Review Article

Seaweed Extract: Potential Applications in Fruit Crops

Abstract

Seaweeds are macroalgae growing under marine ecosystems and it plays diversified roles in human life. Different types of seaweeds are available and among them, thewidely used ones for extraction are brown seaweeds.One of the significant plants bio-stimulants with a wide range of applications in horticulture and agriculture is seaweed extract (SE).Various methods are employed fortheir extraction process. Thebioactive compositionof SEvaries according to the type or species of seaweeds and methods of extraction. It has got almost similar effects as that of phytohormones.Seaweed extract application alone or in combination with other bio-stimulants or nutrients during different crop stages are being practised ina broad group of fruit crops (temperate,sub-tropical and tropical fruit crops). It has proven significant improvements in growth, yield, quality, storage, and stress tolerance. An array of research studies have also revealed that the usage of seaweed extracts is more environmentally friendly owing to their organic nature and cost-effectiveness.It has proven significant improvementson growth, yield, quality, storage and stress tolerance. An array of research studieshavealso revealed that the usage of seaweed extracts aremore environment-friendlyowing to their organic nature and cost-effectiveness. Hence,the use of seaweed extract at the appropriate time and right concentration to a variety of fruit crops can support the industry's overall growth.

Keywords: Seaweed extract, Bio-stimulant, Phytohormones, Brown seaweeds, Growth, Yield.

1. Introduction

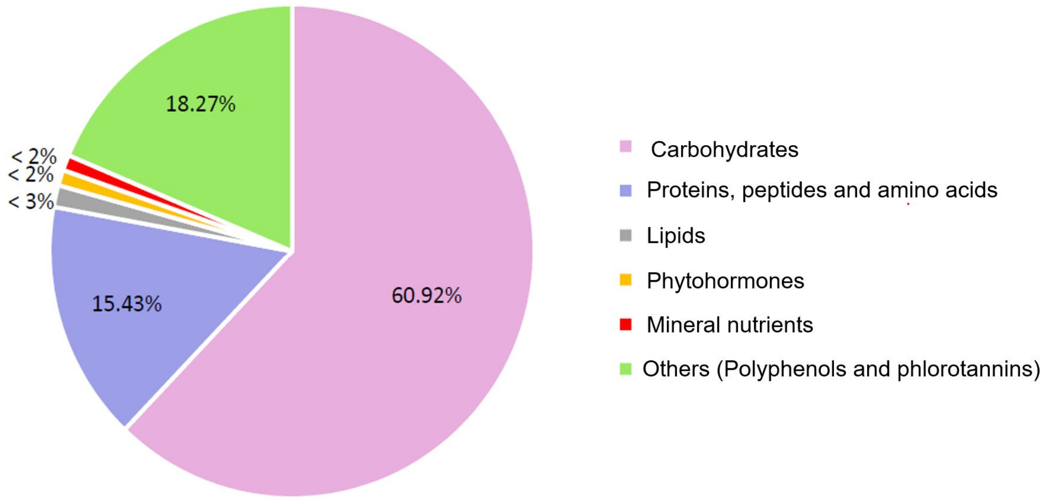
A plant biostimulant derived from marine macroalgae known as seaweeds is referred to as seaweed extract (SE).It is used for multifarious purposes in agriculture, food, medicine, cosmetics, textiles,colouring dyes etc. Variety of seaweeds have already secured their place in manifoldapplicationaround the globe and the products from SE are extremely versatile and are usedin different crops (Battacharyya et al., 2015). Seaweeds have been classified as Phaeophyta (brown), Chlorophyta (green) andRhodophyta (red), and among these Phaeophyta are being widely used for SE. Bioactive components in SE depend on the species of seaweeds and methods of extraction being employed. However, major constituentsare carbohydrates (60.92%) such as alginates, fucoidans, laminarans and lichenan. They aid in the stimulation of plant development and stimulate defence mechanisms in plants against bacterial and fungal infections.Proteins like histidine, isoleucine, and leucine are present in SE, along with lipids like glycolipids, betaine lipids, and non-polar glycerolipids, as well as good amount of mineral nutrients.Seaweed extract reminiscences the activity of phytohormones, at low concentration improves the growth and at higher concentration inhibits the growth processes. Brown seaweed extracts are abundant in secondary metabolites that are produced during stress, such as phlorotannins and polyphenols, which aid in the defence of cells and their constituent parts.

The SE is extracted by different methods of extraction such as enzymatic, ultrasound, water, acidic and alkaline, and among these, the most widely used extraction method is the alkaline extraction.According toEl-Boukhari *et al*. (2020)after the extraction process, SE is subjected to determination of phytotoxicity threshold followed byfirst screening of efficacy is done through seed germination assay. Further validation of SE is done by conducting greenhouse and field trials. Ali et al. (2021) state that the mechanism of action of SE is through activating Mitogen-Activated Protein Kinase (MAPK), which in turn activates transcription factors and defence genes.

Though methods of application of SE vary with species and stage of crop, the commonly followed methods are foliar application, fertigation, seedling root dip and seed treatment. Application of SE increases the activity of phytohormones *viz.*, cytokinins, auxins and gibberellins and can positively influence on stomatal conductance which in turnwill help the production of more chlorophyll thereby enhancing the rate of photosynthesis. It also boosts the soil activity which includes soil enzyme activity, microbial population, soil texture and water retention. SE induces tolerance in plants against biotic and abiotic stresses.Fruit quality and production increase as a result of all the aforementioned plant system actions (El-Boukhari et al., 2020).Numerous studies have shown that seaweed extracts can improve crop development and yield while also reducing the effects of a variety of abiotic stresses, like salt and drought(Craigie, 2011).

2. Type of seaweeds

Seaweeds have been classified as Phaeophyta-brown seaweeds, Rhodophyta-red seaweeds and Chlorophyta-green seaweeds, and among these Phaeophyta are being widely used for SE. The major species of seaweeds under Phaeophyta are *Ascophyllum nodosum, Ecklonia maxima, Fucus vesiculosus,Durvilleaprotatorum*etc. which are most frequently used for commercial extraction in industries. In the case of Rhodophyta,*Porphyra perforata, Gelidiumserrulatum, Acanthophoraspicifera, Gracilaria edulis etc.,* are being used and *Ulva lactuca, Enteromorpha prolifera, Caulerpa paspaloides, Codium tomentosum etc.,* are the major species under Chlorophyta (Ali *et al*., 2021).



(Ali *et al*., 2021)

Fig .1 Major bioactive components of seaweed extract (SE)

The types of seaweeds used and the extraction techniques used determine the SE bioactive components contents.However, major constituents are carbohydrates (60.92%) such as alginates, fucoidans, laminarans and lichenan.They aid in the stimulation of plant development and stimulate defence mechanisms in plants against bacterial and fungalpathogens infections.In addition, SE contains proteins (histidine, isoleucine, leucine *etc.*), lipids (betaine lipids, glycolipids, and non-polar glycerolipids) (Ali *et al*., 2021) and good amount of mineral nutrients (Ahmed et al., 2015).Seaweedextractscan reminiscent of the activity of phytohormones, at low concentration improve the growth and at higher concentration inhibit the growth processes.Brown seaweeds are used to produce seaweed extracts, which are abundant in secondary metabolites including polyphenols and phlorotannins that are synthesized under stress, which helps in protecting the cells and cellular components (Ali et al., 2021).

a. Carbohydrates

Major constituents of carbohydrates (60.92%) such as alginates, fucoidans, laminarans and lichenan, are assessed by HPAEC-PAD (High Performance Anion Exchange Chromatography-Pulsed Amperometric Detection). The viscosity of alginates, which are polymers of guluronic and mannuronic acids, vary according to the type of seaweed.It has been demonstrated that alginates encourage plant development(Yaburet al., 2007).Conversely, plant defence responses against bacterial and fungal diseases are recognised and reported to be elicited by laminarins(Mercier *et al*., 2001). Fucoidans are involved in antiviral and antioxidant activity. Lichenan possess the antiviral activity (Stubler and Buchenauer, 1996).

b. Proteins

In addition to carbohydrates, SE contains proteins in the form of amino acids andpeptides. These playsvarious roles in plants, like directs the signals, regulation of flowering and imparting stress defense.Even nitrogen is transported primarily in the form of amino acids in most of the plants. These are estimated by Accelerated Solvent Extraction (ASE) - protein extraction technique (Harrysson *et al*., 2018). Some amino acids playansignificant act in plant systems, such as histidine, which participates in acid-base catalysis and co-ordination of metal ions. Isoleucine enhances plant resistance against *Botrytis cinerea* via the jasmonate signalling pathway and also acts as a precursor for jasmonate and leucine showing stress response (Dufayard*et al*., 2017). Lysineregulates plant growth and responses to the environment (Galili, 2002), and Methionine is a special amino acid that contains sulphur and aids in the synthesis of numerous compounds in the body as well as proteins.This is a fundamental metabolite which controls the level of several key metabolites, such as ethylene, polyamines and biotin.

c. Lipids

Seaweed extract contain betaine lipids,glycolipids, and non-polar glycerolipids.These lipid forms have specific rolesin plant growth and development. Glycolipids act as receptors and help in cell aggregation and in achieving optimal efficiency of photosynthesis (Kalisch *et al*., 2016).Betaine lipids are involved in adapting to low temperatures and non-polar glycerolipids (neutral lipids) are implicated in membrane formation, caloric storage and crucial intracellular signalling processes. Lipids in SE are estimated by chloroform-methanol extraction method.

d. Phytohormone

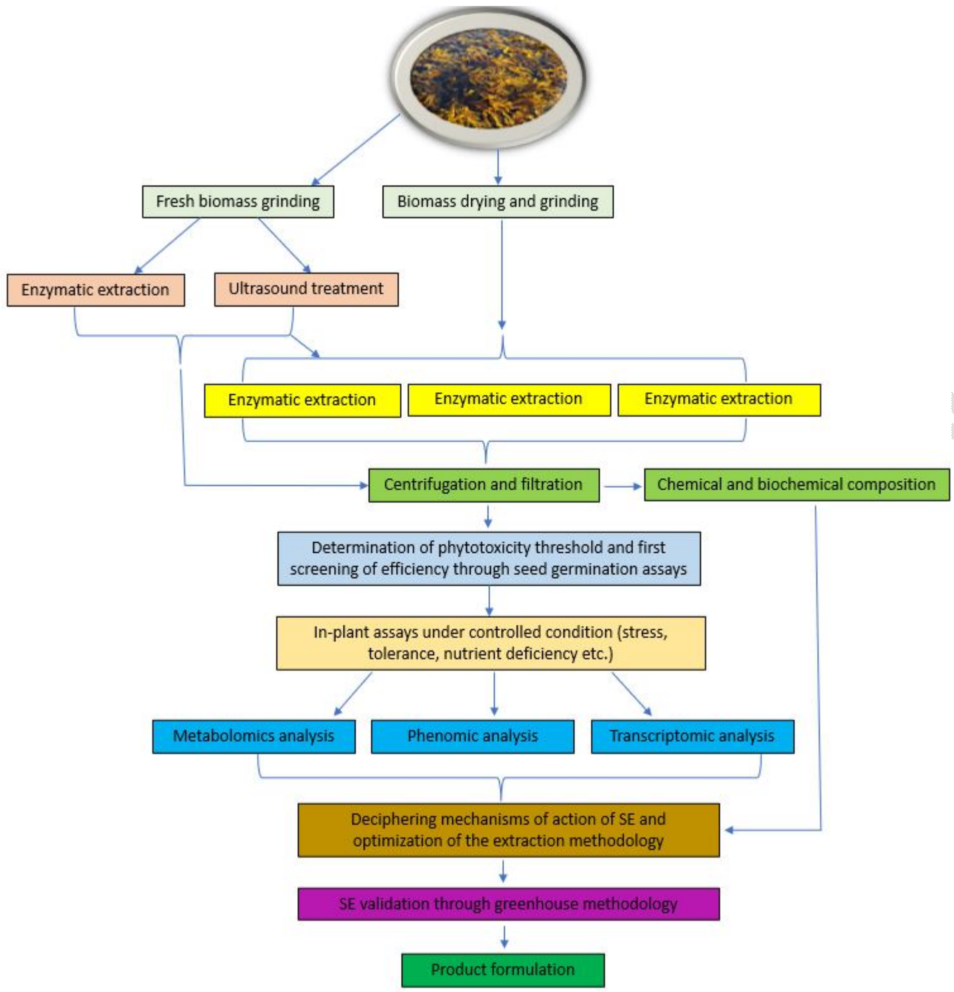
Phytohormones are present in very small quantities in SE and can be estimated by Ultra Performance Liquid Chromatography Mass Spectrometer (UPLCMS). The phytohormones present in SE are zeatin (0.5–50 ng/ml), BAP (0.5 -10 ng/ml), GA and kinetin (5–500 ng/ml),IAA and ABA (2.5–500 ng/ml). Activity of SE is similar to phytohormones at low concentrations improves growth and high concentrations inhibit growth (Khan *et al*., 2009).

e. Mineral nutrients

Good number and amount of nutrients are available in SE such asnitrogen-0.6%, phosphorus-6%, potassium-20%, magnesium-0.06%, calcium-1%, iron-0.3%, sulphur-1% and copper-30 ppm. These nutrients play crucial role in plant growth.Hence,the application of SE increases the nutrient availability and nutrient use efficiency (Ahmed *et al*., 2015).

f. Polyphenols and Phlorotannins

Estimation of polyphenols and phlorotannins could be done by High-Performance Liquid Chromatography (HPLC). Major polyphenols and phlorotannins are flavonoids,bromophenols, phenolic terpenoids, eckol,dieckol, and phloroglucinol (Ali *et al*., 2021). These are the stress-induced secondary metabolites that safeguard cells and their constituent parts. One significant function of phenolic compounds is their ability to scavenge free radicals and exhibit antioxidant activity.The concentration of total phenolics is high in brown seaweeds, including *Ascophyllum nodosum, Fucus vesiculosus,* and *Fucus serratus*. Metal ions get chelated by polyphenols (Battacharyya*et al*., 2015).

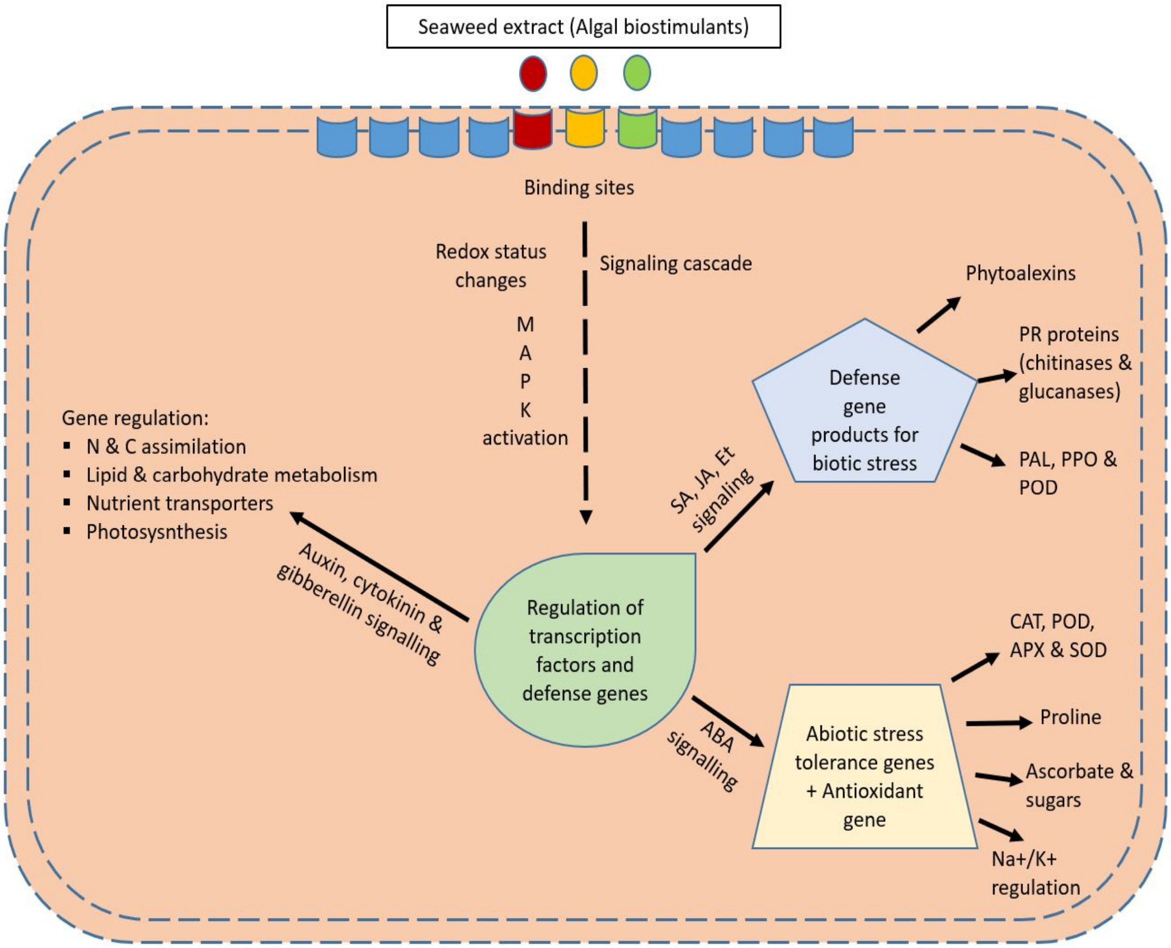


(Boukhari *et al*., 2020)

Fig .2 Flowchart for SE process

The SE is extracted by different methods of extraction such as enzymatic, ultrasound, water, acidic and alkalineextraction. Among these, themost widely used extraction method is alkaline extraction. After the extraction process, SE is subjected to determination of phytotoxicity threshold and then the first screening of efficacy is done through seed germination assay.later validation of SE is done by conducting greenhouse and field trials (El-Boukhari *et al*., 2020).

Fig .3 Mechanism of action of SE in systems of plant



MAPK- Mitogenactivated protein kinase

PAL-Phenylalanine ammonia lyase

PPO- Polyphenol oxidases

POD- Peroxidase

APX- Ascorbate peroxidase

CAT-Catalase

SOD - Superoxide dismutase

(Ali *et al.*, 2021)

Mode of bio-stimulatory activities at gene level

Upregulation genes by involvement of SE

- *Bn-Sultr4.1/BnSultr4.2* and*BnNRT1.1/BnNRT2.1*– Uptake nutrients enhancessuch as nitrogen, iron and sulphur.

- *GOLS2* and *GOLS3* – Enhancecarbohydrate biosynthesis.
- *DREB1A* and *COR78/RD29A* - Cold stress tolerance by cryoprotection of chloroplast and protein.
- *5CS1* and *P5CS2* – Increase proline biosynthesis.

Downregulation genes by SE

- *AtCLH1* and *AtCLH2 (*chlorophylldegradation genes) – inhibit the chlorophyll degradation
- *ProDH* (proline degradation gene) - inhibits the proline degradation

(Ali *et al*., 2021)

Table 1 :Methods of application of SE

Sl. No	Methods of applicatio	SE (Sagarika) dosage	Application schedule
1.	Foliar application	2.5 - 5 ml/L	Pre-flowering stage Post-flowering stage
2	Fertigation	2.5 - 5 ml/L	Initial and critical growth stages of crop
3	Seedling root dip	0.5 ml/L	Before planting
4	Seed treatment	1.0 ml/L	Before sowing

7. Positive impact of SE on soil and plant system

Positive impacts of SE on both soil and plant systems through its effects on phytohormones and plant physiology, soil activity, tolerance to biotic and abiotic stress, as well as improvement in yield and quality of fruits.

a. Phytohormones and plant physiology

Application of SE will increase the concentration of plant hormones which includes gibberellins,cytokinins, and auxins in the plant system and enhance the chlorophyll content. Furthermore, it also hastens the physiological processes like stomatal conductance and photosynthesis rate.

b. Soil activity

Soil application of SE promotes following the enzymes activity in soil.

- Hydrogenase catalyzes the reversible oxidation of H_2.
- Invertase is involved in metabolism, osmoregulation, development and defense system.
- Urease is effective in reducing nitrogen loss from soil.

- Proteinase mediates the hydrolysis of protein and proteolysis is an important process in the nitrogen cycle.
- Phosphatase is involved in the phosphorus cycle for acquiring phosphate ions.
- Increased microbial activity of proteobacteria, actinobacteria and cyanobacteria (Lovdal*et al*., 2021).

c. Tolerance to biotic stress

Seaweed extracts from *Ascophyllum nodosum*, *Sargassum wightii*, *Padina pavonica*and *Laminaria*spp.haveshown significant insecticidal properties.The decrease in infestation was brought about by the pests' cytotoxicity on their ovarian tissue cells, growth inhibition, and antifeedant actions.It acts as a trigger for the defence mechanisms that plants have against dangerous bacterial, fungal, and even viral infections.Application of SE inducessystemic type of acquired resistance in plants and enhances soil suppressiveness by increasing microbial dynamics (Ali *et al.*, 2021).

d. Tolerance to abiotic stress

Abiotic stresses factors like salt, high temperature, drought, and freezing conditions will hinder theproductivity of crop. The plant system damagedby abiotic stress builds up due toreactive oxygen species (ROS) which. SE treated plants can withstand the damaging effects caused by abiotic stress (Ali *et al*., 2021).

e. Yield and fruit quality

Using SE improves yield cum fruit quality by positively influencing the Total Soluble Solids (TSS), vitamin C, fructose, anthocyanins, antioxidants activity, and total phenols of the fruits (El-Boukhari et al., 2020).

8. Potential applications of SE on fruit crops

Use of SE has been reported to perform a vibrant role in the growth as well as overall development of horticultural and agriculturalcrops. The quality of fruits produced by the fruit crops been enhanced by different types of SE application and had been justified in a variety of fruit crops, as discussed below.

Mango

Application of seaweed extract at 2 percent in combination with 5 percent garlic extracts or10 percent roselle, or alone had been provedto have positive influence on vegetative growth, leaf major nutrients likenitrogen, phosphorus and potassiumcontents, which results enhancement of fruit set followed fruit retention, yield as well as quality of mango cv. Fagri Kalan (El-Sharony et al., 2015).Seaweed extract application by foliar spray at 3 mlL^{-1}documentedthe morenumber of leaves (10.77 leaves per plant), maximum plant height (26.38 cm), leaf nitrogen content (1.153%) and IAA content of leaf in mango(43.82μg g^{-1} fresh weight) (Almashhadani*et al.*, 2020).

Carotenoids and photosynthetic components were enhanced in conditions of water deprivation by the extract supplication of marine algae Ascophyllum nodosum and proline, leads toaccumulation of more amount of carbohydrate and favouringmaturation of shoots. Higher blooming and production as well as an increased ability of mango to withstand the negative impacts of water scarcity in semi-arid locations were the outcomes of these physiological alterations(Cunha *et al*., 2022).When applied before storage, extract of *Ascophyllum nodosum* directly affected the physicochemical characteristics of Tommy Atkins mangoes. Loss of fruit mass was reduced, extended the fruit's shelf life, shelf life of fruits got maintained pulp firmness, colour of pulp, pH and acidity (Melo *et al*., 2018).

Banana

Karthikeyan and Shanmugam (2014) reported that foliar application of 5% SE (Aquasap) on four varieties of banana such as Robusta, Njalipoovan, Red Banana and Nendran,at 3rd month (juvenile phase), 5th month (bud differentiation stage and flowering) and 7th month stages of planting resulted in increased yield an averagely of 56.58, 19.08, 39.35and 11.46percent respectively. The GrandNaine banana plants recorded the good outcome in terms of yield, bio-chemical properties of fruits when the plants were sprayed with a combination that contained 0.05% seaweed extract and potassium silicate in the mid of April, May, June, and also July (Roshdy, 2014).When a solution comprising 100 parts per million of glutamic acid, 0.1% part seaweed, and 100 parts per million selenium was sprayed for four times (mid-April, May, June, and July),superior results were obtained in terms of vegetative growth, yield and quality properties Grand Nainevarietyof banana fruits of (Eisa *etal*., 2023).The seaweed bio-formulation LBS6S@1 mlL^{-1} had done the best with respect to the yield and yield components as well as quality criteria of Grand Naine (AAA) (Ravi *et al*., 2018).

Significant improvements were observed in the vegetative growth (as measured bynumber of leaves per plant, leaf area,pseudostem girth, and pseudostem length) as well as the chemical constituents of the leaves (percentage of potassium,nitrogen, phosphorus, and magnesium), bunch weight, weight offinger, and fruit physical parameters (fruit dimension, fruit weight, andpulp:peel ratio) and chemical properties (total sugars, TSS, and total acidity) when humic acid at 0.5to 2.0 percent and seaweed at 0.25 to 0.75 percent was sprayed on Williams banana plants. In every examined character, the combination application of seaweed and humic acid proved to be more efficient than the use of each constituent separately (Gomaa and Ibrahim, 2020).

Lemon

In lemon, combined application of seaweed extract at 30 ml with copper sulfate at 15 mlL^{-1}resulted in maximum plant height, diameter ofstem, leaf area, length ofroot, and leaves chlorophyll content (Almoussawi and Al-Abbasi, 2023).

Mandarin orange

Four sprays of liquid potassium 2%, micronutrients 3%, and seaweed extracts to Balady mandarin trees through spraying 2.0% at full flowering, the first week of July and September, right after just fruit set, had resulted increase in fruit quality and quantity (Mohamed *et al*., 2022). In comparison of recommended dose nitrogen via mineral-nitrogen source only, the highest values for Balady mandarin charactershad been recorded on trees that were fertilised with the triple form (33% mineral nitrogen, 33 g humic acid, and 33 g seaweed extract). These trees also showed improved quality of fruit in terms of increasing pulp percentage, fruit weight, sugar, total soluble solids, and vitamin C, as well as reduced the total acidity (El-Salhy*et al*., 2017).

When Navelina orangeand'de Nules' clementine mandarintrees weresupplementedby a combination of *Ascophyllum nodosum*seaweed extract from at 0.15% to 0.30% and gibberellic acid (GA_3) at 6 mg L^{-1} duringinitial bud sprouting andpeak bloom, in addition at the end of the June drop, increased yield by 41% was obtained (Fornes *et al*., 2002).

In an experiment, cultivars of citrus*viz*., "Feutrell's Early" "Kinnow," Mandarins, as well "Blood Red" were sprayed by foliar meansat 0.5 mL L^{-1} "Primo" (seaweed extract (*Ascophylum nodosum)*+ amino acid + 0.01% "Tween 20") in three different locations including exogenous supplementary application. Primo at 0.05% applied at the peak bloom andstage offruit setting of Kinnow resulted in a significant increase infruit size (11.5%), marketable fruit (9%), Soluble Solids Content (SSC) (16%), SSC:TA ratio (26.8%), ascorbic acid (21.8%), reducing sugars (37.5%), total phenolic contents (42%), height oftree (28.5%), fruits tree^{-1} (28.6%),fruit weight tree^{-1} (42.6%), and total marketable fruit (9%), in contrast to untreated control trees. Similarly, Primoat 0.05% sprayed to 'Feutrell's Early' mandarin trees during full bloom and fruit setting stage showed an increase in leaf N (27%), Zn (26.4%), Fe (11.9%), fruit weight tree^{-1} (28.5%), fruits tree^{-1} (40%), marketable fruit (12.7%), fruit size (15.9%), juice weight percentage (17.6%), taste (23%), SSC (15.7%), and total sugars (42%) against the control. The same treatment *i.e.* 0.05% Primowhen sprayed to trees during full bloom and fruit setting, produced the highest levels of leaf N (50%), Fe (15%), tree height (37%), leaf size (38.8%), fruit weight tree^{-1} (42%), number of fruits tree^{-1} (45%), total marketable fruit (8%), percentage of juice weight (15.6%), reducing sugars (45%),SSC (19%), SSC:TA ratio (43.8%), and contents of total phenolic (28%) in comparison with control in the case of "Blood Red" oranges(Khan *et al*., 2022).

Sweet orange

The varieties of Washington navel and Valencia orange trees had been applied with seaweed extract during two stages of the season *i.e.,* prior to flowering and subsequent to initial fruit set.The results obtained were improved leaf surface area, shoot length, and initial percentage offruit set. Additionally, there was hiked yield per tree, enhanced fruit quality, improved the contentleaf minerals,fruit drop has reduced in June,with highest net profit when compared to the control treatment. (Hikal, 2015).

Pomegranate

When pomegranate trees were sprayed with seaweed extract (Alga300) @10 mg/L anotable increase was observed in majority of the growth and yield parameterssuch as leaf area, average size of fruit and weight of fruit, mean number of fruits, TSS%, and yield tree^{-1}, (Hussein *et al*., 2021).The maximum yield from 41.97 to 51.61%, in addition the exportable grade fruitsincreased by 23.08–33.38%. An improved quality attributes such as anthocyanin,ascorbic acid, protein,non-reducing sugar, and minerals of fruits via enhancementfertility of soil and status of trees micronutrient, were recorded by combining application of 5 kg ha^{-1} microbial-based product Aand 625 ml ha^{-1}seaweed extract based liquid formulation B, as well 1-2 g L^{-1}foliar spray of wettable granular formulation seaweed extract C with Chemical fertiliser (Maity et al., 2024).

The treatment containing Kelpak extract 6 $mlL^{-1}$and chelated iron 250 mgplant^{-1} was found to be significantly superior for the vegetative characteristics as represented by leaf area (6.65 cm^2), length of the new growth (20.14 cm), dry weight of leaves (68.74g)and concentration of chlorophyll (71.22 mg per 100 g fresh weight) when comparison to control (Neamah*et al*., 2021).

Maximum values on the various parameters of the seedlings as well as a hike in theleavesdry matter content and chlorophyll were achieved by spraying pomegranate seedlings with a 50 mlL^{-1} concentrated seaweed extract water solution (Radhi and Ridha, 2022).

A positive significant shift was observed during propagation studies of pomegranate in various parameters such asnumber of shoots, leaf area, number of leaves, length of roots, and number of roots, when foliar spray of Alga 600 was given in combination with peatmoss as the growth medium (Salih *et al*., 2023).

The extracts of marine algae at 4 ml L^{-1} and fertiliser of NPK at 400 $kgha^{-1}$ produced the highest values for all traits which includedlength and diameter of seedling, leaf area, number of leaves, dry and fresh weight of vegetative shoot, and leaves total chlorophyll contentin pomegranate (Al-Abbasi, *et al*., 2019).

Grapes

Astudy conducted at four locations of three Australian states using four cultivars, demonstrated that recurrent soil application of extract of seaweed through drip irrigation markable enhancement in yield of wine grapes by an average of 14.7% (Arioli *et al.,* 2021). Research carried out by Ahmed *et al*. (2015) had recorded highest leaf nutrient status and fruit quality attributes in Taimour mango variety when SE was applied @ 8%. The results of another study which examined the influence of three concentrations at 0.25, 0.5, and 0.75 $gL^{-1}$of extract of seaweed on two different grapes varieties showed that the concentrations of 0.75 gL^{-1} had the good impact on the performance of the vine, titratable acidity (TA), vitamin C,and soluble solids content (SSC) (Abo-Zaid *et al*., 2019).

Vines of grapes treated with many applications of a concoction of seaweed extract and amino acids at flowering, fruit set, and month later stages of fruit setting showed remarkably higher chlorophyll content (18.15 mg g^{-1}), leaf size (41.5%), berry set (6.66%), rachis length (13.5%),number of bunches per cane (6.66%),berry size (7.33%), berry weight (14.78%), soluble solid concentrations (SSC)(16%), SSC:titrable acidity (TA) ratio (29), pH of juice (3%), reducing sugars(28%) and total sugars (35%) with decreased berry drop (10.6%) and ascorbic acid (28.6%) (Khan *et al*., 2012).Seaweed extracts from *Hypneamusciformis,Ascophyllum nodosum, Sargassum vulgare* and *Lithothamnium*sp. applied at 0.6% has been proved to have positive influences on the nutrient content ofleaf such as K, Mg, B, Cu, and Zn, net photosynthetic rate, water use efficiency, stomatal conductance, and yield of table grapes cv. Niagara Rosada (de Carvalho *et al*., 2019).

Brown seaweed*Ascophyllum nodosum*has reported to produce a bio-stimulant that had been used to improve fruit quality and ripening dynamics in wine grapes. Multiple seaweed extract applications had been documented very productivein enhancing grapes quality for the preparation of high-end red wines(Frioni *et al*., 2018).Applications of seaweed extract to grapevines increased the number of stilbenes in grapes regardless of season but their effects on phenolic compounds in the grapes as well as wines were found to be highly dependent on the season andwith the colour intensity(Garde-Cerdan *et al*., 2021).

Guava

Combined spray of seaweed extract at 15 mg $L^{-1}$and GA_3 at 3mg L^{-1}had recorded maximumbeneficialinfluenceon improvingtotal chlorophyll,vegetative attributes, fruit set percentage, yield, and total soluble solids (TSS). Furthermore, it surged K,N, and P in the leaves in both seasons, as contrast to control and the remaining treatments (Harhash*et al*., 2019).Vegetative growth of guava plants had been increasedmarkablein terms of height of plant, leaf area, leaves per plant, new shoots, diameter ofstem, chlorophyll of content leaf, and mineral contents of leaf (N, K, P, Mg, Ca, Fe, Mn, Zn,and Cu) when fertilizer was applied at half the recommended dose and algae extracts were sprayed on the leaves (Farag *et al*., 2023).

The combined soil application of seaweed extract (SE) and fulvic acid (FA) had significant effect onpositive benefits on length of shoot, diameter of shoot, leaf area, total chlorophyll content leaf and also yield contributing parameters such as fruit set percentage, tree yield and productivity per hectare.In addition, fruit chemical and physical characteristics of fruits such as weight offruit, firmness, volume, TSS%, content of juice, total, nonreduced and reduced sugars, and vitamin C, with reduction in percentage of fruit acidity when compared with control during theseasons of experiment(Mosa*et al*., 2021).Harhash et al. (2019) found that the Maamoura guava cultivar exhibited the highest concentration of vitamin C and non-reducingsugars by the influence of SE.

There was beneficial interactive effect was observed between bio-fertilizers and bio-stimulantsas they influenced significantly on yield parameters of guava. One of the twelve treatment combinations was the application of seaweed extract (75 g $tree^{-1}$)+ phosphate solubilizing bacteria (50 g $tree^{-1}$) +B3S3-Azotobacter (50 g $tree^{-1}$) recorded fruit retention (54.95%), maximum fruit set (56.68%), fruit weight (180.69 g),fruit length (7.12 cm), fruit diameter (7.14 cm), yield pertree (4.51 kg) andyield perhectare(22.56 t) (Sandhyarani*et al*., 2022).

Papaya

seaweed extract (Agazone) andAmino acid (tryptophan),in higher concentration of10 ml $L^{-1}$and 100 mg L^{-1}respectively,improved the characteristics of vegetative growth such as diameter of the stem, stem height, leaf area, number of leaves, wet weight anddry weights of vegetative growthwhen sprayed during papaya seedlings stage (Morales-Payan and Stall, 2005).In papaya cv. Red Lady, the use of 4% of seaweed extract and 0.4%potassium silicate was documentedthe more productivecombination in decreasing physiological lossof weight, shelf life extension, and enhancement of fruit firmness (Patel *et al*., 2020).Machado et al. (2014) reported on the possible use of seaweed extracts as a good source of antifungal agent to prevent anthracnose in papaya and banana during storage with minimal adverse effects on fruits.

Sapota

Christian et al. (2022) discovered that enhancement in the number of flower buds, improve fruit sets, and retention, and also to shorten the development periods in sapota cv. Kalipatti by application of seaweed extract.

Date palm

Spraying urea and seaweed extract was found to bea useful way to nurture the Zahdi variety of datepalm. It helps date palm trees to grow more quickly and to have a higher biochemical composition. For increase thegrowth of the trees of date palm cultivar Zahdi in a complimentary and efficient manner, a spray of seaweed extract and urea can be administrated(Murad and Al-Dulaimy, 2021).

According to Hashmi (2022), use of7 ml $L^{-1}$of seaweed extract was found significantlyon majority of the properties that were tested in dried fruits of date palm, such as the size, length, and colour of the fresh date fruits with notably higherin total soluble solids percentage, sucrose, and whole sugars.

Merwad*et al*. (2019) reported that seaweed extract combination sprays were found to be fruitful rather thanonly combined use of boric acid and zinc sulphate sprays.During pollination and a month later, spraying bunches of Barhee date palms with a solution of 1000 ppm zinc sulphate, 1000 ppm boric acid, and 1% seaweed extract produced the best fruit quality and yield.

According to Anli *et al*. (2020), in date palmstreated with AMF (arbuscular mycorrhizal fungus), SE (seaweed extract), and AMF+SE increased the photochemistry of PSII (Fv/Fm)quantum yield. Fibre of sclerenchyma counts rose by 681, 164, and 154percentage in the AMF+SE, SE, and AMF treatments, respectively, whereas the SE alone treatment recorded in a 24% rise in vascular bundle counts against to the control. Finally, the results showed that SE or

AMF, and particularly their combination, had a congenial impact on date palm overall growth. Increased xylem and phloem vessels could enhance nutrient, and water uptake, photosynthetic production, and phytohormone interaction between aerial and root parts of plants (Konrad *et al.*, 2018).

Fig

Al-Hameedawi and Al-Malikshah, (2017) found that foliar spray treatment of a combination of seaweed extract amino acids, and grapes bleed improved thegrowth and fruit attributes as well as the fruits quality in fig trees cv. Aswod Diala.

Litchi

The best nutrient and bioregulator from among the different treatments under study were observed to be 0.3% borax, 0.1% SE (seaweed extract), and 1% HA (humic acid). This treatment was suggested as a recommendation to enhance the quality yield characteristics of Bombai cultivar of litchi (Nayak *et al.*, 2024).

Loquat

Highest values of the vegetative growth contributing characters in loquat, i.e.height of plant and main diameter of stem had observed whenthe trees were foliar application byKelpak (seaweed extract) at 1:250 (seaweed extract: water) (Al-Hawezy, 2014).

Kiwi fruit

All biochemical measures, including sugars, ascorbic acid, titratable acidity, and soluble solid content, were found to be better when kiwi fruits were subjected tothe dip treatment using SE at 3000 ppm for 10 days later fruit setcompared to the fruits supplementedby CPPU (N-(2-Chloro-4-pyridyl)-N′-phenylurea). Seaweed extract treated fruits were harvested three to six days earlier than the control group (Rana *et al*., 2023).According to Ghafouri *et al*. (2024), a brown macroalgal extract at 3 gL^{-1}had the potential to improves the Hayward kiwifruitsquality. According to Dutta *et al*. (2023), seaweed extract and humic acid were effective alternatives to synthetic hormones in promoting the growth of the shoots and roots of kiwifruit cuttings. Ghafouri and associates (2023) found seaweed extract to be highly beneficial for growth and also for the environment where kiwifruit cv. Hayward was grown. Application of SE during storage resulting in significant improvement in firmness, improvement in weight of fruit, nutrients, and antioxidant properties.

Avocado

Saline stress impact on height of plant in avocado mitigated within thirty days of the stress treatment impositionby the administration of seaweed extract (Bonomelli*et al*., 2018).As per the Arioli *et al*. (2024), application ofextract of seaweed through fertigation greatly increased avocado yield by 38%, hardiness of fruit skin by 4% and flesh by 22%, colour of fruit (hue) by 1°, and enhanced the score of visual maturity. An increase in yield was observed (42% more fruits produced per tree)byliquid seaweed extract application. According to this finding, the seaweed extract might be contributing towards the enhanced yield in avocado through influencing the physiological mechanisms to reduce fruit and flower abscission.

When combined with the application of conventional fertilizer, Morales-Payan and Candelas during the year 2014 reported that foliar six sprays of a *Ascophyllum nodosum*algal extract at 4 L ha^{-1} enhanced the avocado fruits number(cv. Butler) that are remainedin tree.El-Shamma *et al*. (2017) demonstrated that the yield of avocado fruit (cv. Fuerte) increased by mean of 30% when administered bysoil application of seaweed extracts from *A. nodosum,Sargassum* sp., and *Laminaria* sp.combined with a microbial bio-stimulant.

Kair

Ahlawat *et al*. (2022) found that suplementation of*Ascophyllum nodosum* seaweed extract in absence of plant growth hormones at a higher dosage at 2000-5000 µl per litreoutcomed in faster germination and shoot initiation inkair(*Capparis decidua*).

Strawberry

According to El-Miniawy*and* co-workers (2014),the treatment of strawberry cv. Sweet Charlie plants using seaweed extract hasincreasedhardness of fruit by 13.33%, weight offruit by 20%, and plant yield by 21%over control.Ashour *et al*. (2022) documented that there was improved in fruit weight, yield, and leaves chlorophyll content in strawberries when extract ofseaweed was supplemented.Applications of 'Actiwave' a bio-stimulant made up of seaweed extracts, enhanced the photosynthetic rate, stomatal density, leaf chlorophyll content, vegetative development, production of fruit and weight of berry. The overall noteworthy outcome was the rose in plant biomass, which included an increase in root dry matter (76%) and dry matter of shoot (up to 27%). The studies further demonstrated that Actiwave® had a favourable impact on microbial biocoenosisassociated with roots as well (Spinelli *et al*., 2010).

The treatments of bio-stimulants (conjugation of aextract of seaweed along with a commercial form of nitrophenolates) enhanced the productivity of plant as resultsmore marketable yield, with absence of any negative impact on fruit quality attributes (Roussos *et al*., 2009). According to a study, soluble *Ascophyllum* extract powder treatments were enhanced the yield of berries, microbial diversity of rhizosphere, and berries physiological activity (Alam *et al*., 2013).

According Rana *et al*. (2022),apply of seaweed extracts during before flowering and at the time of fruit set period boosted flowering characters and production of runnersin strawberry. Additionally, seaweed extract treated plantsat 1.0–1.25 ml L^{-1} showed maximum total yield and superior fruit quality attributes during the ahead of flowering and fruit set stages. Al-Shatri*et al*. (2020) found that a 8 gL^{-1} of seaweed extract was recorded more efficient in enhancing the overall growth, flowering, and yield attributes of strawberry cv. Albion.

Two strawberry cultivars, Camarosa and Nabila, benefited greatly from foliar sprays of 2.0 ml L^{-1} HA (Humic Acid) along with 1.0 ml L^{-1} SE. This resulted in significant increase in the spread of plant, leaves number, crowns count, leaf area, petiole length, total flowers, fruits, weight offruit, length of fruit, and whole fruit yield when compared to plants of control (Chakraborty *et al*., 2023).

Apple

By applying seaweed extract to apple trees, the meanweight offruit enhanced and also the yield oscillations between "on" and "off" years were reduced. Additionally, SE treated trees had higher leaf chlorophyll concentrations (increase of 12%), which led to better rates of respiration and photosynthesis (Spinelli *et al*., 2009).Usage of seaweed extract enhanced the growth of 'Jonathan' trees ofapple by increasing leaf area, chlorophyll content, and photosynthetic rate (Soppelsa*et al*. 2018).During the experimentation seaweed extract enhanced the red colour of apple peel by inducing anthocyanin production (Malaguti *et al*., 2002; Soppelsa*et al*., 2018).

Size together with red colour in apple were improved by foliar spray of seaweed extract-based products like Kelpak® and Goemar BM 86® (Basak, 2008).Beneficial effect was recorded by seaweed extracts on the fruits per tree, average fruit weight, percentage of bigger fruits (larger than 7.5 cm in size) in apple var.Golden Delicious compared to the control (Kaplan et al., 2023).According to Augusto *et al*. (2016), seaweed extract was superior to other treatments, in terms of citric acid, preserving the freshness and reducing browning of freshly cut fruits of apple.

The diameter offruit, shape, and weight showed substantial improvements after seaweed treatment, although the contents of microelements remained unchanged from the control. Fruit yield and marketability apple were generally influenced by seaweed extracts (Tamas *et al*., 2019).

Seaweed extracts (*Ascophyllum nodosu)* and Thidiazuron were applied directly to apple cv. Gala at doses of 0.1, 0.2, 0.3, 0.4, and 0.6%. High concentrations of seaweed extracts improvedthe number offruits, , yield per plant, mean fruit weight,seeds per fruit, fruit diameter and length, length to diameter ratio, soluble solids, firmness, and fruit growth (Ayub *et al*., 2019). Additionally, they claimed that seaweed extract from*Ascophyllum nodosum* worked better than Thidiazuron.

The amount ofnitrogen, iron, phosphorus, chlorophyll a and b contents, relative water content, size of fruit, and yield were reported to increasein apple cultivar 'Golden Delicious' after the administration of seaweed extract (Mousavi *et al*., 2024).According to Bradshaw *et al*. (2013) the spray of algae extracts Seacrop16 and Stimplex, from the seaweed *Ascophyllum nodosum*, had a major influence on the vegetative development of apple trees.

Peach

The impact of seaweed extracttreatments extracted by*Ascophyllum nodosum* on peachtrees were examined by Colavita *et al*. (2010). They observed that the fruit diameter, weight, and size were not significantly affected by first treatment, which involved spraying the solution at the stages of budinitiation, full bloom, and petal fall, and the second treatment spraying solution at peak flowering, flower fall, and initial development offruit stage had a substantial impacted on growth and development, but the amount of chlorophyll did not differ significantly. Their results showed that in the first treatment, the yield was improved by 4-5%, and in the second treatment it was 7-9%.Mannino et al. (2022) examined the outcome of yeast and seaweed extracts on two *Prunus persica* L.varieties. Findings showed reduction in ripening time, enhancement in secondary metabolism, and increased nutraceutical and antioxidant properties, particularly in the peel.

Apricot

During a two year study, in comparison to the control trees during both experimented years, the spraying of humic acid (HA) at 2000 mgL^{-1}, brassinosteroid **(**BR) at 2 mlL^{-1}, and SE at 3000 mgL^{-1} constructively enhanced the length of shoot, leaf area, chlorophyll content ofleaf, fruit set, total yields, and fruit chemical and physical characteristics. It also hiked the contents of leaf major andtrace nutrients (Al-Saif *et al*., 2023). According to Al-Hadethi and Al-Qatan, (2013) apricot trees traits of vegetative growth and content of leaf chlorophyll were enhanced by seaweed extract recommendation.

Sweet cherry

According to preliminary findings, sweet cherry cv. Simone treated with aseaweed-based product derived from *Ascophyllum nodosum* showed improved fruit quality,primarily in the form of increased fruit weight and a greater proportion of larger-sized fruits(Bund and Norre, 2011).According to Correia *et al*. (2015), *Ascophyllum nodosum*, a seaweed bio-stimulant,could lessen cracking in cvs. Sweetheart andSkeena, along with an upsurge of fruitwaxes, average fruit weight, fruit diameter, and pH status of fruit juice.Foliar spray of seaweed extracts in sweet cherry cv. Staccato resulted in improved fruitsize, total soluble solids, contents of polyphenols, and vitamin C (Gonçalves *et al*., 2020).Use of 150 ml $L^{-1}$of seaweed extract led to a 3% minimized thecracking index and a 2% increase in fruit weight in sweet cherry (Santos *et al.,* 2024).According to Correia *et al*. (2017), extract of seaweed treatments imposed three weeks after peak blooming showed an enhancement in weight and size of fruit as well as limiting in fruit breakingin cherries.

Almond

A study by Erogul, *et al.* (2022) found that applying 4000 ppm seaweed as a foliar spray on the 10th day following full flowering in almondimproved yields. In comparison to the control group, the kernel ratio fruits applied with seaweed extract was registered 6% more in "Texas" variety and 14% more in the "Nonpareil" type. Furthermore, since the seaweed treatments promoted the fruit set of almond trees, the total yield per tree increased in "Texas" type by 11.18% variety and "Nonpareil" typeby 12.12%.

Hazelnut

The use of seaweed extracts enhanced yield per tree, kernel yield per tree, fruitweight, and kernel size in hazelnut. The foliar spray resulted in higher quantities of starchin the buds and the lower percentage of blank nuts. Applying 3Lha^{-1} of seaweed extractduring the fruit set and development offruit has documented increase yield and higherquality nuts during summer season (Ellena *et al.*, 2022).

Pistachio

According to Nikoogoftar-Sedghi *et al*. (2023), applying *Ascophyllum nodosum*seaweed extract on pistachios increased their levels of protein, carbohydrates, and flavonoids as wellas their total phenol and antioxidant enzyme activity.Among the hard-shelled fruits, pistachios exhibited an improvement in quality yield of fruits by utilization of seaweed extract treatment(Ahmadi *et al.*, 2019).

Conclusions

It can be concluded that, the application of seaweed extracts alone or in combination with other bio-stimulants/ or nutrients during different crop stages in a wide range of fruit crops (tropical, sub-tropical, and temperate) has been found to significantly influence crop growth, yield, quality, storage, and stress tolerance. Various research studies also revealed that the use of seaweed extracts is more environmentally friendly due to their organic nature. So, administration of seaweed extract to various fruit crops at the right stages and in suitable concentrations will have a stronger impact on the modern fruit crop industry.

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