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REVIEW

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Sustainable production through biostimulants under fruit orchards

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Abstract

The world population is expected to be around 9 billion by 2050 which would be 34 per cent greater than the today's population. This will enhance the food demand to match the rising population. Horticultural commodities in general and fruit in the particular has been designated as the source of nutraceuticals. For reaching up optimum level of production, Biostimulants may come up with and the emerging concept of to meet out with this challenge and over the last decade, utilization of natural plant biostimulants is gaining importance. The use of biostimulants can be extensively exploited under fruit crops as they contribute towards a crucial role in enhancing the anatomical, morphological, physiological, that ultimately ameliorated the fruit productivity, and quality of the fruits. In addition, the application of biostimulants helps in promoting physiological actions like photosynthesis, nutrients metabolism, enzymatic activities, chlorophyll, protein and carbohydrate content. It also helps to mitigate abiotic stress like water stress, salinity, temperature, and changes related to oxidation–reduction reaction, reactive oxygen species detoxification, stress signaling, and hormonal pathways. After much exploration regarding the effects of biostimulants on fruit crops, there is still a void that exists in the area related to its impact on various traits. Henceforth, an appropriate tactics approach is much needed under the areas of research about biostimulants.

Keywords: Abiotic stress, Growth and yield, Quality, Biostimulants, Stress tolerance

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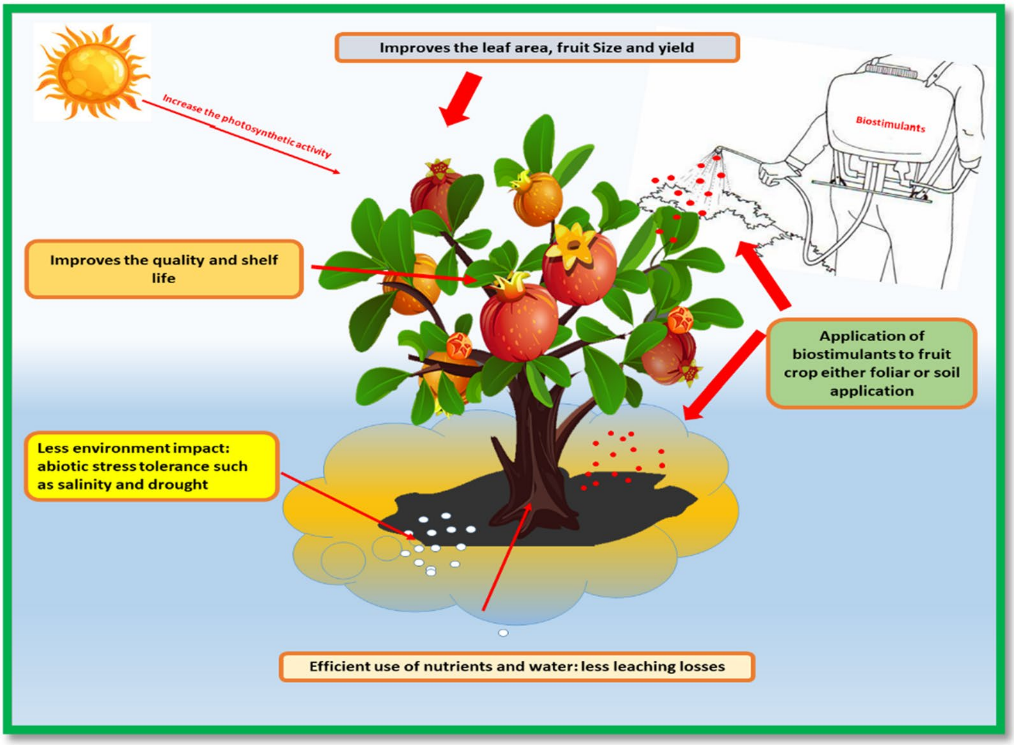
Graphical Abstract



Introduction

The global population estimated around 9.1 billion in next three decades that will be 34 per cent more than the today's population (FAO 2018). This lead to the increase the demand for food requirements will also be going to increase to the same trend. But arable land is the major bottleneck for crop production. This problem can be overcome by using the synthetic or inorganic fertilizers and pesticides, GM crop, insect pest, and disease-resistant crop varieties (Yadav et al. 2013). Chemical fertilizers had played a chief role in an increasing the food production for many times but also deteriorate food quality and soil health (Sharma et al. 2021). The indiscriminate use of chemical fertilizers in food crops, is a critical challenge among worldwide (Sharma et al. 2022). The intensive character of fertilizers is supplying the nutrition to crop for achieving its influential biological expression; however, the current crop production practices are unable to fulfill the demand of food without the use of the fertilizers (Zhang et al. 2015a, b; Sharma et al. 2022).

Fruits are good source of nutrition hence, their consumption fight against the major diseases. According to the World health organization (WHO), healthy diet contains 400 g of fruits and vegetables i.e. recommended allowance or adult individual (RDA or AI) (WHO 2003; FAO 2018). Inappropriately, less consumption of fruits and vegetables created high risk of mortality around the globe. According to the Global Burden of Disease (GBD) reported that annually 3.4 million deaths due to the less consumption of fruit (GBD 2013). Fruit culture is the dominant branch of the horticulture sciences that contributes 10–15 percent production to the overall agriculture (Sharma et al. 2021). Fruit crops are heavy feeders of nutrients and growth regulators that required good nutrient management practices related to growth and production (Ramírez et al. 2011). But, the horticultural sector is facing challenges towards enhancing the productivity for feeding as well enhances the resources use efficiency (RUE) while reducing the environmental impacts on the flora & fauna and human health (Rouphael and Colla 2020).

In recent years, to improve sustainable production in horticultural crops, many new types of strategies have been evolved. A potential tool such as 'biostimulants' which promotes the fruit quality, nutrient use efficiency, and tolerance against abiotic stress (Colla et al. 2015;

Rouphael and Colla 2020). The progression of plant bio-stimulant science, and the principles of legal frameworks of plant protection and nutrient products term “bio-stimulant.” There are many synonyms of “Biostimulants” namely; biogenic stimulants, metabolic promoters, strengtheners, PGRs, allelopathic preparation, Phyto-conditioners, Phyto-stimulators, bioinnoculants, biopesticides, bacteriocide, bioherbicides and biofertilizers (Sharma et al. 2018a, b, 2021b; Rouphael and Colla 2020). Legally “biostimulants contains trace amount of natural hormones or can be registered as plant growth regulators” (Bulgari et al. 2015; Du Jardin 2012; La Torre et al. 2016).

According to “biogenic stimulant” theory, it is a biological material that is made up from living entities, can act as a stress suppressor, affects metabolic and energetic process in plants (Filatov 1944, 1951; Sharma et al. 2021a, c). The target of sustainability can be achiecved by using natural products, said as “Plant biostimulants”.

Sustainable practices and the use of environmentally friendly technologies can help break this feedforward loop by improving resource use efficiency and increasing yield under a range of more extreme environmental conditions (Sharma et al. 2021b; Sunny et al. 2022), with the goal of improving healthy food production while reducing unsustainable inputs, thereby controlling extreme climatic conditions, and improving soil health by sequestering soil carbon. Biostimulants can be used in this way to achieve the objective of developing a more sustainable and robust agricultural production system without the need of extra chemical fertilizers. The goal of this review is to better understand long-term strategy for increasing agricultural yield. The importance of developing a broad formulation of this technology for worldwide use in the face of climate change issues is also discussed. Abiotic stress management is one of the most important challenges facing in horticultural sectors. These stresses can persistently limit the crops choice and fruit production over large areas and lead to total crop failures. Abiotic stresses adversely affect the livelihoods of individual farmers and their families as well as national economies and food security. Biostimulant cans be the effective tools for Keeping given above facts this article is to contribute to better understand the plant biostimulants concept based on the theoretical and practical knowledge of the main categories will be briefly described which is used in horticulture.

Methodology

Only studies that provide recommendations on doing a literature review technique were considered. This study included literature reviews for a specific issue like biostimulants applications. We incorporated research from a biology and crop physiology. Preliminary relevance was determined for each manuscript based on the title. We have collected more than 150–200 paper from the different publishing agency on the basis of keywords as well potential effects on the fruit crops. We gathered the whole reference, including author, year, title, and abstract, for additional examination. We looked through Google Scholar, Web of Science, and EBSCOhost, three databases that are regularly utilized. Because archiving and retrieval methods are changing due to technology advancements. The literature review technique required us to study the abstracts of the 150 studies to determine their relevance to the research issue.

Main categories of plant biostimulants

There is no availability of permissible or administrative classification of biostimulants in the world. The detailed listing and categorization of the biostimulants are standardize by many researchers. They have called as a Biostimulants (Calvo et al. 2014; Halpern et al. 2015; Yakhin et al. 2017; Sharma et al. 2022a). Microorganisms refers to living entities like beneficial bacteria, mainly PGPRs, and beneficial fungi (Sharma et al. 2018a, b). The non-Microbial compound inorganic compounds like seaweed extract, protein hydrolysates, phosphites (Thao and Yamakawa 2010), and inorganic compounds (Silicon) (Table 1). The first grouping of Biostimulants was described by Filatov in 1951 by which he suggested the various biostimulants; Ikrina and Kolbin (2004) 9 categories; Du Jardin (2012) described 8 categories of biostimulants and 7 categories by Du Jardin 2015. Whereas Bulgari et al. (2015) categorized the biostimulants based on their mode of action. Du Jardin (2015) has suggested that biofertilizers as a sub-category of biostimulants and microorganisms have also been described as biofertilizers (Radkowski and Radkowska 2013; Bhardwaj et al. 2014 and Sharma et al. 2018a, b). The Biostimulants categories have been briefly summarized in Table. 1

Description of biostimulants

Humic substances (HS)

Humic substances are a natural fraction of soil organic matter, resultant of a plant decomposition, animal, and microbial residues. These substances were firstly introduced by Sprengel in 1837 and their explanation was based on their solubility (Hayes 2006). But chemically, these compounds are the product of a saponification reaction from soils by alkaline extraction from soils and heterogeneous compounds, originally characterized according to their molecular weight and fragmentation into humins, humic acids, and fulvic acids (Piccolo 2002).

Humic acids (HA) are defined as product of the combination of hydrophobic compounds like poly-methylene

Table 1 Categorization of Biostimulants on the basis of material used as per the passage of time along with examples and used by various researchers

Researchers	**Proposed Categories of Biostimulants**						
Filatov (1951)	Carboxylic fatty acids (oxalic acid and succinic acid)	Carboxylic fatty hydroxy acids (malic and tartaric acids)	Unsaturated fatty acids, aromatic and phenolic acids (cinnamic and hydroxycinnamic acids, coumarin)	Phenolic aromatic acids containing several benzene rings linked via carbon atoms (humic acids)			
Ikrina and Kolbin (2004)	Humate and humus containing substances	Microorganisms (bacteria, fungi)	Plant materials (land, freshwater and marine)	Sea shellfish, animals, bees	Vegetable oils Natural minerals	Water (activated, degassed,Thermal, Resins)	
Kauffman et al. (2007)	Humic substances	Amino acid containing products	(Seaweed extracts)				
Du Jardin (2012)	Beneficial chemical elements	Chitin and chitosan derivatives	Complex organic materials	Free amino acids and other N-containing substance	Humic substances	Inorganic salts (such as phosphite)	Seaweed extracts
Calvo et al. (2014)	Fulvic acids	Humic acids	Microbial inoculants	Protein hydrolysates and amino acids	Seaweed extracts		
Gu et al. (2014)	Humic substances	Microbial inoculants	Seaweeds extracts	Organic material blends			
Halpern et al. (2015)	Humic substances	Plant-growth-promoting microorganisms	Protein hydrolysate and amino acid	Seaweed extract			
Du Jardin (2015)	Beneficial fungi& Beneficial bacteria	Chitosan and other biopolymers	Fulvic acids	Humic acids	Inorganic compound	Protein hydrolysates and other N-containing compounds	Seaweed extracts and botanicals
La Torre et al. (2016)	Humic substances	Microorganism	Hydrolyzed proteins and amino acids	Seaweed extracts	Inorganic salts		
Rouphael and Colla (2018)	Organic Non-microbial Plant Biostimulants	Microbial Plant Biostimulants					
Albrecht (2019)	Beneficial bacteria, and beneficial fungi	Chitosans	Fulvic acids	Humic acid	Inorganic compounds such as	Protein hydrolysates	Silicon seaweed extracts
Rouphael and Colla (2020)	Microbial	Non-microbial					

chains, fatty acids, steroid compounds and the humus fraction that is soluble in aqueous alkaline solution but precipitate when the pH is acidic (Du Jardin 2015). Likewise, Fulvic acids (FA) is an organic compound that is made up from the combination of hydrophilic molecules in which there are enough acid functional groups to keep the fulvic clusters dispersed in solution at any pH. According to Piccolo 2002, water-soluble associations, humic substances are primarily stabilized by weak forces. The organic acids which are secreted by the root can easily affects the stability of humic substances. Hence, it is recognized as essential suppliers of nutrient because application of humic substances improves the physico-chemical and biological properties of soil (Jindo et al. 2012). Likewise, it can also improve the enzymatic activities of soil as well as of plant (du Jardin 2012). The activation of secondary metabolite like phenolics (Phenylpropanoid) might be helpful for the stress responses. (Schiavon et al. 2010; Canellas et al. 2015).

These substances are the wide source of organic fertilizers because contains greater than 60 percent of the soil organic matter (SOM) (Stevenson 1994) due to which it promotes plant growth by carbon and nitrogen metabolism (Nitrate reductase, glutamate dehydrogenase and glutamine synthetase (Canellas et al. 2015; Hernandez et al. 2015) and Many scientists has reported that treatment of Humic substances 50% decrease of leaf total carbohydrate content compared to the untreated control plants, and, while glucose and fructose content decreased, starch content enhanced concurrently Canellas et al. (2015). Nardi et al. (2016) reported that HS negatively affected the activity of glucokinase, phosphoglucose isomerase, aldolase, and pyruvate kinase, enzymes involved in glucose metabolism. Invertase activity was enhanced and favored hydrolysis of sucrose into hexose as a substrate available to growing cells (Pizzeghello et al. 2001). When total carbohydrate content as well as reducing sugar decreased following the application of humates, these metabolites can be used to sustain growth and enhance N metabolism, since enzymes linked to N assimilation were usually stimulated by HS. As a consequence, it was possible to observe high net photosynthesis rates in maize treated with HS (Canellas et al. 2015). The effect of humic substances on plant primary metabolism has been challenged by a new biological molecular approach.

The advancement of plant growth by these substances is well documented in the literature (Canellas et al. 2015; Nardi et al. 2016; Yakhin et al. 2017). Rose et al. (2014) resulted that the exogenous application of humic substances promote the shoot and root dry weight of different plant species increased by 22 percent. Besides, crop responses with application of humic substances are varied from species to species, method and amount of application, source of these substances, management and climatic conditions (Trevisan et al. 2010).

Seaweed extracts and botanicals

Seaweeds are green, brown, and red marine microalgae that help to the nourishment of marine ecosystems by improving the properties of the sea water (Khan et al. 2009; Bhattacharyya and Jha 2012).

It can be used in various ways such as seed treatment, foliar and soil application for plant growth promotion (Yakhin et al. 2017; Rouphael and Colla 2020). The application of Seaweed extract is convenient than synthetic fertilizers because of its non-toxic in nature bio-as well as eco-friendly property (Mukherjee and Patel 2020). Hence, it's the appropriate reason of using seaweed extracts in recent years for sustainable fruit production. Its application promotes the enhancement of plant growth, nutrient incorporation, fruit setting, resistance properties against pests and diseases, improving the stress management like drought, salinity and temperature (Yakhin et al. 2017; Rouphael and Colla 2020; El Boukhari et al. 2020). The most common brown seaweeds extract are achieved from Ascophyllum (*Ascophyllum nodosum*), Sea bamboo (*Ecklonia maxima*), Giant kelp (*Macrocystis pyrifera*) and Southern Bull kelp (*Durvillea potatorum*) by the various extract industries with different processes like acid extraction, alkali extraction, and cell bust technology. The composition of the nutrient in the seaweed extract is dependent on the raw material as well as the method of of extraction (MacKinnon et al. 2010; Kim 2012 and Khairy and El-Shafay 2013). Brown algae also contain active secondary metabolites, and vitamin precursors (Berlyn and Russo 1990) and are rich in phenolic compounds (Wang et al. 2009) and good antioxidant activity (Andjelkovic et al. 2006). Among all the Brown SWE, total phenolics are found higher in *F. serrat*us and *Ascophyllum nodosum* (Audibert et al. 2010; Balboa et al. 2013).

Protein hydrolysates

Protein hydrolysates (PHs) as a plant biostimulants defined as 'combination of amino acids and peptides (oligopeptides and Polypeptides) that are prepared by partial hydrolysis (Schaafsma 2009). These can be categorized on the basis of protein sources and hydrolysis method. Acid hydrolysis is a typical process by which high temperature more than 121 °C and pressure more than 220.6 kPa and acid like HCl and H_2SO_4 broadly used as agents for extraction (Pasupuleti and Braun 2010; Colla et al. 2015). Likewise, Alkaline hydrolysis is quite easy methods as compared to acid hydrolysis in which protein gets solubilized with the help of heating as well as using agent like calcium, sodium, or Potassium hydroxide (Pasupuleti and Braun 2010).

These biostimulant have been showed the positive effects in growth and development in the horticulture crops especially in fruit crops (Paradikovic et al. 2011; Colla et al. 2014; Ertani et al. 2013; Du Jardin 2015). It can also increased the iron and nitrogen metabolism, improves the water and nutrient use efficiency (Halpern et al. 2015). Hence, improve stress tolerance against various environmental conditions (du Jardin 2012). Moreover, the application protein hydrolysates improved the soil enzymatic & microbial activities, in rhizosphere zone and helps to increase the root length, density and number of the lateral roots and, increase in nitrate reductase activities (García-Martínez et al. 2010; Colla et al. 2015; Lucini et al. 2015). Besides this, PHs also improve the quality of fruits in terms of physicochemical properties of the fruit(i.e., carotenoids, flavonoids, polyphenols, aromatics, and pungency) (Colla et al. 2015, Du Jardin 2015; Sharma et al. 2021a).

Arbuscular mycorrhizal fungi (AM Fungi)

Arbuscular mycorrhizal fungi is one of the soil-borne fungi that belong phylum *Mucoromycota* and sub-phylum *Glomeromycotina*, (Spatafora et al. 2016; Sun et al. 2017) and orders like *Glomerales, Archaeosporales, Paraglomerales*, and *Diversisporales*, (Redecker et al., 2013). These fungi are obligate biotrophic in nature and consume photosynthetic products of the plant-like sucrose (Bago et al. 2000; Jiang et al. 2017). AM fungi considerably enhance not only the nutrient uptake of plant and resistance to several abiotic stress factors but save the plant from fungal infections (Smith and Read 2008; Gianinazzi et al. 2010). Besides, AM fungi can only be grown in the presence of host plants i.e. obligate symbionts. The fungi like *Rhizophagus, Funneliformis* (formerly known as Glomus) is chiefly used for fruit production (Krügeret al. 2012; Owen et al. 2015; Begum et al. 2009).

AM fungi can be produced phosphatases from organic phosphorus compounds (Koide and Kabir 2000; Marschner 2011) due to which abundance supply of nutrient to crop (Begum et al. 2019). Moreover, it is also increase the extra radical hyphae which promotes nitorgen uptake, micronutrients like Cu and Zn (immobile) and mineral cations (K^+, Ca^{2+}, Mg^{2+}, and Fe^{3+}) (Smith and Read 2008) and act as bio fertilizers, bio-regulator and bio-protectors (Antunes et al. 2012). Application of AM fungi improved yield as well as physico-chemical properties of fruit (i.e. carotenoids, flavonoids, aromatic, and polyphenols (Rouphael et al. 2015).

Chitosan

In the world, Chitin is the 2nd most essential natural polymer. It mainly composed of marine crustaceans, shrimp, and crabs (Rinaudo 2006). It is a biopolymer in nature that arises from natural component i.e. cell walls of fungi, exoskeletons of insect, and crustacean shells (Chaudhary et al. 2020, 2021). The physiological activity of chitosan oligomers in plants is to binding of DNA, plasma membrane and cell wall elements (cellular components) as well as bind to the specific receptors that involved in the defense mechanism of gene activation (Katiyar et al. 2015; Pichyangkura and Chadchawan 2015).

It has the wide applications in many sectors like agriculture, food industry, and pharmaceutical and cosmetics. In agriculture chitosan, uses as a biostimulator in cereal, ornamental, Vegetable, fruit and Plantation crops (Limpanavech et al. 2008; Kananont et al. 2010; Pornpienpakdee et al. 2010) that improves the growth and development and protects from the various diseases (Maqbool et al. 2010; Ali et al. 2013).

Phosphite

Phosphorus plays a major role in genetic heredity (nucleic acids DNA and RNA) structural membrane, signal-transduction pathways, and cell metabolism to all forms of life existing on earth, including both lower and higher plants (Gómez-Merino andTrejo-Tellez 2015). Phosphite (Phi), a reduced form of phosphate considered as a unique biostimulator in horticulture especially in fruit cultur. Phosphorus fertilizers can have only one limitation as compared other macronutrients (Ramaekers et al. 2010 and Sharma et al. 2018a, b) i.e. least mobile in nature. It has been studied that phosphite and conjugate form of phosphorus is good for the nourishment of the plant and used as pesticide, supplementary fertilizers, biostimulator (López-Arredondo et al. 2014). It can also improves the nutrient assimilation and uptake, tolerance against abiotic & biotic stress and produce quality (Brunings et al. 2012; Burra et al. 2014; Dalio et al. 2014; Groves et al. 2015).

Bacteria

Soil microorganisms can be played the critical role for regulating the decomposition of organic matter and the availability of plant nutrients. Out of various microorganisms, Bacteria interacted with plants as for mutualism and parasitism (Ahmad et al. 2008; Sharma et al. 2018a). In agricultural production system, Bacteria as biostimulants are of two main types based on taxonomic, functional and ecological diversity: (1) Rhizobium in association with the plant and (ii) PGPR ('plant growth-promoting rhizobacteria') near the rhizosphere (Philippot et al. 2013; Vacheron et al. 2013 and Berg et al. 2014; Du Jardin 2015; Sharma et al. 2018a, b). The main functions of bacteria to decompose the organic matter which helps to supply of nutrients as well as the increase in nutrient use efficiency, and enhancing the capacity of plant against the insect-pest and disease, abiotic stress tolerance, promotes the plant growth regulators production (Berg et al. 2014; Du Jardin 2015; Sharma et al. 2018a, b).

Botanicals

'Botanicals' defined as the naturally occurring secondary metabolites (phytochemicals) extracted from the plant which can be used in pharmaceutical (drug), cosmetic (creams), food (food ingredients), and agriculture industries (Plant protection). (Dimetry 2014 and Seiber et al. 2014). These compounds are generally safer to humans and environment than conventional chemical pesticides, hence used as biostimulants (Dimetry 2014; Ertani et al. 2013; Ziosi et al. 2012).

Impacts of biostimulants on growth, yield and quality

The information on the use of biostimulants for enhancement of growth, yield and quality of fruit crops has been reviewed and presented in Table 2. Biostimulants promote the blooming, growth and yield of the fruit plants, but there is scanty information on their influence on the flowering of fruit crops. Some of the most prominent findings on the effect of different biostimulator in improving fruit crop especially focused on growth, yield, and fruit quality, (Shearer and Crane 2012). An enhancement in NUE was found to be the major biostimulants effect associated with the promotion of fruit crops in the aspect of growth, yield, and quality by Humic substances (Farahi et al. 2013; Cavalcante et al. 2013). Foliar spray application of Humic substances @ 4 kg ha^{-1} improves the yield per vine and also amoleriated the physico-chemical charactesrtics like total soluble solids and ascorbic acid in kiwifruit (Hadi et al. 2018).

Protein hydrolysates promote the growth and yield and quality of fruit crops as well as improves the nutrients uptake in several fruit crops (Halpern et al. 2015). Many researchers observed that the application of protein hydrolysates improves the growth, yield, and Quality than untreated ones; Morales-Pajan and Stall (2003) in papaya; Quartieri et al. (2002) in kiwifruit plants; Lachhab et al. (2014) in grapes showed in Table 2. Several researchers have been reported that application of phosphite showed positive effects in many fruit crops like foliar applications of potassium phosphite to *Citrus sp.* (Navel orange) trees significantly increased the numbers of large size fruit showed by Lovatt (1998), while fruit quality was improved, as compared to untreated trees (Lovatt 1999). Moor et al. (2009) found that the application Phosphite with irrigation enhanced the quality of strawberry by triggering the production of Vitamin C (ascorbic acid) and anthocyanins contents. Consequently, Ortiz et al. (2011) showed that the application of phosphite in the strawberry field increased free amino acids contents protein contents in leaves, and sugar content, and anthocyanin content in strawberry fruits. (Ortiz et al. 2011, 2013).

As like other biostimulants, AM fungi can be also used as biostimulants which modifies the secondary metabolism (Sbrana et al., 2014), an increase of level antioxidant content (Strack and Fester 2006) as well as improve the Vitamin C (ascorbic acid), flavonoids, and cichoric acid levels (Larose et al. 2002; Schliemann et al. 2008). In strawberry, *R. intraradices* treatment improved the anthocyanidin (cyanidin-3-glucoside) [Castellanos-Morales et al. 2010] and twice inoculation of Glomus spp. and Pseudomonas spp. were able to enhance the production of the two main forms of anthocyanins in strawberry fruit, pelargonidin malonyl glucoside, and pelargonidin 3-rutinosidein (Lingua et al. 2013).

Chitosan is also used as biostimulants in fruit crops which help to increase the growth, yield, and quality. Application of chitosan in grapevine nursery improved chlorophyll contents, rooting (Górnik et al. 2008). Likewise, the foliar application in strawberries increased vegetative growth and yield (El-Miniawy et al. 2013) improves the fruit shelf life (Kerch et al. 2011; and Ma et al. 2013) and decline the prevalence of infection (Abbasi et al. 2009; Badawya and Rabea 2009). It also improved post-harvest shelf-life e.g. fruit dipping of papaya, (1.5–2.0% w/v) chitosan decline the severity *Colletotrichum gloeosporioides* infection (Ali et al. 2012).

Beneficial bacteria also act as a biostimulant by which it improves the NUE, growth, yield, and quality of the fruit. Many scientists have been reported the bacteria as a biostimulant. Application of PGPR with reduced levels of Nitrogen improves the flower initiation, yield increase, and quality in banana orchards banana (Baset et al. 2010). The application of FYM + Azotobacter + P solubilizers + K mobilizers on cultivar "Bombai" litchi gave a positive on the yield as well as fruit quality (Devi et al. 2014). The positive effects of biostimulants application have been summarized in Table.2.

Table 2 Different Biostimulants and their impact on Fruit crops

Fruit crop	Biostimulants name	Doses or concentrations	Mode of application	Positive effects on the fruit trees	References
1. Humic substances (Humic acid & Fulvic Acid)					
Apricot	Actosol® (contains 2.9% humic acid)	Foliar spraying with 15 cm^3 per tree and 75 cm^3/3 L as a weekly soil addition	Both foliar as well as soil Application	•↑↑ the vegetative growth (shoot length, chlorophyll content •↑↑most of yield determinations and fruit quality	Fathy et al. (2010)
Pineapple	Humic acid + Vermicompost + Microbes		Soil Application	•↑↑ growth and adaptation of pineapple plantlets to the ex vitro environment	Baldotto et al. (2010)
Strawberry	Vermicompost leachates (Humic substances)		Foliar spray	•↑↑ fruit yield (10–14%) and •↓↓ incidence of grey mould	Singh et al. (2009)
Strawberry	Humic acids		Foliar spray and fertigation	•↑↑ nutrient use efficiency	Ameri et al. (2012)
Peach	Commercial humic acids	5 cm^3/tree three times	Both foliar as well assoil Application	•↑↑ fruit yield and quality	Mansour et al. (2013)
Strawberry	HA commercial soluble product	–	foliar spray	•↑↑ yield (33%), fruit firmness and total soluble solid percent	Farahi et al. (2013)
Yellow passion fruit	Humic acids	7.5, 15.0, 22.5 and 30 ml/L	Foliar spray	•↑↑root dry weight by 124% in seedlings •Amoleriated seedling quality	Cavalcante et al. (2013)
Lime	Humic acid	4.5 ml/L	Soil Application	•↑↑ shoot fresh and dry weights, root dry weight and shoot potassium concentration	Jahromi and Hassanzadeh (2016)
Strawberry	Humic acid + seaweed extract (1500 mg/L)	400 mg/L + SWE 1500 mg/L	Both soil and foliar spray	•↑↑yield, and physico-chemical characteristics [total soluble solids and titratable acidity; amount of vitamin C (Ascorbic acid)]	Alkharpotly et al. (2017)
Mango	Humic acids	7.5 ml/L	Drenching	•↑↑ the plant height, leaf area, plant spread, girth at collar, root length, •number of secondary and tertiary roots, •↑↑dry matter production	Rajan et al. (2018)
Kiwifruit	Humic acid	4 ml/L	Both foliar and Drenching	•↑↑yield, and physico-chemical characteristics [total soluble solids and titratable acidity; amount of vitamin C (Ascorbic acid)]	Hadi et al. (2018)

Table 2 (continued)

Fruit crop	Biostimulants name	Doses or concentrations	Mode of application	Positive effects on the fruit trees	References
Strawberry	Nitrogen and humic acid	100 kg ha^{-1} and 4 kg ha^{-1}, respectively	Soil application and foliar	•highest values for the leaf area, fruit yield, •chlorophyll a, carotenoids and titratable acidity are associated with the combined treatments of with concentrations of	Rostami et al. (2022)
Olive	Arginine + humic acid	–	Foliar	•↑↑ fruit protein content and total chlorophyll	Nargesi et al. (2022)
2. Phosphites					
Banana	Phosphorous acid	(50% P as HPO_4^{2-} and 50% as H_2PO^{3-}	Nutrient solution in hydroponics	•↑↑ Biomass dry weight, foliar area and P content in the whole plant	Bertsch et al. (2009)
Strawberry	Phosphoric acid (Liquid NPK 3:12:15 fertilizer Phosfik1)	0.3% liquid NP	Plants soaked and irrigated	•↑↑ fruit acidity, ascorbic acid and anthocyanin content	Moor et al. (2009)
Strawberry	Potassium phosphite	6.7% of total P as Phi	Root application through a controlled watering system	•↑↑ roots growth and shoots	Glinicki et al. (2010)
Strawberry	Phosphoric acid	30% of total P as Phi	Nutrient solution applied to the roots	•↑↑ chlorophyll, amino acids and proteins contents in leaves	Ortiz et al. (2011)
Strawberry	Phosphorous acid	(20% of total P as Phi)	Nutrient solution applied to the roots	•↑↑ sugar concentration and firmness of fruits; improves shelf life	Ortiz et al. (2012)
Grapes	Potassium phosphite	5.0 g L^{-1} of P_2O_5	Foliar spray	•↑↑ productivity, total soluble phenolic compounds; •↑↑ total soluble solids and pH, •↓↓ total titratable acidity of the berries	Pereira et al. (2012)
Strawberry	Phosphorous acid	(20–30% of total P as Phi)	Nutrient solution applied to the roots	•↑↑ acidity, sugars, ions concentration and anthocyanin concentration in fruits	Ortiz et al. (2013)
3. Seaweed extracts					
Mango	Seaweed extract	0.2% Seaweeds	Foliar spray	•↑↑ fruit yield producing large sized fruits with superior quality	Mohamed and El-Sehrawy (2013)
Peach	Seaweed extract	4 $ml.L^{-1}$	Foliar spray	•↑↑ total leaves area, leaf chlorophyll content; leaf carbohydrates, leaf nitrogen content and leaf zinc content	Al-Rawi et al. (2016)

Table 2 (continued)

Fruit crop	Biostimulants name	Doses or concentrations	Mode of application	Positive effects on the fruit trees	References
Date palm	Sea weed extact + postassium nitrate	Seaweed extracts and KNO_3 at 2%	Foliar spray	•↑↑ bunch weight, fruit yield, fruit and flesh weight •↑↑soluble solids content, sugars content and fruit moisture	Omar et al. (2017)
Mulberry	seaweed extract from *A. nodosum*	0.5 ml/L at 21, 28 and 35 days	Foliar spray	•↑↑ leaf yield per plant and protein content	Pappachan et al. (2017)
Banana	Seaweed (*A. nodosum* L.)	2 g/L	Foliar spray	•↑↑bunch weight and yield,	El-Kholy (2017)
Olive	Sea weed extract	6 ml/L	Foliar spray	•↑↑ leaf area, leaves chlorophyll content, leaves dry weight and leaves carbohydrates content	Al-Hadethi (2019)
Grapevine	Seaweed (*A. nodosum* L.)	1 g/Lt	Foliar spray	•↑↑ yield and no. of berries •↑↑ anthocyanin content	Taskos et al. (2019)
Sour orange	Sea weed extact + CPPU	SWE (Agazone algae extract @ 9 ml/L + CPPU@ 8 mg/ L^{-1})	Foliar spray	•↑↑ seedling height, number of leaves, area of leaves and increase plant stem diameter rate	Ali and Al-Araji (2020)
Strawberry	Seaweed extracts (Alga 600)	4, g/L-1	Fertigation	•↑↑ number of flowers per plant, yielding units/plant •↑↑ in fruit quality like TSS, sugar acids ratio	Al-Shatri et al. (2020)
Mango seedling	Seaweed extract	4 ml/L	Foliar Spray	•↑↑ leaf nitrogen content, leaf potassium, leaf iron and leaf zinc content	Al-Marsoumi and Al-Hadethi (2020)
Grapes	seaweed extract	2 g/L	Foliar spray	•↑↑ yield and berry attributes •↑↑amino acid content and Vitamins improved vine C/N ratio,	El-Sese et al. 2020
4. Protein hydrolysates					
Strawberry	Animal derived PH (Aminoflor)	5 L/ha	Foliar spray	•↑↑ dry matter and nitrate content of leaves •↓↓ weight of daughter plants	Lisiecka et al. (2011)
Banana	Chicken feather derived PH	10 g/ L	Soil and foliar	•↑↑ nutrient, chlorophyll content, and proline in leaves •↑↑ sugars, proteins, amino acids, phenolics and flavonoids in fruits	Gurav and Jadhav (2013)

Table 2 (continued)

Fruit crop	Biostimulants name	Doses or concentrations	Mode of application	Positive effects on the fruit trees	References
Pecannut	Protein hydrolysate Supramino + urea + boric acid + zinc sulphate	5 ml/L supramino + 0.5% urea + 0.1% boric acid + 0.5% zinc sulphate	Foliar spray	•↑↑ nut weight, kernel weight/length/breadth; fruit size and weight; kernel protein content •↑↑ Zn, Fe, Mn, Cu foliar contents	Ashraf et al. (2013)
Persimmon	Protein hydrolysate + calcium salts	5 L/ha, every 8 days, 7 times in 2012 and 23 L ha^{-1}, every 6 days, 24 times in 2013	Drenching and injection	•↓↓ Cl^- uptake, leaf necrosis, and leaf water potential	Visconti et al. (2015)
Strawberry	Amino-acids of animal origin	5, 1.0 and 1.5 g per plant	Four drench applications	•↑↑ resistance to frost damages	Bogunovic et al. (2015)
Date palm	Coconut Milk + Casein Hydrolysate	Coconut Milk 30% and Casein Hydrolysate 2.5 g/L	Foliar spray	•↑↑ chlorophyll content, total carbohydrate, protein, amino acid, phenol and indole	Hosny et al. (2016)
Grapevine	Protein hydrolysates (PHs)	1.6 and 6.4 g/L	Foliar spray	•↑↑ yield per vines •↑↑ qualitative parameter like anthocyanin content colour shape, phenolic content, TSS	Boselli et al. (2019)
5. Chitosan					
Dragon fruit	Chitosan from crab shell	50 kDa, 75–85% DD encapsulated as droplets of 200, 600 and 1000 nm diameter	Fruit dipping in post-harvest	•↑↑ fruit firmness and titratable acidity, total phenolics, flavonoids, lycopene and antioxidants, d •↓↓ weight loss and respiration rate	Ali et al. (2013)
Peach	Chitosan + oligochitosan	Chitosan and oligochitosan @ 0.5 and 5.0 g/L	Foliar spray	•↓↓ post-harvest losses by delaying fruit softening & promotes antioxidant and	Ma et al. (2013)
Kiwifruit	Chitosan	Chitosan (~85% DD, MW = 20–30 kDa) applied at 1.0 kg/ha	Foliar spray	•↑↑ fruit fresh weight and yield, •↓↓ the incidence of disease	Scortichini (2014)
White and red prickly pears	Medium-MW chitosan	Medium-MW chitosan (85% DD) at 1% (w/v) in 0.6% (v/v)	Fruit dipping (peeled) in post-harvest	•↓↓ weight loss, • = firmness and colour •↑↑Improved the sensory values	Ochoa and Guerrero-Beltrán (2014)
Citrus	Neem + kurtuma leaf extract	30% neem and kurtuma leaf extract	Foliar application	•↓↓ infestation of citrus leaf-miner	Shareef et al. (2016)

Table 2 (continued)

Fruit crop	Biostimulants name	Doses or concentrations	Mode of application	Positive effects on the fruit trees	References
Grapevines	Chitosan + Salicylic acid + Fulvic acid	500 mg/L	Foliar Spray	•↑↑ shoot length, leaf area, •↑↑total chlorophyll and total protein, •↑↑yield per vine, cluster weight, berry weight, soluble solids content •↑↑ total phenols while reducing total acidity, cluster weight loss%,berry shatter % and berry decay% •↓↓loss in cluster weight percentages during storage shelf life period	El-Kenawy (2017)
Mango	Nano-chitosan	Nano-chitosan 5 ml/L	Foliar Spray	•↑↑ fruits yield as number of fruit or weight/tree •↓↓ malformation percentage	Zagzog et al. 2017
Washington Navel Orange	Chitosan	2 g/L	Foliar spray	•↑↑ leafy inflorescence •↑↑ fruit set % and Canopy yield as weight (kg/m3) •↑↑ chlorophyll contents •↑↑physico-chemical properties of fruit	Mohamed and Ahmed 2019
Pomegranate	Chitosan	chitosan at 0.5%	Foliar spray	•↑↑ improved the yield and fruit quality comparing •↓↓ the fruit cracking	Ibtesam et al. (2019)
Cherry	Chitosan coatings	2%	Dipping	•↑↑firmness •↓↓ reduced the expression of pectin methylesterase-related genes	Xin et al. (2020)
6. Botanicals					
Citrus	Neem + kurtuma leaf extract	30% neem and kurtuma leaf extract	foliar application	•↓↓ infestation of citrus leaf-miner	Shareef et al. (2016)
Cherry	Wildflower strips	height of 20 cm with regular cutting		•↓↓ aphids (bait cards) in by 25%	Mateos et al. (2021)
7. Arbuscular mycorrhizal fungi (AM Fungi)					
Grapevines	Arbuscular-mycorrhizal fungi (AMF)	20 g of mycorrhizal inoculum per plant	Soil application	•↑↑chlorophyll, carotenoids, proline, phenol	Krishna et al. (2005)

Table 2 (continued)

Fruit crop	Biostimulants name	Doses or concentrations	Mode of application	Positive effects on the fruit trees	References
Tangerine orange	AMF (*Glomus versiforme*)	30 g innoculum per pot	Soil application	•↑↑ leaf water potential, transpiration rates, photosynthetic rate, stomatal, conductance, relative water content and reduced leaf temperature	Wu and Xia (2006)
Citrus	Arbuscular mycorrhizal (AM) fungi	–	Soil application	•↑↑ plant height, stem diameter, shoot, root and total plant biomass, photosynthetic rate, transpiration rate and stomatal conductance	Wu et al. (2010)
Loquat	AMF (*Funneliformis mosseae)*	300 g of mycorrhizal inoculum per plant	Soil application	•↑↑ dry biomass and leaf water potential,	Zhang et al. (2015a, b)
Kiwifruit	,Glomus mosseae(G.m)and G.versiforme(G.v)	5 g of inoculum	Soil application	•↑↑ absorption of N,P and K nutrients •↑↑ photosynthetic activity	Chen and Zeng 2016
Strawberry	*Claroideoglomus aff. luteum, C. claroideum, C. etunicatum, Funneliformis mosseae* and *Glomus sp*	–	Soil application	•↑↑ root system and fruit anthocyanin content	Chiomento et al. (2019)
Newhall navel orange	*Diversispora spurca and D. versiformis*		Soil application	•↑↑ Root fungal colonization •↑↑increased soil phosphatases, and aggregate stability •↑↑ fruit quality and mineral element contents	Cheng et al. (2022)
9. Beneficial bacteria					
Sour cherry	*Bacillus mycoides* T8 + *Bacillus subtilis* OSU-142	OSU-142	Floral and foliar	•↑↑ shoot length and fruit yield	Arikan and Pirlak (2016)
Quince	*Pseudomonas fluorescens*) and (*Rhodococcus rhodochrous*)	PGPR + NPK and PGPR + 1/2 NPK	Soil combination	•↑↑ average flesh firmness, values andyield	Gerçekcİoğlu et al. (2018)
Strawberry	*Bacillus licheniformis CKA 1*+ Root dip method + Foliar application	10^{9} *cfu/ ml*	Root + foliar application	•↑↑ growth and yield •↑↑ fruit quality like TSS compared to	Kumari et al. (2018)

↓↓ Decreased = maintained ↑↑ increased

Molecular and physiological effect of biostimulants to abiotic stresses tolerance

The major limiting factor the of fruit crops is the dependency on the climatic factors For e.g.- apple crop required at least 700–1000 chilling hours for breaking the dormancy. The unfavorable environmental conditions and soil health, including salinity, drought, thermal stress, adverse soil pH, and nutrient deficiency, leads to cause reduction in growth and development process of the plant (Rouphael and Colla 2018). It has been estimated that abiotic stresses lower the production upto 50 percent (Moghaddam and Soleimani 2012). Biostimulants are a unique tool that might helpful to mitigate from abiotic stress (Table 3). Biostimulant like seaweed extract can help to mitigate the abiotic stresses of fruit crops because it release some beneficial proteins along with osmoprotectants, transporter and detoxifying enzymes.

To manage stress, some metabolisms may be altered by synthesizing regulatory molecules like abscisic acid (ABA), salicylic acid (SA)and proline (Calvo et al. 2014). It helps to stabilize the protein structure and cell wall by the secretion of glycine whereas maintenance of turgor pressure, retards the production reactive oxygen species (ROS). The mechanism of plant stress tolerance due to application of seaweeds is not well reported, but some researchers suggested that bioactive components like betaines and cytokinins are present in the seaweed extract that might be involved in stress management. However, seaweed polysaccharides have the ability to act as an elicitor of defenses responses in the plant (Salah et al. 2018).

Likewise, the application of protein hydrolysates like glycine betaine, glutamate, and/or ornithine and arginine can activates the plant defense mechanism which able to protect the plant from the abiotic stress (Ertani et al. 2013 and Calvo et al. 2014). Salinity alone could significantly reduce the yield of major fruit crops (Márquez-García et al. 2011). In abiotic stress like salt, the enzymatic activity of catalase (CAT), guaiacol peroxidase (GPX) and ascorbate peroxidase (APX) are increased the fruit trees. Protein hydrolysates enhance the antioxidant activity and control of redox signaling (Hoque et al. 2007 and Abogadallah 2010). The mechanism of stress tolerance has been summarized in Fig. 1. Besides, applications of humic substances in fruit crops result in reduces the effect of abiotic stress. Humic substances can chiefly work against the drought stress where fruit trees showed the ability to osmotic adjustment (Azevedo and Lea 2011). Under the drought stress the production of ROS which is quite harmful to the plant because it reduces the enzymatic activity, degradation of chlorophyll, destruction of an organic molecule, and damage to the lipid peroxidation (Kellos et al. 2008 and Márquez-García et al. 2011). The non-enzymatic antioxidant system comprises compounds such as ascorbate, glutathione, alkaloids, phenols, tocopherols, and carotenoids which also degraded during drought stress (Gratão et al. 2005) but stimulated with the application of humic acids (Schiavon et al. 2010). Peroxidase is a scavenging enzyme involved in regulating oxidative stress, controlling the formation of ROS content and modification of the expression of OsTIP by a gene that translates tonoplast intrinsic proteins (TIPs) (Kaldenhoff and Fischer 2006).

Although Chitosan is also worked against the abiotic stresses salt, drought, and temperature stress (Qiao et al. 2014). Besides, H_2O_2 act as a signal molecule in abiotic stress responses (Qiao et al. 2014 and Frederickson Matika and Loake 2014). And its production in the cell triggers the ROS scavenging system and expression of oxidative stress receptive genes (Desikan et al., 2001). The production of enzymes like superoxide dismutase (SOD), peroxidase (POX), and CAT in the ROS scavenging system is done with application of chitosan. The dipping application of chitosan to the grapevine cuttings in (0.5–1.0% w/v) can tolerate the low and high-temperature stress, respectively, while the 1.0%(w/v) from drought stress, by the regulation of the chlorophyll content (Górnik et al. 2008) and excised leaves grapevine in treated with 75–150 mg/L chitosan led to the enhance the activity of lipoxygenase (LOX) (Trotel-Aziz et al. 2006), which may play a vital role in the defense signaling pathway leads to acquired resistance (Doares et al. 1995 and Hu et al. 2015). The working of biostimulants has been summarized in Table 3 whereas, mechanism of abiotic stress tolerance is depicted in Fig. 1.

Problems and future perspectives

The major challenges of biostimulants are production units (industry), raw material, toxicity level, optimistic dose, and mode of action. Many of biostimulants showed an effective results during the experimentation. Out of which few biostimulants expressed their mechanisms or modes of action of biostimulants (Khan et al. 2009). The another challenge to biostimulants production is procurement of raw materials, their availability and composition that can be influenced by many factors such as the environment, plant species, and growing condition etc. (Dragovoz et al. 2009). Similarly, the attention towards the effect of biostimulants toxicity on plant has been lessen emphasized. These above issues can be mitigate by the developments in approaches like collective agronomics Metabolomics, and phenomics that help to workout discovery of mode of action of biostimulants (Aliferis and Jabaji 2011; El-Sese et al. 2020) and optimizing their dose level. Because, the use of multidisciplinary tools are essential to identify the mode of action and active

Table 3 Biostimulants effects to mitigate from the different types of abiotic stress in fruit crops

Types of abiotic stress	Name of crop	Biostimulants agent	Doses and conc	Mode of application	Effects	References
Cold stress	Avocado, Grapefruit	Methyl Jasmonates	(2.5 μM)-25 μM	Dipping	•↓↓ chilling injuries •↑↑ shelf life	Meir et al. (1996)
	Strawberry	Protein hydrolysate from animal origin	2.5 g/L	Drenching	•↑↑Increased plant biomass •Promotes flowering, and early production of fruit	Marfà et al. (2008)
	Grapevines	PGPB (*Burkholderia phytofirmans* PsJN	3×10^8 CFU/ml bacterial Suspension	Root immersion	•Promotes Stress-related gene transcripts and metabolite levels •↑↑ metabolic activity	Theocharis et al. (2012)
	strawberry	amino-acids of animal origin (porcine blood)	Alba at 1.5 g and cv. Clery and Alba at 0.5 g	Foliar spray	•Delay spring frosts and other climatic hazards for growing outdoors	Bogunović et al. (2015)
	Strawberry	Boron and plant growth promoting bacteria suspension	10% boron and 10^9 CFU/ml bacterial, 90 L/ha	Both Foliar spray and soil	•↑↑ yield, antioxidant enzyme activities and decreased freeze •↓↓Injury	Gunes et al. (2016)
	Blueberry	AMF (*Glomus mosseae*)	–	Soil application	•↑↑ superoxide dismutase, ascorbate peroxidase •↑↑ improves peroxidase activities, soluble •↑↑ sugar, proline ascorbate and glutathione accumulation	Liu et al. (2017)
Heat stress	Apple	Carnauba wax	12.5% (v/v) withwater	Foliar spray	•↓↓ sunburn damage •↓↓ fruit surface temperature and transmission of ultraviolet radiation	Schrader (2011)
	Pomegranate	Kaolin	3% concentration	Foliar spray	•↓↓ sunburn •↓↓ fruit cracking and incidence of fruit borer and bacterial blight •↑↑ physico-chemical properties of the fruit	Sharma et al. (2018a)
Drought stress	Grapevines	AMF (Glomus mosseae)	50 cm^3 of inoculum per pot	Soil application	•↑↑ pre-dawn leaf water potential, stomatal conductance and leaf net-CO2 exchange rates	Nikolaou et al. (2003)
	Grapevines	Marine active substances extracted from seaweeds	0.1% Potted plants in greenhouse	Foliar spray	•↑↑ mid day leaf water potential, •↑↑stomatal conductance and leaf net-CO2 exchange rates	Mancuso et al. (2006)

Table 3 (continued)

Types of abiotic stress	Name of crop	Biostimulants agent	Doses and conc	Mode of application	Effects	References
	Grapes	chitosan (Biochikol 020 PC)	0.5, 1 and 2%	Dipping	•↑↑ rooting of the cuttings, •↑↑ the number of new canes & no. of internodes and chlorophyll content in the leaves	Gornik et al. (2008)
	Citrus	Seaweed extract Brown *Ascophyllum nodosum* seaweed extract	–	Soil drench or foliar application	•↑↑ growth and stem water potential	Spann and Little (2011)
	Loquat	AMF (*Funneliformis mosseae)*	300 g of mycorrhizal inoculum per plant	Soil application	•↑↑ dry biomass and leaf water potential •↑↑ osmotic adjustments at root level (high proline concentration) and to the anti-oxidative molecule (i.e. glutathione)	Zhang et al. (2015a, b)
	Mango,	Potassium silicate	1.5 m M Si	Drenching	•↑↑ vegetative and productive growth •↑↑ tolerance to water stressed conditions •↓↓ harmful effects of ROS	Helaly et al. (2017)
Salinity stress	Tangerine orange	AMF (*Glomus mosseae* and *Paraglomus occultum*)	Plants exposed to 0 and 100 mM NaCl	Soil application	•↑↑ plant growth (height, stem diameter, shoot, root and total plant biomass) •↑↑ photosynthetic rate, transpiration rate and stomatal conductance	Wu et al (2010)
	Strawberry	PGPB (*Bacillus subtilis* EY2, *Bacillus atrophaeus* EY6, Bacillus spharicus GC	10^8 CFU ml^{-1}) for 30 min	Root dipping in bacterial suspensions	•↓↓ Sodium and chloride leaf and root content •↑↑ Increased leaf relative water content and final yield	Karlidag et al. (2013)
	Apple	AMF (Glomus versiforme)	(100 ml of inoculum) Potted plants	Drenching	•↑↑ leaf turgidity •↑↑ root length •↓↓ harmful effects of ROS •↑↑ ascorbate peroxidase and catalase activities) •↑↑ K+/Na+ratio	Yang et al. (2009)
	Strawberry	AMF (*Funneliformis caledonius, Funneliformis mosseae and Rhizophagus irregularis*	100 or 50 fungal propagules per plant)	Soil application	•↑↑ salt tolerance •↑↑ increased shoot and root mass •Promotes Genotype-specific effect of AMF inoculation	Sinclair et al. (2014)

Table 3 (continued)

Types of abiotic stress	Name of crop	Biostimulants agent	Doses and conc	Mode of application	Effects	References
	Persimmon	Protein hydrolysate	5 L/ha,	Drenching	•↓↓ Cl^- uptake, leaf necrosis, and leaf water potential •↑↑ biosynthesis of salt-stress-response proteins	Visconti et al. (2015)
	Date palm	AMF (*Glomus mosseae*), PGPB (*Azospirillum lipoferum*, *Paenibacillus polymyxa* and *Bacillus circulans*) and putrescine amine	Soil drench application with 85 ml per plant	Drenching	•↓↓ salt-induced oxidative damage •↑↑ photosynthetic pigments, antioxidant enzyme activity, organic solutes •promotes growth substances (e.g. gibberellic acid) •↓↓ lipid peroxidation and abscisic acid level	Naser et al. (2016)
	Grapevines	Potassium silicate (K2SiO3•9H2O)	Dosage: (2 mM)	Drenching	•↑↑leaf-area expansion rates, plant height growth, leaf photosynthesis, •↑↑ yield and potential •↑↑ the efficiency of the photosystem II	Qin et al. (2016)
	Strawberry	Potassium silicate	1 g/L	Drenching	•↑↑ peroxidase and superoxide dismutase enzyme activity •↓↓ion of proline content •↑↑ fruit yield	Yaghubi et al. (2016)
	Citrus	Unisale	7.9 L/fed	Drenching	•Protect from the saline condition improves growth and development	Hamed et al. (2017)
Nutritional	Olive	Leonardite extract (Leonardite derived humic acid)	–	Drenching	•↑↑ shoot growth, •↑↑ leaf K, B, Mg, Ca and Fe content Foliar spray	Fernández Escobar et al. (1996)
	Pear	Amino acid chelate Commercial aminoacid chelate foliar fertlizers	–	Foliar spray	•↑↑ leaf Fe, Cu, Mn and Zn content Foliar spray	Koksal et al. (1999)

Table 3 (continued)

Types of abiotic stress	Name of crop	Biostimulants agent	Doses and conc	Mode of application	Effects	References
	Strawberry	Actiwave® (Ascophyllum nodosum)	10 ml/L	Nutrient solution	•↑↑ vegetative growth & chlorophyll "stomatal •↑↑ physico-chemical properties of fruit	Spinelli et al. (2010)
	Pecannut	Protein hydrolysate Commercial organic biostimulant (Supramino) combined with urea, boric acid and zinc sulfate	0.5% urea + 0.1% boric acid + 0.5% zinc sulphate + 5 ml/L supramino	Foliar spray	•↑↑ nut weight, kernel weight/length/breadth •↑↑ Increased fruit size and weight •↑↑ kernel protein content •↑↑Zn, Fe, Mn, Cu foliar content	Ashraf et al. (2013)
	Almond	Seaweed extract Mixture of commercial plant based biostimulants (Mega Fol, Brexil-Zn, and MC-Extra) (GroZyme)	–	Foliar spray	•↑↑ shoot leaf area, shoot length •↑↑ biomass	Saa et al. (2015)
	Apricot	Humic substances Commercial Leonardite derived humic acid (Actosol) and yeast (Saccharomyces cerevisiae) extract	–	Foliar spray	•↑↑ tree yield •↑↑ vegetative growth •↑↑ total leaf chlorophyll a •↑↑ leaf N, P, K, Mg content Foliar spray	Fatma et al. (2015)

↓↓ Decreased, ↑↑ increased = maintained

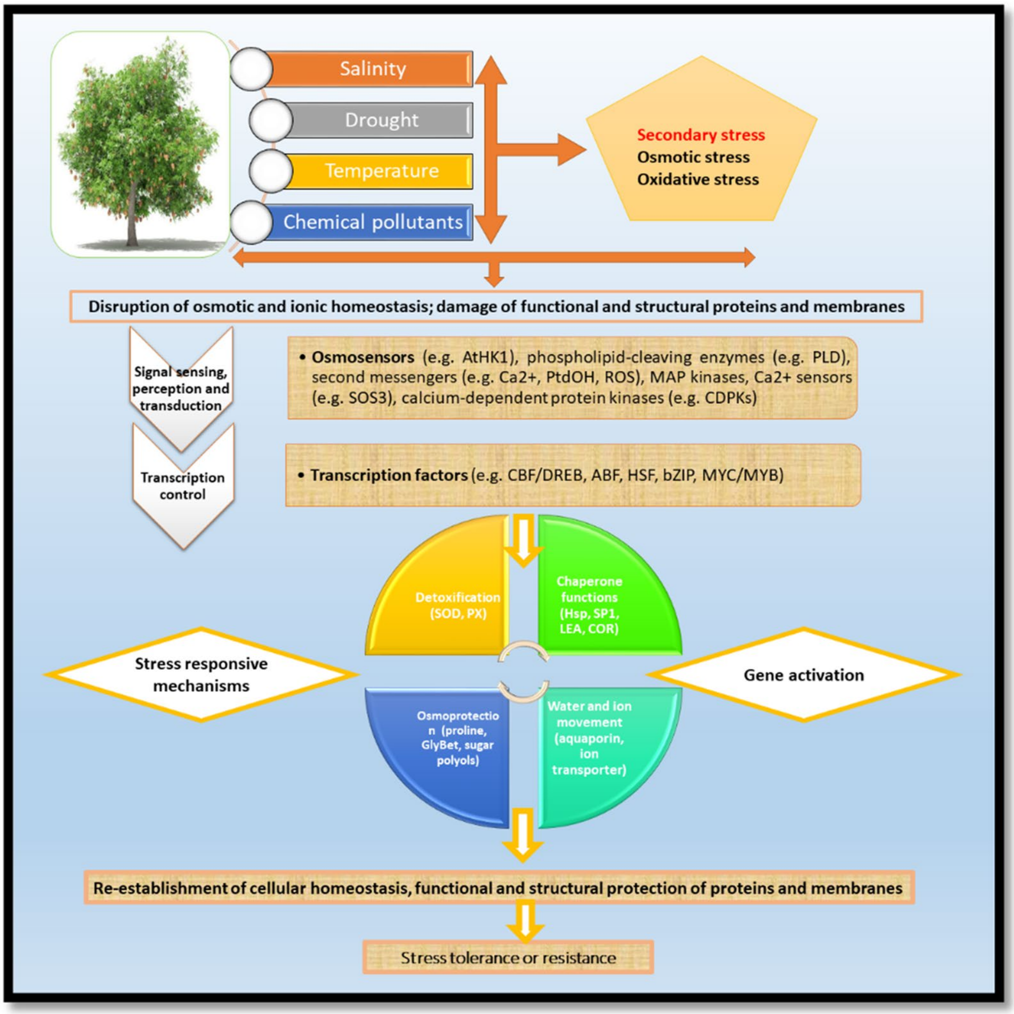


Fig.1 Responses mechanism towards abiotic stress tolerance. Primary stresses such as drought, salinity, cold, heat and chemical pollution, cause cellular level injury and secondary stresses like osmotic and oxidative stress. The initial stress signals that is osmotic and ionic effects or changes in temperature or membrane fluidity activates the signaling process and transcription panels, which activate stress- mechanisms to restore homeostasis and to defend and repair damaged proteins and membranes. Inadequate responses at one or more steps in the signaling and gene activation process might ultimately result in irreversible changes in cellular homeostasis and in the destruction of functional and structural proteins and membranes, leading to cell death. Reprinted from Vinocur and Altman (2005) with permission of © (2005) Elsevier. *ABF* ABRE binding factor, *AtHK1* Arabidopsis thaliana histidine kinase-1, *bZIP* basic leucine zipper transcription factor, *CBF/DREB* C-repeat-binding factor/dehydration-responsive binding protein, *CDPK* calcium-dependent protein kinase, *COR* cold-responsive protein, *Hsp* heat shock protein, *LEA* late embryogenesis abundant, *MAP* mitogen-activated protein, *PLD* phospholipase D, *PtdOH*, phosphatidic acid, *PX* peroxidase, *ROS* reactive oxygen species, *SOD* superoxide dismutase, *SP1* stable protein 1

components (Raldugin 2004; Craigie 2011; Jannin et al. 2012).

By reviewing the above findings, it can be confined that biostimulants promote plant growth as well as elicit the plant defense mechanism against abiotic stresses. The seaweeds extract, Humic substance and other compounds can work as biostimulators for fruit crop enhance their nutritional quality. Biostimulants exhibited no negative impacts on growth development of the plant. Biostimulants like Seaweed extract are the chief source of micro and macronutrients, which helps to amoleriate the nutrient prominence of essential nutrients (El-Sese et al. 2020) A recent report suggested the use of seaweed extract for the sustainable fruit production (Hamed et al. 2017). Direct application of seaweeds in the agricultural soil may change the soil nutrient index as well as fertility of the soil, resulting in a significant increment in the crop production. Seaweed extracts can be used either in powder or liquid form as a seed treatment. Nanoparticle synthesis by seaweed extract known as green nanoparticle synthesis has been reported (Kathiraven et al. 2015). Biostimulants may also be applied along with inorganic fertilizers, resulting reduction the cost of cultivation, which is an critical aspect of sustainable fruit production (Al-Marsoumi and Al-Hadethi 2020). Present situation in developing countries like India and their public concern is to reduce the use of unsafe chemicals (fertilizers & pesticides) for fruit crop production. The main aim is to produce the crop by eco-friendly means and are becoming more important to horticultural crop production.

Conclusion

It can be concluded from the recognized discussions that the biostimulants are the unique technologies that can work as tool for upgrading the conventional farming systems. The application of various biostimulants have shown their constructive roles in fruit orchard with respect to plant growth, fruiting improvements and environmental stability. But, there is a long way for advocating such technologies for sustainable fruit production as many challenges like legal procedures are required to be addressed for implementation on large scale. The potential uses of biostimulants will definitely create a rebellion under fertilizer industry and will meet out the problem of food insecurity in developing world.

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Author contributions

SS, VSR: (Writing—original draft preparation); SS and VSR- (Figures and Tables); VSR and SS (Conceptualization and supervision); VSR and SS (Helped in data compilation and arrangement); SS NR and US (Reviewed the write up and Helped in finalizing the draft). All authors read and approved the final manuscript.

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