVA for repeated measures, viz pH and EC, shows that the results are statistically significant at $p < 0.05$. The p-value is < 0.00001 .

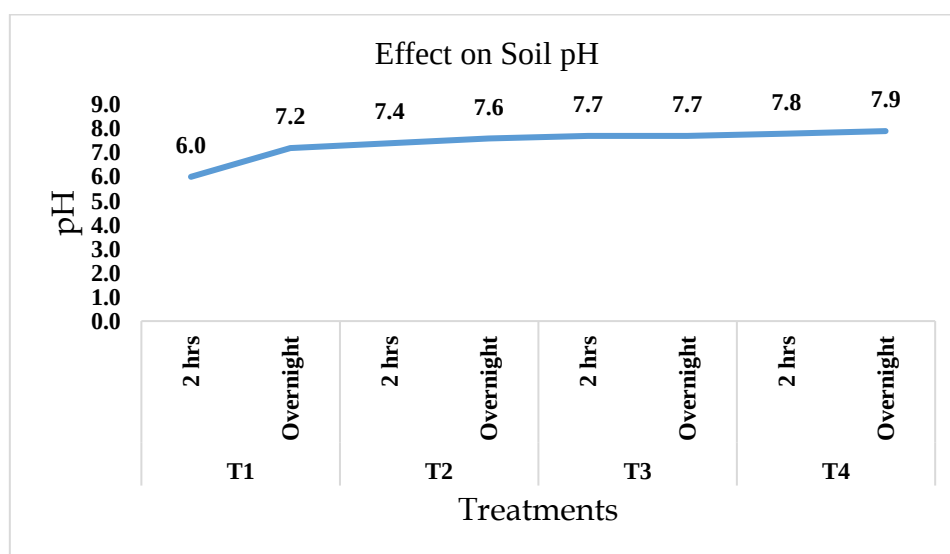


Fig. 6: The change in soil pH after 21 days of treatments of *Sargassum wightii* seaweed extract in green gram: T1 (Control), T2 (20%), T3 (50%), and T4 (100%) in both the conditions of absorption for 2 hrs and overnight.

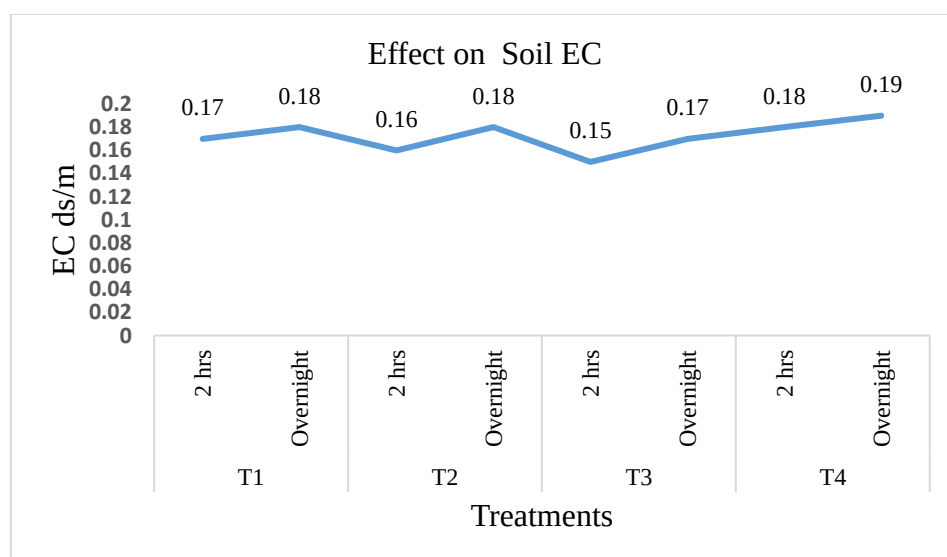


Fig. 7: The change in soil electrical conductivity (EC) after 21 days of treatments of *Sargassum wightii* seaweed extract in green gram: T1 (Control), T2 (20%), T3 (50%), and T4 (100%) in both the conditions of absorption for 2 hrs and overnight.

Seaweed extract can influence soil pH and EC to varying degrees, often leading to a more balanced and favourable environment for plant growth. The alkaline nature of seaweed extract can help neutralise acidic soils, while its impact on EC depends on factors like the specific seaweed species and application rate. Similar observations were reported by Kumari S et al. [71]. The concentration of available phosphorus in pot soil of different treatments is showing an increase with increasing concentrations of seaweed extracts T2 to T4 in both conditions, as shown in Fig.8. One-way ANOVA for independent measures, including Tukey HSD, shows that the results are statistically significant at $p < 0.05$. The p-value is < 0.00001 .

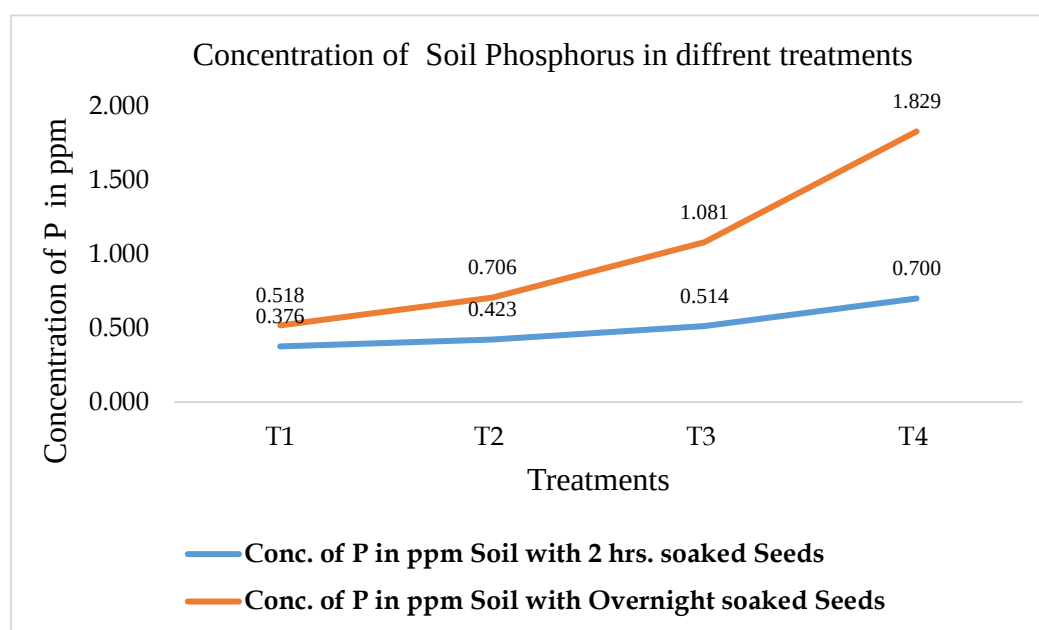


Fig. 8 Concentrations of soluble phosphorus in pot soil of green gram after 21 days of treatments of *Sargassum wightii* seaweed extract: T1 (Control), T2 (20%), T3 (50%), and T4 (100%) in both the conditions of absorption for 2 hrs and overnight.

Mario et al. [72] investigated the impact of seaweed on the availability of phosphorus and nitrogen in calcareous soils. They reported that seaweed application increased the levels of available inorganic phosphorus; our observations are similar to theirs. Seaweed extracts' impact on available phosphorus in soil is multifaceted, involving improvements to soil properties, stimulation of beneficial microbes, and potentially influencing phosphate binding, all contributing to increased phosphorus availability for plant uptake [9], [20].

During the period of experimentation, there was a change in environmental temperature due to the hot summer. The effect of temperature on plants was more pronounced in T4 and T3 than in T2 and T1. This shows that higher concentrations of seaweed extract are more susceptible to temperature burning than lower concentrations of seaweed extract, whereas the control plants were least affected by temperature effects. Some of the T4 and T3 treated plants were completely burnt due to scorching sun than the plants of T1 and T2, as shown in Fig. 4. This shows that high concentration of seaweed extract is more susceptible to heat shock, whereas at low concentration it may act as climate resilient as observed in the case of T2 treated plants. Seaweed extracts can enhance a plant's tolerance to temperature stress by improving its resilience and regulating stress-response genes. This is achieved through the presence of bioactive compounds like betaines and polysaccharides, which act as osmolytes and improve plant metabolism. These extracts can also boost antioxidant activity, helping plants cope with the oxidative stress caused by high temperatures [73].

In the present investigation, seeds treated with 20% (T2) concentration of seaweed extract increased germination, plant biomass, phosphorus availability, and imparted tolerance to environmental temperature due to the hot summer. This observation is in agreement with the earlier reports as per the literature survey presented in Table 1; however, it depends upon the types of seaweed extract, doses, method of application, and the crop types. It is very important to optimise to get the desired benefit. It was observed in the present study that apart from its normal benefit in the test plant, it also has a high potential to evolve as a climate resilient agent for the adoption in adverse abiotic & biotic conditions.

CONCLUSIONS

The results of this study showed that seeds treated with a 20% (T2) concentration of seaweed extract improved germination, plant biomass, and phosphorus availability. They also developed a tolerance to the hot summer temperatures. As the percentage of seaweed extracts increases, so does the amount of accessible phosphorus in the pot soil of the various treatments. There was no discernible change in the electrical conductivity of the soil, although there was a minor rise in pH as the content of seaweed extract increased. While seaweed extract served as a climate-resilient substance at low concentrations, as in the case of T2-treated plants, it is more vulnerable to heat shock at high concentrations.

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Author Contributions. The original and final versions of this manuscript were written by Nirmal S Sahay, who also conceptualised the study, designed the experiment, methodology and participated in data analysis. Yashwi S Soyantar executed the experimental work and collected the data. Bhargavi Trivedi took part in supervision & formal analysis. The final manuscript was read and approved by all writers.

Conflict of Interest. The Authors hereby declare that they have no conflict of interest.

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