Chapter

Biostimulants Application: An Innovative Approach to Food Security under Drought Stress

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Abstract

Climate change is a global threat to food security as it causes various biotic and abiotic stresses that adversely disturb agriculture production. With an increase in the worldwide population, the demand for food has also arisen. It is an immediate challenge for the scientific community to introduce an innovative tool to achieve food security with quality plant production and develop tolerance against abiotic stresses, specifically drought. Genetically modifications are effective and time-consuming, while biostimulants are in/organic substances with the potential to support plant development under stress conditions. This chapter focuses on the impacts of climate change on agriculture, challenges for agriculture sustainability and food security, the interrelationship between drought, climate change and food security, the potential role of biostimulants against drought, future aspects and challenges due to climate change specifically drought, and food security challenges. Various studies reported that the application of biostimulants results in enhancement of crop productivity and mitigates the harmful effects due to climate change. To ensure the quality of chapter, we collected references from well-reputed international journals using keywords ""biostimulants," "drought," "food security," "agriculture sustainability," and "climate change." In conclusion, biostimulants has a potential to address adverse environmental conditions without affecting crop quality and yield loss.

Keywords: abiotic stress, biostimulants, climate change, food security

1. Introduction

The world population has doubled since 1960, resulting in increased food demand and agricultural production [1]. World food production needs to be increased to 70% to feed this population in 2050 [2]. Due to high warming temperatures and precipitation shifts, agriculture has faced a massive yield decline, especially in lower latitudes [3]. Global warming speeds up crop development and reduces the maturity time and photo-assimilation period thus disturbs crop yield and quality. Moreover, such climatic conditions are more optimistic for pests. During the growing season, the climatic water balance has been projected to increase negatively, leading to water shortage [4]. Furthermore, it also affects the stomatal closure, cell damage, delayed seed germination, disturbed structure and functionality of cell membranes, enzyme inactivity, and interferences on protein synthesis, ultimately damaging crop productivity [5].

Drought is another environmental hazard described as a long period of reduced precipitation occurring in almost all climatic zones, including low and high rainfall [6]. Crop productivity and yield depend upon irrigation management, water quality, and regimes. At the same time, water shortage disturbs gaseous exchange, photosynthetic activity, evapotranspiration, stomatal closure, and nutrient uptake and consequently affects plant biomass [1]. Drought stress events are mainly associated with low rainfall and high soil evaporation due to high-temperature events, dry wind, and high light intensity. Scientists and agriculturists have introduced various drought-resistance induction strategies to cope with drought and other global warming impacts [7].

Biostimulants are substances having the potential to improve nutrient use efficiency and uptake, develop resistance against biotic and abiotic stresses, and improve quality characteristics when applied to plants [8]. Moreover, biostimulants vary in composition depending on the material used in their preparation. It enhances plant growth and nutrition when applied in minute quantities; therefore, it should not be termed as fertilizers and other soil amendments used in considerable amounts to achieve the required yield [9]. Studies reported that paramylon [10], commercial *Ascophyllum nodosum* extracts [11], and exogenous application of melatonin developed drought resistance and improved tomato quality [12]. Under drought conditions, mint quality and quantity were improved using biostimulants [13].

The objectives of this chapter were to identify the impacts of climate change on agriculture sustainability and the role of biostimulants in drought. Climate change has adversely impacted the agriculture sustainability while the biostimulants are gaining popularity due to its potential in addressing abiotic stresses. Therefore, the chapter focuses on provided the alarming signals about climate change and how farmers and other landholders can use biostimulants to achieve food security. The chapter consists of eight sections, which include the introduction (Section 1), methodology (Section 2), impacts of climate change on agriculture, both biotic and abiotic stresses (Section 3), challenges for agriculture sustainability and food security (Section 4), the interrelationship between drought, climate change, and food security (Section 5), potential role of biostimulants against drought (Section 6), future aspects and challenges (Section 7), and conclusion (Section 8), respectively.

2. Methodology

To ensure the quality of the chapter, we reviewed researched articles, review articles, books, and scientific reports only indexed by Scopus, Web of Science, Science Direct, and Google Scholar. We targeted specific keywords including "biostimulants," "drought," "food security," "agriculture sustainability," and "climate change." The articles published in well-reputed journals were studied. Moreover, the articles not related to objectives of the chapter were eliminated. The data and information collected were transformed into table and figures.

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3. Impact of climate change on agriculture

Overwhelming environmental changes have harmed agricultural production, human health, and natural systems [14]. Agriculture and climate change are linked in numerous ways since climate change is the leading driver of biotic and abiotic pressures that have detrimental effects on agriculture in an area. Concerns over the stability of the worldwide environment have led to an increase in food demand in tandem with the rapid growth of the global population. Agriculture productivity is greatly affected by water availability, air pollution, and soil quality [15]. Climate change impacts land and agriculture in many ways, including changes in yearly rainfall, heat waves, average temperature, weeds, insects, microbes, and atmospheric CO_2 or ozone level.

3.1 Effects on abiotic factors

3.1.1 Temperature

Temperature affects the growth and development of plants depending on the crop being grown [16]. Climate change reduces rainfall, wind speed, and snow cover due to rising temperatures and shortens the growing season for plants, affecting crop quality and agricultural productivity [7]. The causes of temperature rise can be traced back to global warming, which varies from place to region. In the future, developing countries will be more vulnerable, which may lead to a rise in food insecurity in the region. According to a study on the effects of frost and extreme temperatures on wheat production (*Triticum aestivum* L), frost produced unfruitfulness and abortion of created grains, while excessive heat resulted in a reduction in the number of grains formed during the filling period of the grain [17]. The high-temperature effects on a pearl millet were studied by [18], and the researchers identified sensitive stages of the plant's growth process. This research assessed temperature thresholds, genetic diversity, and pollen fertility.

Moreover, the high temperature reduces pollen germination and seed production. This also impacts pollen and pistil fertility [18, 19]. Due to the effects of climate change on agricultural production, climatic variance threatens crop production patterns, causing food insecurity.

3.1.2 Drought and rainfall

One essential abiotic variable that reduces the number of agricultural products harvested worldwide is drought [20]. It influences not only the growth of the crops but also the yield value. In an experiment on miscanthus for biofuel generation, drought treatment lowered plant weight by 45% and affected biomass composition and cell wall structural stiffness [21]. Due to the distribution and pattern of precipitation in tropical regions, the water content of the soil in these regions varies significantly [22]. This means plant water in the soil is dwindling. In addition, research to investigate the impact of precipitation timing on rainforest and grassland in the United States found that plant-usable soil water content depends on precipitation [23]. In other words, when rainfall distribution is uneven, the soil water content decreases, producing stress on plants in afflicted locations. This is frequently the outcome of climate change.

3.1.3 Waterlogging/flooding

Climate change has disrupted the hydrological cycle, reducing or impairing agricultural growth in many parts of the world. As a result, waterlogging significantly impacts agricultural productivity, particularly on flatland or areas near rivers [24]. Heavy rainfall in the area is the primary source of waterlogging, although irrigation canal leaks and clean surface drainage can also contribute. Soil compaction increases, and the amount of accessible O_2 for plant cells decreases because the diffusion process of O_2 is sluggish in ponding water [25]. Consequently, anaerobic bacteria release iron ions, manganese ions, and sulfide in large quantities because oxygen is scarce. Physiological and morphological changes occur in crops that are waterlogged [25]. In reaction to waterlogging, a plant's stomata closes, which affects gas exchange and water uptake, as well as anaerobic conditions in the rhizosphere, harms the plant's ability to absorb water [24].

3.1.4 Salinity

According to [19], worldwide salinity affects crop yield and food supplies. Since salt-sensitive crops (wheat and rice) are grown worldwide (F.A.O., 2015), salinity must be addressed soon. According to [26], rice is one of the most widely cultivated crops since it is a crucial source of sustenance for nearly all of humanity. Salinity is a stressor in dry and semiarid environments when evapotranspiration exceeds rainfall, resulting in insufficient rain to filter soluble salts from the root zone. The salinity stressor inhibits plants' capacity to absorb nutrients and water from the soil, stunting their development; salt deposits in the transpiration stream harm leaf cells, causing leaf burn; it also alters enzyme activity within the plant [27].

3.2 Effects on biotic factors

3.2.1 Livestock

The focus of the cattle industry during the past quarter-century has been on enhancing production, altering the environment, and enhancing nutritional management rather than improving stress resistance. This method substantially boosted the output of domestic animals but also increased their susceptibility to hot surroundings. The modes by which domestic animals adjust to environmental changes are crucial to their survival, but they frequently have a detrimental impact on the productivity and profitability of livestock systems [28]. Heat stress has damaging effects on the health and welfare of animals. The direct and indirect impacts of heat stress on the health of farm animals in hot environments. Increased temperatures, frequency, and severity of heat waves are the primary causes of the direct consequences. These climatic circumstances can harm the health of cattle by generating metabolic changes, oxidative stress, and immunological suppression, which can lead to illnesses and mortality. Indirect consequences include changes in the availability and quality of feedstuffs and drinking water and the survival and redistribution of diseases and/or their vectors [29].

3.2.2 Aquaculture and fisheries

Aquatic ecosystems are essential to the global environment. In addition to being crucial contributors to biodiversity and ecological production, wetlands offer several benefits to human populations, such as water for drinking and irrigation, recreational activities, and habitat for commercially significant fisheries [30]. Marine fisheries contribute significantly to people's and society's well-being, particularly in the tropics, where coastal populations rely on fisheries for food security, livelihoods, economic growth, and culture [31]. Fisheries are becoming increasingly vulnerable to changes in the physical and biogeochemical properties of the ocean (such as warming, sea-level rise, deoxygenation, acidification, and altered nutrient concentrations) caused by rising concentrations of anthropogenic greenhouse gases, particularly CO_2 [32]. The distribution, abundance, and reproduction of fish and invertebrate species are also being affected by physical and biogeochemical stresses via ecosystems, directly and indirectly impacting fisheries productivity [33]. By the year 2050, climate change may cause 10–40% of species that are appropriate for marine aquaculture to become extinct in the tropics and subtropics [34].

3.2.3 Insect pests

Pests are a key biotic component also affected by climate change and weather disturbances. Temperature increases have an immediate impact on pest reproduction, survival, dissemination, population dynamics, and interactions between pests, the environment, and natural enemies. As a result, it is critical to monitor pest presence and abundance since the conditions of their occurrence might change quickly [35]. The effect of climate change on arthropod extinction rates is between 100 and 1000 times more prominent than in the past, with 45–275 species becoming extinct daily. A temperature increase of 6°C would result in the extinction of several species, including humans. In North America and Europe, bumblebee populations have decreased by 46% and 17%, respectively, because of extreme temperatures caused by climate change, compared with the base period of 1901–1974 [36]. Climate change produces new ecological niches that allow insect pests to develop and proliferate in new geographic locations and migrate from one region to another. Due to the changing environment, farmers should expect to encounter new and significant insect issues in the following years. The spread of agricultural pests across physical and political borders threatens food security and is a global issue shared by all nations and regions.

The physiology of insects is extremely sensitive to variations in temperature; as a rule, their metabolic rate will almost double for every 10°C increase in temperature [36]. Populations of whiteflies are primarily influenced by environmental conditions such as temperature, precipitation, and humidity. Whitefly population growth is favorably associated with high temperature and humidity [37]. Increased atmospheric CO_2 levels can impact the distribution, number, and productivity of insects that feed on plants. Such increases may impact insect pests' growth, fertility, consumption rates, and population densities [38]. Climate change is expected to affect the amount, distribution, and seasonal timing of pests and their natural enemies, changing biological control activities [39]. Aphids are handled by natural enemies such as parasitic wasps and ladybirds. These species may react differently to temperature changes due to global warming [40].

4. Challenges for agricultural sustainability and food security

Agriculture, covering more than 40 of the world's land, is the sole food provider for human beings and animals [41]. It also plays a vital role in most countries' economic growth [42]. Furthermore, on an average basis, about 77% of the per capita energy requirements in the world are also fulfilled through crop base food products, while 23% of the remaining food comes from other sources, including meat, egg, and milk [43]. Consequently, the nutritional demand of the increasing population is one of the basic needs that can only be attained by increasing agricultural production [44]. So, in developing economies, there is a direct relationship between employment generation and poverty eradication with the progress in the agricultural sector [45]. However, this sector faces many problems but is also developing constantly through adopting various measures to handle these numerous challenges.

Climate change is likely to have harsh effects on various influences, including water resources, coastal regions, agriculture, human liveliness, food security, ecosystems and biodiversity. According to [46], climate change may predict about a 30% decrease in the yield of different crops in some parts of south and central Asia. Modifications in agricultural practices increased industrial products because of the global inevitability to assure access to nutrition on behalf of the increasing population along with the assimilation of markets and globalization (**Figure 1**) [47].

The world's food demand is increasing daily because of the increasing population. So, adequate food security is a critical problem [48]. According to the World Food Summit, food security can be defined as "when all the people in the world, any time, have economically and physically access to adequate, enough, and safe nutritious

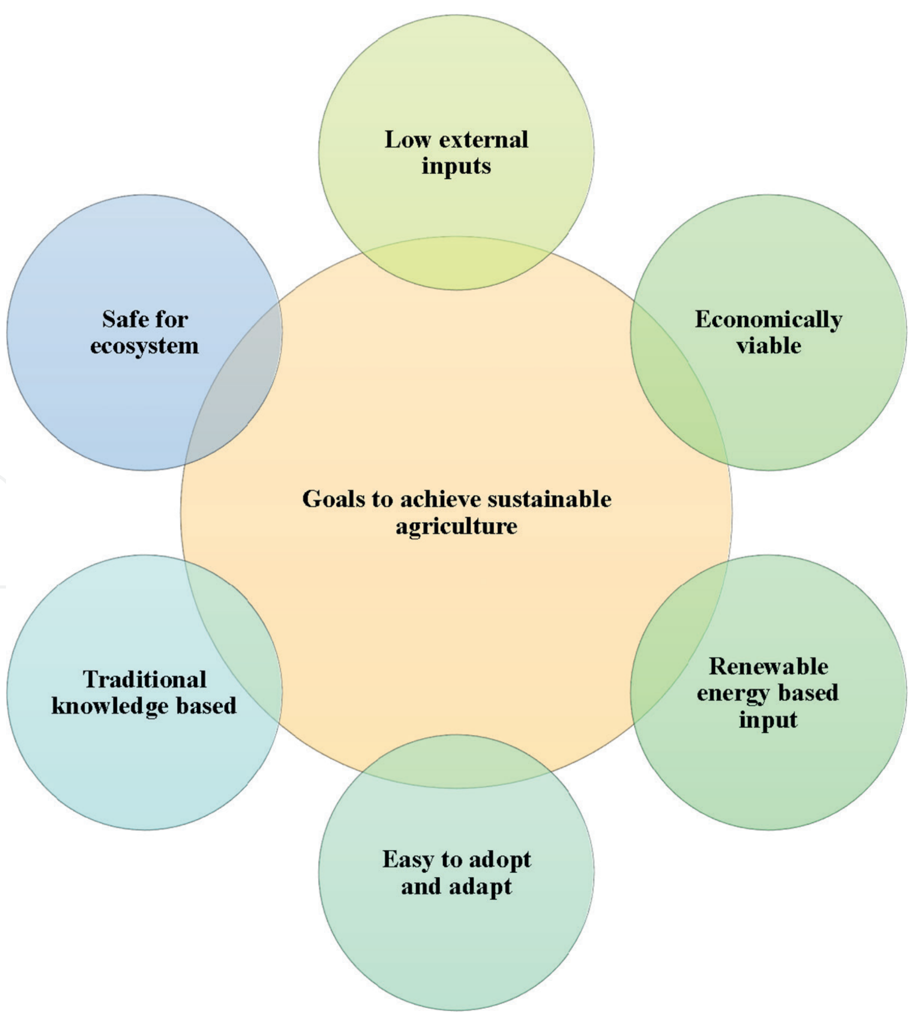

Figure 1.
Need and goals to achieve agricultural sustainability.

to fulfil their dietary requirements along with food partialities to spent healthy and active life" [49]. Food security has four main components: stability, availability, utilization, and access to food [50]. Nowadays, many challenges are faced by food security, starting from the application of various fertilizers, such as phosphorous, potassium, and nitrogen, to agricultural lands [51], then the deteriorating water tables, increasing temperatures, and an abrupt increase in population as well as consumption progression [52]. So, the two main challenges to food security are global inequity and entrepreneurial forms of production and distribution.

To cope with all these challenges, there is a need to make progress in scientific knowledge along with novel agricultural technologies that allow the communal urban agriculture practices to change with the present advanced urban agriculture. There are two types of urban agriculture, controlled environment agriculture and uncontrolled environment agriculture. According to [53], controlled environment agriculture contains agriculture practices related to environmental optimization, usually in combination with immediate urban assemblies, such as uses of greenhouse, internal farming, vertical farming, and building assimilated agriculture. While, in uncontrolled environment agriculture, vegetable farming is done in open space instead of a greenhouse and contains different types of gardens, including rooftop and community gardens that are usually indicated to play a vital role in food security globally.

5. The interrelationship between drought, climate change, and food security

Drought causes many physiological and molecular disorders in plants through excessive production of reactive oxygen species (ROS). It negatively influences the morphophysiological traits, including plant height, leaf area, relative water content, stomatal oscillation, chlorophyll contents, osmotic potential, and leaf water potential in crops [54]. Drought damages the photosynthetic process and causes stomatal closure. The reduced photosynthesis due to stomatal closure is reported to limit the supply of CO_2 [55]. Food security is dependent on social, economic, and climatic factors. Climatic extremes, particularly droughts and floods, affect the state of food security in Africa [56].

One of the key predictions of climate change is that in some regions, droughts are likely to increase in frequency and severity. This will have significant implications for the long-term viability of plant populations, especially where water availability plays a key role in delineating species ranges [57]. The human influence on the earth's climate is becoming increasingly prominent. Climate observations prove the existence of a global warming trend: global average temperature has increased by 0.88°C since 1900 [58], and the 12 hottest years observed globally since 1880 all occurred between 1990 and 2005. The climate changes will also have associated consequences for biotic (frequency and effects of pest and disease outbreaks) and abiotic disturbances (changes in fire occurrence, changes in wind storm frequency and intensity) with substantial implications for forest ecosystems [59].

Public awareness of the importance of extreme climatic events is growing [60]. While longer-term climatic reconstructions suggest that the occurrence and impacts of such climatic events are not new (e.g., Acuna-Soto et al., 2005; Benson et al., 2007), there is now a growing concern that anthropogenic global warming could increase the severity and frequency of extreme climatic events in the future [60]. From an ecological perspective, climate change also represents a major threat to global biodiversity

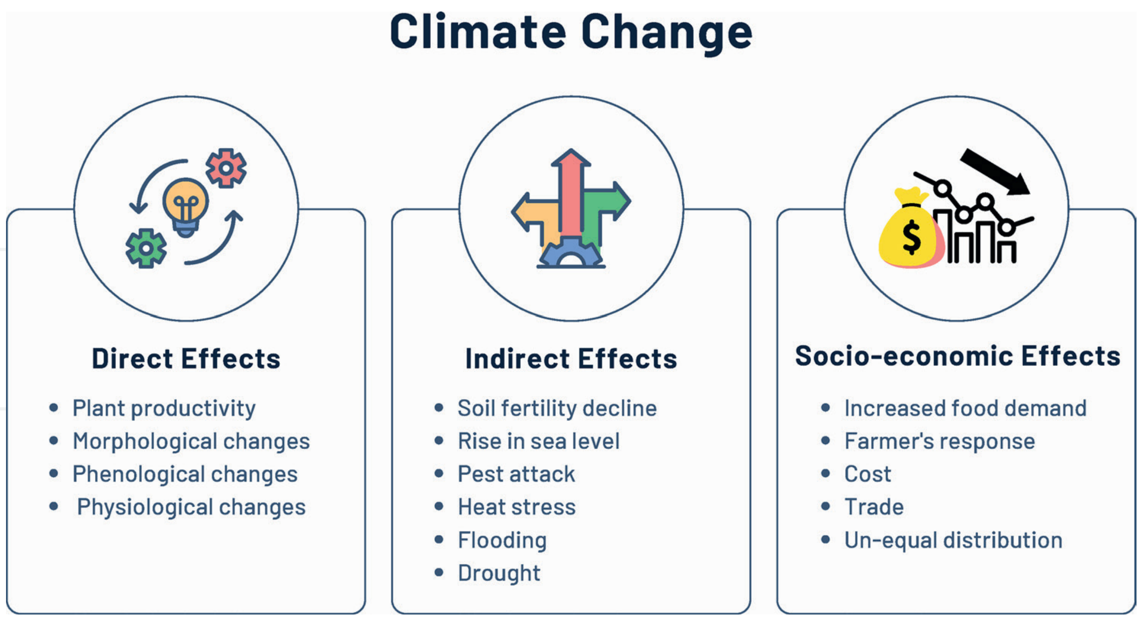

Figure 2.
Direct, indirect, and socioeconomic effects of climate change.

conservation. Indeed, it is argued that in the absence of rapid implementation of strategies to reduce global greenhouse gas emissions and other processes, many of the earth's biota will likely be committed to extinction [61]. By disturbing plant populations and derived ecosystem functions that depend on complex species interactions, extreme climatic events are likely to play a central mechanistic role, which influences food security [62]. The relationship between drought and agriculture is particularly important as 84% of the damage and losses caused by droughts relate to the agriculture sector [63]. Globally, droughts and extreme heat significantly reduced national cereal production by 9–10%, whereas the analysis could not identify flood and harsh cold effects [64]. Drought disasters in Indonesia mainly occur in Java and Madura since both islands have higher risk and vulnerability than other islands (**Figure 2**) [65].

Whereas the outcomes of abiotic stresses on crop yield are hard to calculate accurately, it is believed that abiotic stresses substantially influence crop production depending upon the extent of damage to the total area under cultivation. In future, the productivity of the major crops is estimated to drop in many countries due to global warming, water shortage, and other environmental impacts [66]. To achieve food security, water must be available at the right place, at the right time, in the right quantity, and be of the right quality. Water-related disasters negatively affect agriculture and crop production, threatening food security [67].

6. Potential role of biostimulants against drought

Drought stress impacts the agriculture sector and can adversely affect the plant's morphological, physiological, biochemical, and molecular changes, leading to reduced plant growth and productivity [68]. Water stress also results in increased reactive oxygen species (ROS) accumulation in the plant, which disturbs different cellular mechanisms, including enzyme inhabitation, protein reductase, DNA, RNA, and membrane lipid peroxidation damage leading to cell death [69]. It also disturbed the stomatal closure, enzyme activity, photosynthesis process, and transpiration rates [70].

Biostimulants can boost crop toleration against drought stress and improve crop productivity [9]. Moreover, it can potentially increase the growth and yield of plants in farming by developing tolerance against drought stresses, enhancing water retention capability, root strengthening and development, and improving nutrient and water use efficiency [71]. The impact of biostimulants highly depends on time and rate of application, abiotic environmental factors, and crop variety [72]. Studies reported that using pollen grain extract as biostimulant improved the growth and essential oil productivity of *Ocimum basilicum* under drought stress conditions [73].

In addition, arbuscular mycorrhizal fungi, plant-growth-promoting rhizobacteria, and local green compost improve date palm productivity under a water stress environment [74]. *Ascophyllum nodosum* extract biostimulants also developed drought tolerance in tomato plants [11]. Under mild drought stress, the application of *A. nodosum* seaweed extract (SWE) enhanced spinach growth [75]. While foliar-applied (SWE) improved bean yield cultivars under irrigation regimes by changing fatty acid and biochemical profiles [76]. Further benefits of biostimulants and plant responses under different conditions are given in **Table 1**.

7. Future aspects and challenges

To make water available for human consumption and irrigation, an adequate water management system must be adopted worldwide for sustainable agriculture and profitable activity of water, especially in arid and semiarid regions [83]. Biostimulants have been reported to address drought stress while maintaining crop yield and productivity [9]. However, the response of different crop cultivars and the long-term impacts of biostimulants need to be studied. Moreover, multiple sources of biostimulants should be adopted after identifying their synergistic effects rather than relying on a single basis. Literature reported the research conducted at tunnel farms, experimental greenhouse areas, and hydroponic conditions. However, field experiments should be performed to find the potential of biostimulants in real-life situations. In addition, the use of biostimulants can also provide environmental benefits. It can be used to tackle food demand by improving productivity under environment stress as well as utilization of waste products to prepare biostimulants for environment sustainability.

Furthermore, the effectiveness of biostimulants in normal environmental conditions and their comparison with chemical fertilizers can also give new insights. The use of biostimulants for sustainable agriculture to reduce agrochemical products (such as chemical fertilizers and pesticides) can be studied. Moreover, the high demand for biofertilizers and biopesticides can be addressed using natural biostimulants, including seaweed, pollen grain, moringa leaf, and many other extracts. Therefore, new and economical biostimulants with different compositions should be introduced into the market along with their specifications to specific crop/cultivar, application method, time, and dose, and their effectiveness toward specific stress conditions should be mentioned. Biostimulants vary in nature depending upon their composition and the material from which they are derived. Due to the uniqueness of every type of biostimulant, the mechanism behind its activity and performance is still not identified; thus, further studies are required in this regard because it can help scientists identify more benefits of biostimulants.

Biostimulant	Crop	Stress	Results	Reference
Saprophytic fungi (*Trichoderma harzianum* ALL-42)	Common bean (*Phaseolus vulgaris)*	Pathogenic stress	Improved shoot biomass production and number of lateral shoots, module plant's metabolism and triggers its defense response	[77]
Plant and seaweed extract	Baby spinach (*Spinacia oleracea*)	None	Improved plant growth, quality, and yield	[78]
Fresh seaweed extract of *Ascophyllum nodosum*	Lettuce	Potassium deficiency	Increased the quality of cut lettuce	[79]
Alfalfa (*Medicago sativa*) and red grape (*Vitis vinifera*) derived biostimulants	*Capsicum chinensis*	None	Promoted plant growth and the production of secondary metabolites	[80]
Salicylic acid, beeswax waste and liquorice extract	Sesame	Drought stress	Mitigate drought stress and oxidative damages, regulate osmoprotectants and antioxidant defense system and improve sesame productivity.	[81]
A. nodosum seaweed extracts	Spinach	Drought stress	Enhanced gas exchange through reduction of stomatal closure, resulting in increased plant resistance to water stress.	[75]
ERANTHIS®® (seaweed A. nodosum, Laminaria digitata, and yeast-based extracts)	Tomato	Drought stress	Mitigate water stress	[82]
Biostimulants, Vitamin B12, and CoQ10	Red radish	None	Improved fresh and dry weights of roots and shoots	[72]
Glycine, lysine, aspartic acid, vitamin B complex, and moringa leaf extract	Radish	None	Improved morpho-physiology properties and yield	[8]
A.M.F. consortium (A.M.F.), indigenous PGPR (B), and local green compost	Date palm	Drought stress	Mitigated drought stress, improved plant biomass and phosphorus uptake, and boosted plant-water relationship	[74]

Table 1.
Benefits of biostimulants and plant responses.

8. Conclusion

High food demand, climate change, increasing incidences of weather extremities, and other biotic and abiotic stresses have created severe pressure on crops. Conventional agriculture practices are challenging to maintain in such scenarios.

Therefore, farmers and scientists are facing the challenge of finding an appropriate approach to tackle environmental stresses and maintain crop productivity. Biostimulants are an innovative tool to address the issue without adversely affecting crop quality and yield loss. We studied the latest research in this aspect, and biostimulants have reported positive responses against adverse environmental conditions. However, further studies are required to identify the crop response in different areas of the globe and its long-term potential under other stress conditions.

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References

[1] Del Buono D. Can biostimulants be used to mitigate the effect of anthropogenic climate change on agriculture? It is time to respond. Science of the Total Environment. 2021;**751**:141763

[2] van Dijk M, Morley T, Rau ML, Saghai Y. A meta-analysis of projected global food demand and population at risk of hunger for the period 2010-2050. Nature Food. 2021;**2**:494-501. DOI: 10.1038/s43016-021-00322-9

[3] Froehlich HE, Koehn JZ, Holsman KK, Halpern BS. Emerging trends in science and news of climate change threats to and adaptation of aquaculture. Aquaculture. 2022;**549**:737812

[4] Bisbis MB, Gruda N, Blanke M. Potential impacts of climate change on vegetable production and product quality – A review. Journal of Cleaner Production. 2018;**170**:1602-1620

[5] Fahad S, Bajwa AA, Nazir U, Anjum SA, Farooq A, Zohaib A, et al. Crop production under drought and heat stress: Plant responses and management options. Frontiers in Plant Science. 2017;8:1147

[6] Orimoloye IR, Belle JA, Orimoloye YM, Olusola AO, Ololade OO. Drought: A common environmental disaster. Atmosphere (Basel). 2022;**13**:111

[7] Seleiman MF, Al-Suhaibani N, Ali N, Akmal M, Alotaibi M, Refay Y, et al. Drought stress impacts on plants and different approaches to alleviate its adverse effects. Plants. 2021;**10**:1-25

[8] Raza Q-U-A, Bashir MA, Rehim A, Ejaz R, Raza HMA, Shahzad U, et al. Biostimulants induce positive changes in the radish morpho-physiology and yield. Frontiers in Plant Science. 2022;**0**:2475. DOI: 10.3389/FPLS.2022.950393

[9] Bashir MA, Rehim A, Raza Q-U-A, Muhammad Ali Raza H, Zhai L, Liu H, et al. Biostimulants as plant growth stimulators in modernized agriculture and environmental sustainability. In: Technology in Agriculture [Working Title]. London, UK: IntechOpen; 2021 ISBN 978-1-83881-922-4

[10] Barsanti L, Coltelli P, Gualtieri P. Paramylon treatment improves quality profile and. Agronomy. 2019;**9**:1-16

[11] Goñi O, Quille P, O'Connell S. Ascophyllum nodosum extract biostimulants and their role in enhancing tolerance to drought stress in tomato plants. Plant Physiology and Biochemistry. 2018;**126**:63-73. DOI: 10.1016/j.plaphy.2018.02.024

[12] Karaca P, Cekic FÖ. Exogenous melatonin-stimulated defense responses in tomato plants treated with polyethylene glycol. International Journal of Vegetable Science. 2019;**25**:601-609. DOI: 10.1080/19315260.2019.1575317

[13] Elansary HO, Mahmoud EA, El-Ansary DO, Mattar MA. Effects of water stress and modern biostimulants on growth and quality characteristics of mint. Agronomy. 2020;**10**:6. DOI: 10.3390/agronomy10010006

[14] Araújo MB, Rahbek C. How does climate change affect biodiversity? Science (80-.). 2006;**313**:1396-1397

[15] Noya I, González-García S, Bacenetti J, Fiala M, Moreira MT. Environmental impacts of the cultivation-phase associated with

agricultural crops for feed production. Journal of Cleaner Production. 2018;**172**:3721-3733. DOI: 10.1016/j.jclepro.2017.07.132

[16] Hatfield JL, Prueger JH. Temperature extremes: Effect on plant growth and development. Weather and Climate Extremes. 2015;**10**:4-10. DOI: 10.1016/j.wace.2015.08.001

[17] Barlow KM, Christy BP, O'Leary GJ, Riffkin PA, Nuttall JG. Simulating the impact of extreme heat and frost events on wheat crop production: A review. Field Crops Research. 2015;**171**:109-119. DOI: 10.1016/J.FCR.2014.11.010

[18] Djanaguiraman M, Perumal R, Ciampitti IA, Gupta SK, Prasad PVV. Quantifying pearl millet response to high temperature stress: Thresholds, sensitive stages, genetic variability and relative sensitivity of pollen and pistil. Plant, Cell & Environment. 2018;**41**:993-1007. DOI: 10.1111/pce.12931

[19] Dhankher OP, Foyer CH. Climate resilient crops for improving global food security and safety. Plant, Cell & Environment. 2018;**41**:877-884

[20] Tuberosa R, Grillo S, Ellis RP. Unravelling the genetic basis of drought tolerance in crops. In: Abiotic Stresses in Plants. Netherlands: Springer; 2003. pp. 71-122

[21] van der Weijde T, Huxley LM, Hawkins S, Sembiring EH, Farrar K, Dolstra O, et al. Impact of drought stress on growth and quality of miscanthus for biofuel production. GCB Bioenergy. 2017;**9**:770-782. DOI: 10.1111/gcbb.12382

[22] Smith MD. An ecological perspective on extreme climatic events: A synthetic definition and framework to guide future research. Journal of Ecology. 2011;**99**:656-663

[23] Zeppel MJB, Wilks JV, Lewis JD. Impacts of extreme precipitation and seasonal changes in precipitation on plants. Biogeosciences. 2014;**11**:3083-3093. DOI: 10.5194/bg-11-3083-2014

[24] Aldana F, García PN, Fischer G. Effect of waterlogging stress on the growth, development and symptomatology of cape gooseberry (Physalis peruviana L.) plants. Revista de la Academia Colombiana de Ciencias Exactas, Físicas y Naturales. 2014;**38**:393. DOI: 10.18257/raccefyn.114

[25] Ashraf M, Mehmood S. Effects of waterlogging on growth and some physiological parameters of four brassica species. Plant and Soil. 1990;**121**:203-209. DOI: 10.1007/BF00012313

[26] Food and Agricultural Organisation of the United Nations. The Future of Food and Agricultural Trends and Challenges. Rome: Food and Agricultural Organisation; 2015

[27] Fowler DN, King SL, Weindorf DC. Evaluating abiotic influences on soil salinity of inland managed wetlands and agricultural croplands in a semi-arid environment. Wetlands. 2014;**34**:1229-1239. DOI: 10.1007/s13157-014-0585-3

[28] Bernabucci U. Climate change: Impact on livestock and how can we adapt. Animal Frontiers. 2019;**9**:3-5

[29] Lacetera N. Impact of climate change on animal health and welfare. Animal Frontiers. 2019;**9**:26-31. DOI: 10.1093/af/vfy030

[30] Prakash S. Impact of climate change on aquatic ecosystem and its biodiversity: An overview. International Journal of Biological Innovations. 2021;**03**:312-317. DOI: 10.46505/ijbi.2021.3210

[31] Teh LCL, Pauly D. Who brings in the fish? The relative contribution of small-scale and industrial fisheries to food security in Southeast Asia. Frontiers in Marine Science. 2018;**5**:44. DOI: 10.3389/fmars.2018.00044

[32] Barange M, Bahri T, Beveridge MCM, Cochrane KL, Funge-Smith S, Poulain F. Impacts of climate change on fisheries and aquaculture. United Nations' Food and Agriculture Organization. 2015;12(4):628-635

[33] Laffoley D, Baxter JM, editors. Explaining ocean warming: Causes, scale, effects and consequences. Gland, Switzerland: IUCN; 2016

[34] Oyinlola MA, Reygondeau G, Wabnitz CCC, Cheung WWL. Projecting global mariculture diversity under climate change. Global Change Biology. 2020;**26**:2134-2148. DOI: 10.1111/gcb.14974

[35] Prakash A, Rao J, Mukherjee AK, Berliner J, Pokhare SS, Adak T, et al. Climate change: Impact on crop pests. Research Today. 2014;**2**:327-329

[36] Dukes JS, Pontius J, Orwig D, Garnas JR, Rodgers VL, Brazee N, et al. Responses of insect pests, pathogens, and invasive plant species to climate change in the forests of northeastern North America: What can we predict? Canadian Journal of Forest Research. 2009;**39**:231-248

[37] Pathania M, Verma A, Singh M, Arora PK, Kaur N. Influence of abiotic factors on the infestation dynamics of whitefly, Bemisia tabaci (Gennadius 1889) in cotton and its management strategies in North-Western India. International Journal of Tropical Insect Science. 2020;**40**:969-981. DOI: 10.1007/s42690-020-00155-2

[38] Fuhrer J. Agroecosystem responses to combinations of elevated CO2, ozone, and global climate change. Agriculture, Ecosystems and Environment. 2003;**97**:1-20

[39] Thomson LJ, Macfadyen S, Hoffmann AA. Predicting the effects of climate change on natural enemies of agricultural pests. Biological Control. 2010;**52**:296-306

[40] Hullé M, Coeur d'Acier A, Bankhead-Dronnet S, Harrington R. Aphids in the face of global changes. Comptes Rendus Biologies. 2010;**333**:497-503. DOI: 10.1016/j.crvi.2010.03.005

[41] Sah D, Devakumar AS. The carbon footprint of agricultural crop cultivation in India. Carbon Management. 2018;**9**:213-225. DOI: 10.1080/17583004.2018.1457908

[42] Bose B, Mondal S. Climate change and sustainable agriculture in context to seed priming and role of nitrate. Vegetos. 2013;**26**:192-204. DOI: 10.5958/j.2229-4473.26.2s.140

[43] Brevik EC, Burgess LC, editors. Soils and human health. Florida, USA: CRC Press; 2012. ISBN 9781439844557

[44] Singh R, Singh H, Raghubanshi AS. Challenges and opportunities for agricultural sustainability in changing climate scenarios: A perspective on Indian agriculture. Tropical Ecology. 2019;**60**:167-185

[45] Srivastava P, Singh R, Tripathi S, Raghubanshi AS. An urgent need for sustainable thinking in agriculture - an Indian scenario. Ecological Indicators. 2016;**67**:611-622. DOI: 10.1016/j.ecolind.2016.03.015

[46] Arora S, Bhatt R. Resource conservation technologies (R.C.T.s) for climate-resilient agriculture in the foothill of Northwest Himalayas. In:

Conservation Agriculture: An Approach to Combat Climate Change in Indian Himalaya. Singapore: Springer; 2016. pp. 71-111 ISBN 9789811025587

[47] Quintero-Angel M, González-Acevedo A. Tendencies and challenges for the assessment of agricultural sustainability. Agriculture, Ecosystems and Environment. 2018;**254**:273-281

[48] Santeramo FG, Carlucci D, De Devitiis B, Seccia A, Stasi A, Viscecchia R, et al. Emerging trends in European food, diets and food industry. Food Research International. 2018;**104**:39-47. DOI: 10.1016/j.foodres.2017.10.039

[49] Mah CL, Hamill C, Rondeau K, McIntyre L. A frame-critical policy analysis of Canada's response to the world food summit 1998-2008. Archives of Public Health. 2014;**72**:1-7. DOI: 10.1186/2049-3258-72-41

[50] Briones Alonso E, Cockx L, Swinnen J. Culture and food security. Global Food Security. 2018;**17**:113-127

[51] Cordell D, Drangert JO, White S. The story of phosphorus: Global food security and food for thought. Global Environmental Change. 2009;**19**:292-305. DOI: 10.1016/j.gloenvcha.2008.10.009

[52] Godfray HCJ, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, et al. Food security: The challenge of feeding 9 billion people. Science (80-.). 2010;**327**:812-818

[53] Al-Kodmany K. The vertical farm: A review of developments and implications for the vertical city. Buildings. 2018;**8**:24

[54] Sammar Raza MA, Saleem M, Khan I, Jamil M, Ijaz M, Khan MA. Evaluating the drought stress tolerance efficiency of wheat (Triticum aestivum l.) cultivars. Russian Journal of Agricultural and Socio-Economic Sciences. 2012;**12**:41-46. DOI: 10.18551/rjoas.2012-12.04

[55] Li M, Yang Y, Raza A, Yin S, Wang H, Zhang Y, et al. Heterologous expression of Arabidopsis thaliana rty gene in strawberry (Fragaria × ananassa Duch.) improves drought tolerance. BMC Plant Biology. 2021;**21**:1-20. DOI: 10.1186/s12870-021-02839-4

[56] Scoones I. Hazards and opportunities: Farming livelihoods in dryland Africa. Lessons from Zimbabwe. London, UK: Zed Books; 1996. ISBN 1856493539

[57] Alizadeh V, Shokri V, Soltani A, Yousefi MA. Effects of climate change and drought-stress on plant Physiologya. International Journal of Advanced Biological and Biomedical Research. 2014;**2**:468-472

[58] Hansen J, Sato M, Ruedy R, Lo K, Lea DW, Medina-Elizade M. Global temperature change. Proceedings of the National Academy of Sciences of the United States of America. 2006;**103**:14288-14293. DOI: 10.1073/pnas.0606291103

[59] Lindner M, Maroschek M, Netherer S, Kremer A, Barbati A, Garcia-Gonzalo J, et al. Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. Forest Ecology and Management. 2010;**259**:698-709. DOI: 10.1016/j.foreco.2009.09.023

[60] Beniston M, Stephenson DB. Extreme climatic events and their evolution under changing climatic conditions. Global and Planetary Change. 2004;**44**:1-9. DOI: 10.1016/j.gloplacha.2004.06.001

[61] Thomas CD, Cameron A, Green RE, Bakkenes M, Beaumont LJ, Collingham YC, et al. Extinction risk from climate change. Nature. 2004;**427**:145-148. DOI: 10.1038/nature02121

[62] Parmesan C, Root TL, Willig MR. Impacts of extreme weather and climate on terrestrial biota. Bulletin of the American Meteorological Society. 2000;**81**:443-450. DOI: 10.1175/1520-0477(2000)081<0443:IOEWAC>2.3.CO;2

[63] F.A.O. Food and Agriculture Organization. National Institute of Health and National Food Nutrition Survey. Rome: Islamabad, Food balance sheet; 2015

[64] Lesk C, Rowhani P, Ramankutty N. Influence of extreme weather disasters on global crop production. Nature. 2016;**529**:84-87. DOI: 10.1038/nature16467

[65] Maarif S. Meningkatkan kapasitas masyarakat dalam mengatasi risiko bencana kekeringan. Jurnal Sains dan Teknologi Indonesia. 2013;**13**:65-73. DOI: 10.29122/jsti.v13i2.886

[66] Bonan GB, Doney SC. Climate, ecosystems, and planetary futures: The challenge to predict life in earth system models. Science. 2018;**359**(6375):eaam8328

[67] Pratiwi EPA, Ramadhani EL, Nurrochmad F, Legono D. The impacts of flood and drought on food security in Central Java. Journal of the Civil Engineering Forum. 2020;**6**:69. DOI: 10.22146/jcef.51872

[68] Bogati K, Walczak M. The impact of drought stress on soil microbial community. Enzyme Activities and Plants. Agronomy. 2022;**12**:189

[69] Challabathula D, Analin B, Mohanan A, Bakka K. Differential modulation of photosynthesis, R.O.S. and antioxidant enzyme activities in stress-sensitive and -tolerant rice cultivars during salinity and drought upon restriction of COX and AOX pathways of mitochondrial oxidative electron transport. Journal of Plant Physiology. 2022;**268**:153583. DOI: 10.1016/j.jplph.2021.153583

[70] Li Z, Su X, Chen Y, Fan X, He L, Guo J, et al. Melatonin improves drought resistance in maize seedlings by enhancing the antioxidant system and regulating abscisic acid metabolism to maintain stomatal opening under PEG-induced drought. Journal of Plant Biology. 2021;**64**:299-312. DOI: 10.1007/s12374-021-09297-3

[71] Bulgari R, Cocetta G, Trivellini A, Vernieri P, Ferrante A. Biostimulants and crop responses: A review. Biological Agriculture and Horticulture. 2015;**31**:1-17

[72] Rehim A, Amjad Bashir M, Raza Q-U-A, Gallagher K, Berlyn GP. Yield enhancement of biostimulants, vitamin B12, and CoQ10 compared to inorganic fertilizer in radish. Agronomy. 2021;**11**:697. DOI: 10.3390/agronomy11040697

[73] Taha RS, Alharby HF, Bamagoos AA, Medani RA, Rady MM. Elevating tolerance of drought stress in Ocimum basilicum using pollen grains extract; a natural biostimulant by regulation of plant performance and antioxidant defense system. South African Journal of Botany. 2020;**128**:42-53. DOI: 10.1016/j.sajb.2019.09.014

[74] Akensous FZ, Anli M, Boutasknit A, Ben-Laouane R, Ait-Rahou Y, Ahmed HB, et al. Boosting date palm (Phoenix dactylifera L.)

growth under drought stress: Effects of innovative biostimulants. Gesunde Pflanz. 2022:1-22. DOI: 10.1007/s10343-022-00651-0

[75] Xu C, Leskovar DI. Effects of a. nodosum seaweed extracts on spinach growth, physiology and nutrition value under drought stress. Science and Horticulture (Amsterdam). 2015;**183**:39-47. DOI: 10.1016/J.SCIENTA.2014.12.004

[76] Ziaei M, Pazoki A. Foliar-applied seaweed extract improves yield of common bean (Phaseolus vulgaris L.) cultivars through changes in biochemical and fatty acid profile under irrigation regimes. Journal of Soil Science and Plant Nutrition. 2022;**1**:1-11. DOI: 10.1007/s42729-022-00860-6

[77] Pereira JL, Queiroz RML, Charneau SO, Felix CR, Ricart CAO, Lopes Da Silva F, et al. Analysis of Phaseolus vulgaris response to its association with Trichoderma harzianum (ALL-42) in the presence or absence of the phytopathogenic fungi Rhizoctonia solani and fusarium solani. PLoS One. 2014;**9**:e98234. DOI: 10.1371/journal.pone.0098234

[78] Rouphael Y, Giordano M, Cardarelli M, Cozzolino E, Mori M, Kyriacou MC, et al. Plant-and seaweed-based extracts increase yield but differentially modulate nutritional quality of greenhouse spinach through biostimulant action. Agronomy. 2018;**8**:126. DOI: 10.3390/agronomy8070126

[79] Chrysargyris A, Xylia P, Anastasiou M, Pantelides I, Tzortzakis N. Effects of Ascophyllum nodosum seaweed extracts on lettuce growth, physiology and fresh-cut salad storage under potassium deficiency. Journal of the Science of Food and Agriculture. 2018;**98**:5861-5872. DOI: 10.1002/jsfa.9139

[80] Ertani A, Pizzeghello D, Francioso O, Sambo P, Sanchez-Cortes S, Nardi S. Capsicum chinensis L. growth and nutraceutical properties are enhanced by biostimulants in a long-term period: Chemical and metabolomic approaches. Frontiers in Plant Science. 2014;**5**:375. DOI: 10.3389/fpls.2014.00375

[81] Pourghasemian N, Moradi R, Naghizadeh M, Landberg T. Mitigating drought stress in sesame by foliar application of salicylic acid, beeswax waste and licorice extract. Agricultural Water Management. 2020;**231**:105997. DOI: 10.1016/j.agwat.2019.105997

[82] Campobenedetto C, Agliassa C, Mannino G, Vigliante I, Contartese V, Secchi F, et al. A biostimulant based on seaweed (Ascophyllum nodosum and Laminaria digitata) and yeast extracts mitigates water stress effects on tomato (Solanum lycopersicum L.). Agriculture. 2021;**11**:557. DOI: 10.3390/AGRICULTURE11060557

[83] Zeggaf Tahiri A, Carmi G, Ünlü M. Promising water management strategies for arid and semiarid environments. In: Landscape Architecture - Processes and Practices Towards Sustainable Development. London, UK: IntechOpen; 2021 ISBN 978-1-83968-377-0