AGRONOMY SCIENCE
wcześniej – formerly
Annales UMCS sectio E Agricultura

VOL. LXXVIII (4) 2023

https://doi.org/10.24326/as.2023.5235

Institute of Horticulture Production, Faculty of Horticulture and Landscape Architecture, University of Life Sciences in Lublin, Akademicka 13, 20-950 Lublin, Poland
* e-mail: kamil.buczynski@up.lublin.pl

KAMIL BUCZYŃSKI

The role of biostimulants in modern fruit tree and shrub cultivation

Rola biostymulatorów w nowoczesnej uprawie drzew i krzewów owocowych

Summary. Dynamic changes in the fruit tree and shrub cultivation sector caused, among other things, by a high increase in production costs, the European Green Deal and increasingly high requirements with regard to the quality parameters of the obtained yield and their safety for consumers force producers to continuously introduce new changes in cultivation technology in order to meet all requirements. Choosing the optimum cultivation technology is also crucial to the economic success of farmers, allowing them to continue to operate and grow. One of the fastest growing branches of crop support today is biostimulation. Although biostimulants are not essential for crop production, their use can be fundamental under certain conditions. The aim of this paper was to provide comprehensive information on research in the field of biostimulation of fruit trees and shrubs and to consider the potential use of such preparations in the perspective of maximising the use of fertilisers, plant protection products and improving the quality, structure and microbial life of soils and substrates. At the same time, obtaining the highest possible yield with the highest possible crop quality, fully safe for consumer consumption.

Key words: biostimulators, plant protection, fertilisation, soil, crop, abiotic stress

INTRODUCTION

In the history of biostimulants, many definitions of this product group have been developed. Some of these definitions have proved helpful in defining biostimulants, but many have been too general or too narrow, and further attempts to define 'biostimulant' are needed [du Jardin 2015, Yakhin et al. 2017]. Biostimulation of plants is developing

Citation: Buczyński K., 2023. The role of biostimulants in modern fruit tree and shrub cultivation. Agron. Sci. 78(4), 127–136. https://doi.org/10.24326/as.2023.5235

rapidly as is the knowledge about them [Colla and Rouphael 2015].The use of biostimulants by growers, has now become a common practice with a number of positive effects in crop production [Van Oosten et al. 2017]. Biostimulants are currently receiving a great deal of attention from both the scientific community and crop formulation manufacturers [Brown and Saa 2015]. Concerns about the efficacy of biostimulants have now died out, due to the myriad scientific evidence of their positive effects on plants [Boukhari et al. 2020].

Biostimulants in their composition include inorganic substances, organic substances and microorganisms [Rouphael and Colla 2018]. Today, biostimulants are produced from a wide range of raw materials and often have a multicomponent composition [du Jardin 2015]. They are produced from seaweeds, humic acids, bacteria, fungi and animal and plant amino acids, among others [Khan et al. 2012, Calvo et al. 2014, Sharma et al. 2014, Battacharyya et al. 2015, Yakhin et al. 2017, Chiaiese et al. 2018]. This diversity also applies to the production processes of these formulations, as well as their processing and purification. The diversity of raw material mixtures, makes it even more difficult to define biostimulants correctly [Colla et al. 2015, Ugolini et al. 2015, Yakhin et al. 2017]. Each biostimulant, depending on its type and on which species and cultivar it was applied to, can cause different and multifaceted effects [Tarantino et al. 2018, Bulgari et al. 2019, Drobek et al. 2019]. Categorising and identifying the mechanisms of action of biostimulants, solely on the basis of the origin of the raw materials used to produce them, is very complicated, as both the environment can affect the raw materials as well as their location, and the application of the biostimulant itself [Shekhar et al. 2012, Hasanuzzaman et al. 2021]. Farmers' knowledge of the effect of biostimulants is still too low, a fact that is mainly due to the multitude of biostimulants available on the market and their functions and rules of application which sometimes results in the fear of increasing crop costs and adverse effects of the treatment [Drobek et al. 2019]. For successful implementation of biostimulants on the market and in practical use, a thorough understanding of their functions and mechanism of action, also at metabolic and molecular levels, is needed [Ma et al. 2022]. Proper data management and analysis is crucial for the discovery, evaluation and marketing of new biostimulants that can contribute to meeting the challenges of modern crop production [Povero et al. 2016]. Obtaining knowledge on the correct use of biostimulants, as well as their regulation, registration and certification, requires the collaboration of biologists, chemists, physiologists, distributor manufacturers and growers themselves [Jannin et al. 2012, Lee et al. 2012].

IMPACT ON GROWTH AND YIELD PARAMETERS

A fundamental goal of crop production is the sustainable development of cropping systems that are friendly to the surrounding environment, while being productive enough to meet the nutritional needs of a growing world population. The decreasing cultivated area and approaching the maximum genetic potential of plants, forces to maximise the growth and yield parameters obtained [Carvalho and Vasconcelos 2013]. The yield obtained should be characterised by a high nutrient content, which is particularly important for the consumers themselves [Eckardt et al. 2009]. The use of biostimulants can influence the participation in the regulation of secondary metabolism of treated plants, having a positive effect on fruit quality and nutritional value [Graziani et al. 2020]. The application of seaweed extract in grapevine cultivation had a positive effect on the weight of the yield obtained [Arioli et al. 2021], as well as the number of berries and the extraction of anthocyanins from fruit skins, while a decrease in phenolic and tannin content was noted [Taskos et al. 2019]. In mandarin cultivation, Ascophyllum extract increased yield [Fornes et al. 2005], and in strawberries, an effect on shoot and root system growth was also shown [Alam et al. 2013]. The application of Göemar biostimulant had a positive effect on yield quality parameters of pear crops, as well as their productivity [Colavita et al. 2011], in apple cultivation the biostimulant increased apple weight, diameter and total yield [Marjańska-Cichoń and Sapieha-Waszkiewicz 2012]. Amino acid-based biostimulants were shown to have a positive effect on improved growth in *Citrus grandis* cultivation [Alalaf et al. 2022], while mango trees showed beneficial effects on fruit setting and yield [Khattab et al. 2016].The application of biostimulants increased the antioxidant activity of apricot fruit [Tarantino et al. 2018].

EFFECTS ON NUTRIENT AVAILABILITY

Although global crop production currently relies on synthetic fertilisers, in the long term biostimulants can reduce fertiliser use and play an important role in ensuring food security for the entire population [Zulfiqar et al. 2020]. Biostimulants are one of the innovative tools to facilitate adaptation to sustainable agriculture to ensure, among other things, a more efficient uptake of nutrients [Povero et al. 2016, Tavarini et al. 2018]. Biostimulant formulations and biofertilisers are environmentally friendly and economically viable alternatives to plant growth regulators as well as synthetic fertilisers, avoiding nutrient leaching to groundwater [Samuels et al. 2022]. Biostimulants especially based on amino acids, increase the assimilation of nutrients such as nitrogen, while also having a positive effect on biomass production, photosynthesis and increasing nitrogen accumulation in the plants [Navarro-León et al. 2022].

In the case of *Citrus grandis* cultivation, biostimulants having amino acids in their composition increased especially the nitrogen, phosphorus and iron content in the leaves, but decreased the zinc content [Alalaf et al. 2022]. Increased efficiency of copper uptake [Turan and Köse 2006] and potassium and calcium uptake has been shown in grapevines after the application of biostimulants based on seaweed extract [Mancuso et al. 2006], in olives increased K, Fe, Cu but decreased Mn content was shown, also after application of seaweed extract [Chouliaras et al. 2009]. The application of four different biostimulants on maiden apple trees, decreased the content of macronutrients in the leaves, except calcium; in the case of micronutrients, the level of iron and manganese increased, but the amount of zinc and copper decreased [Świerczyński and Antonowicz 2021]. The application of biostimulants in strawberry cultivation affected Si, Zn, B and Fe concentrations in leaves and roots, but there were no significant differences in macronutrient cases [Soppelsa et al. 2019]. Biostimulants at reduced mineral fertilisation compared to the control set had no effect on photosynthetic and conductance intensity, but increased leaf transpiration coefficient and carbon dioxide concentrations, also having an effect on increasing the total length and number of shoots of maiden apple trees [Świerczyński et al. 2021].

ROLE IN PROTECTION AGAINST PATHOGENS AND PESTS

In addition to increasing production efficiency and yield quality, the horticultural sector needs to reduce reliance on agrochemicals and also increase their efficiency, biostimulants in the long term can play a key role here [Zulfiqar et al. 2020]. Particularly in the lapse of recent years, the practice of using biostimulants including defence inducers to reduce plant pathogens is gaining popularity [Calvo et al. 2014]. The effect of inducing plant defences against biotic stresses has now been proven for some of the biostimulants based on seaweed extracts and plant-derived substances [du Jardin 2015, Pylak et al. 2019].

Seaweed-based biostimulants have phyto-stimulatory properties, inducing phytoelicitor activity to activate plant defence responses to certain pests and diseases, a phenomenon that is often associated with the regulation of genes and pathways linked to the immune system [Ali et al. 2021]. Biostimulant preparations based on seaweed extract in grapevines increase resistance to fungal diseases [Samuels et al. 2022]. Seaweed extracts of various origins show biological activity against harmful bacteria, nematodes, viruses and fungi [Nabti et al. 2017]. The use of chitosan-based formulations reduced the development of *Botrytis cinerea* and *Neonectria liriodendri* in grapevine [Romanazzi et al. 2002, Nascimento et al. 2007], while a biostimulant formulation based on salicylic acid and chitosan nanoparticles [SA-CS NP] showed antifungal activity and induced natural plant immunity [Kumaraswamy et al. 2019]. The biostimulant PSP1 limits the growth of many pathogens and is based on the activation of the natural plant immune system [AsES], an intracellular prosthesis that is produced by the harmful pathogen in strawberry *Acremonium strictum* [Chalfoun et al. 2018]. Biostimulant preparations from marine algae, not only affect the efficacy of pesticides, but also have an antifungal effect, an effect that has been confirmed over the reduction of anthracnose on banana and papaya plants [Machado et al. 2014]. Amino acids had an effect on reducing the percentage of vines with symptoms of *Candidatus phytoplasma solani* infestation [Moussa et al. 2021], and the application of amino acids with zinc reduced the incidence of 'Jonathan spot' during apple storage [Soppelsa et al. 2019]. Biostimulants based on amino acids, phosphines and plant extracts can contribute to reducing the incidence of apple scab on leaves and fruit [Araujo et al. 2020]. The application of a biostimulant based on a mixture of seaweed and plant extract together with the fungicide IMZ, showed an effective and synergistic effect of the two products in the control of green mould disease caused by the pathogen *Penicillium digitatum* in orange cultivation, this mixture had less residual fungicide in the fruit peel than when this plant protection product was applied without the addition of the biostimulant [La Spada et al. 2021]. The soil application of biostimulants based on soapberry extract, Indian honeybush, sesame oil and seaweed had a reducing effect on the population of phytoparasitic nematodes [D'Addabbo et al. 2019].

INDUCTION OF RESISTANCE TO ABIOTIC FACTORS

Plant production is particularly vulnerable to the effects of negative climatic events [Maciejewski et al. 2007]. Abiotic stresses occurring globally, e.g. UV radiation, excessively high humidity, salinity, extremely low or high temperatures, heavy metals and drought, reduce crop productivity and the quality of the yield obtained from them;

biostimulants, thanks to their properties, are used to increase tolerance to these phenomena, limiting their negative effect [Ma et al. 2022]. Biostimulants are one of the agronomic tools available, for reducing the effects of abiotic stress. Many manufacturers of formulations for plant crops, are developing their biostimulant products, particularly optimising their composition, which is capable of initiating selected plant responses to abiotic factors [Bulgari et al. 2019]. Many of the available biostimulant products have properties that reduce stress caused by unfavourable temperatures, salinity of soil or substrates and water deficit [du Jardin 2015]. Biostimulants show a high potential to overcome oxidative stress, the key to their effectiveness is to understand the interaction of these formulations with ROS signalling (generation of reactive oxygen species), as well as the antioxidant defence system of plants. The application of the optimal biostimulant concentration is fundamental but also very complicated [Hasanuzzaman et al. 2021]. Biostimulants based on phytoextracts can be a valuable tool for induction on both abiotic and biotic stresses, research on these formulations should focus on juxtaposing them with synthetic counterparts, emphasising practical application and implementing them into sustainable practice as natural products [Akram et al. 2022]. The exogenous use of amino acids, prevents the breakdown of proteins, thus saving the plant’s energy resources, so amino acid-based biostimulants can play a regenerative role after heat stress, maintaining higher photosynthetic efficiency, chlorophyll and carotenoid levels [Botta 2013]. In the case of strawberry cultivation, the use of this type of biostimulants increased their frost hardiness [Bogunovic et al. 2015] and also reduced low temperature stress affecting higher new root growth and earlier flowering [Marfà et al. 2009]. The use of preparations based on brown seaweed extract *Ascophyllum nodosum* partially reduced drought stress in container grown orange [Spann and Little 2011]. An amino acid-based biostimulant had a positive effect on vine shoot regeneration after hailstorms, increasing the number of shoots, including fertile shoots [Baniță et al. 2020].

IMPROVING SOIL AND SUBSTRATE PROPERTIES

One of the basic functions of soil is its ability to produce plant biomass [Mueller et al. 2010]. Fertile soil ensures proper plant growth and high yields, and is influenced by nutrient levels, biological, physical and chemical processes, air exchange, activity of soil organisms, amount and type of clay minerals [Alley and Vanlauwe 2009]. Severe soil degradation can result in a significant reduction in plant growth and yield [Morris et al. 2007]. Biostimulants, while increasing soil microbial activity, also accelerate the biodegradation of soil contaminants [Pankratz 2000]. In recent years, the use of biostimulants aimed at increasing plant growth and improving soil properties has contributed to environmental protection. The application of a biostimulant based on humic acids, probiotics and prebiotics to sandy and sandy loam soils had a positive effect on microbial activity as well as soil chemistry, increasing the availability of calcium, potassium, phosphorus, magnesium, while pH and electrical conductivity were reduced. The biostimulant also had a stimulating effect on root system development [García-Martínez et al. 2010]. Biostimulants have been shown to have a beneficial effect on soil microbial activity, as well as a pH neutralising effect, increasing the mineralisation of organic residues and microbial biomass [Hellequin et al. 2020]. The application of some seaweed extracts resulted in increased microbial populations in the rhizosphere [Shukla et al. 2019]. The use of Actiwave® biostimulant in strawberry cultivation increased the population of microorganisms in the rhizosphere [Spinelli et al. 2010]. The use of soluble Ascophyllum extract powder in field and greenhouse cultivation of strawberries had a positive effect on the microbial diversity and physiological activity of the rhizosphere [Alam et al. 2013].

CONCLUSION

In the long term, biostimulation could become a fundamental tool in crop production. This is primarily due to the current changes in the crop cultivation sector, which are forcing the optimisation of fertilisation and the reduction of pesticide use, but also to reduce the risk of losses due to abiotic factors, progressive soil degradation and increasingly high consumer demands for food quality. Progressive development in the field of biostimulant preparations is systematically providing new scientific evidence of their multifaceted action, increasing the possibilities of modern agrotechnology. A key aspect for the proper development of biostimulants is their appropriate selection in terms of practical applicability, taking into account the selection of suitable raw materials and their mixtures, and choosing the most effective way of application. We should focus on research that will enable more precise and optimal use of biostimulants to achieve specific effects, while at the same time developing new biostimulatory products that will enable us to meet the increasing demands in the fruit sector.

REFERENCES

Akram N.A., Saleem M.H., Shafiq S., Naz H., Farid-ul-Haq M., Ali B., Shafiq F., Iqbal M., Jaremko M., Qureshi K.A., 2022. Phytoextracts as crop biostimulants and natural protective agents – a critical review. Sustainability 14(21), 14498. https://doi.org/10.3390/su142114498

Alalaf A.H., Alalam, S.A.T., Al-zebari S.M.K., 2022. The effect of spraying amino acid fertilizer on the growth characteristics and mineral content of pomelo (*Citrus grandis*) seedlings. Iran. J. Ichthyol. 9, 123–126. https://doi.org/10.13140/RG.2.2.30445.05609

Alam M. Zahidul A.M., Braun G., Norrie J., Hodges D.M., 2013. Effect of *Ascophyllum* extract application on plant growth, fruit yield and soil microbial communities of strawberry. Can. J. Plant Sci. 93(1), 23–36. https://doi.org/10.4141/cjps2011-260

Ali O., Ramsubhag A., Jayaraman J., 2021. Biostimulant properties of seaweed extracts in plants: implications towards sustainable crop production. Plants (Basel) 10(3), 531. https://doi.org/10.3390/plants10030531

Alley M.M., Vanlauwe B., 2009. The role of fertilizers in integrated plant nutrient management. International Fertilizer Industry Association. Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture, Paris. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=7c5c2ba4191283ec94126b4dfd7980a2407c3e57 [access: 10.04.2023].

Araujo L., Pinto F. A.M.F., Vieira J. de S., Pasa M. da S., Valdebenito-Sanhueza R.M., Stadnik M.J., 2020. Use of biostimulants for the management of Apple Scab in orchards. Agropecu. Catarin. 33(3), 60–66. https://doi.org/10.52945/rac.v33i3.751

Arioli T., Mattner S., Hepworth, G., McClintock D., McClinock R., 2021. Effect of seaweed extract application on wine grape yield in Australia. J. Appl. Phycol. 33(3). https://10.1007/s10811-021-02423-1

Baniță S., Sestras A., Oltean I., Anamaria C., Bunea C-I., 2020. The influence of hail and treatments with amino-acids on the fertility and biologic balance of grapevines. RJH 1, 111–118. https://doi.org/10.51258/RJH.2020.15

Battacharyya D., Babgohari M.Z., Rathor P., Prithiviraj B., 2015. Seaweed extracts as biostimulants in horticulture. Hortic. Sci. 196, 39–48. https://doi.org/10.1016/j.scienta.2015.09.012

Bogunovic I., Duralija B., Gadze J., Kisic I., 2015. Biostimulant usage for preserving strawberries to climate damages. Hort. Sci. 42(3), 132–140. https://doi.org/10.17221/161/2014-HORTSCI

Botta A., 2013. Enhancing plant tolerance to temperature stress with amino acids: an approach to their mode of action. Acta Hortic. 1009, 29–35. https://doi.org/10.17660/ActaHortic.2013.1009.1

Boukhari EL. M.E.M., Barakate M., Bouhia Y., Lyamlouli K., 2020. Trends in seaweed extract based biostimulants: manufacturing process and beneficial effect on soil-plant systems. Plants 9(3), 359. https://doi.org/10.3390/plants9030359

Brown P., Saa S., 2015. Biostimulants in agriculture. Front. Plant Sci. 6, 671. https://doi.org/10.3389/fpls.2015.00671

Bulgari R., Franzoni G., Ferrante A., 2019. Biostimulants application in horticultural crops under abiotic stress conditions. Agronomy 9, 306. https://doi.org/10.3390/agronomy9060306

Calvo P., Nelson L., Kloepper J.W., 2014. Agricultural uses of plant biostimulants. Plant Soil 383, 3–41. https://doi.org/10.1007/s11104-014-2131-8

Carvalho S.M.P., Vasconcelos M.W., 2013. Producing more with less: Strategies and novel technologies for plant-based food biofortification. Food Res. Int. 54(1), 961–971. https://doi.org/10.1016/j.foodres.2012.12.021

Chalfoun N.R., Durman S.B., Budeguer F., CaroM.d.P., Bertani R.P., Di Peto P., Stenglein S.A., Filippone M.P., Moretti E.R., Díaz R.J.C., Welin B., Castagnaro A.P., 2018. Development of PSP1, a biostimulant based on the elicitor AsES for disease management in monocot and dicot crops. Front. Plant Sci. 9. https://doi.org/10.3389/fpls.2018.00844

Chiaiese P., Corrado G., Colla G., Kyriacou M.C., Rouphael Y., 2018. Renewable sources of plant biostimulation: microalgae as a sustainable means to improve crop performance. Front. Plant Sci. 9, 1782. https://doi.org/10.3389/fpls.2018.01782

Chouliaras V., Tasioula-Margari M. Chatzissavvidis C., Therios I., Tsabolatidou E., 2009. The effects of a seaweed extract in addition to nitrogen and boron fertilization on productivity, fruit maturation, leaf nutritional status and oil quality of the olive (*Olea europaea* L.) cultivar Koroneiki. J. Sci. Food Agric. 89, 984–988. https://doi.org/10.1002/jsfa.3543

Colavita G.M., Spera N., Blackhall V., Sepulveda G.M., 2011. Effect of seaweed extract on pear fruit quality and yield. Acta Hortic 909, 601–607.https://doi.org/10.17660/ActaHortic.2011.909.72

Colla G., Nardi S., Cardarelli M., Ertani A., Lucini L., Canaguier R., Rouphael Y., 2015. Protein hydrolysates as biostimulants in horticulture. Hortic. Sci. 196, 28–38. https://doi.org/10.1016/j.scienta.2015.08.037

Colla G., Rouphael Y., 2015. Biostimulants in horticulture. Hortic. Sci. 196, 1–2. https://doi.org/10.1016/j.scienta.2015.10.044

D'Addabbo T., Laquale, S., Perniola M., Candido V., 2019. Biostimulants for plant growth promotion and sustainable management of phytoparasitic nematodes in vegetable crops. Agronomy 9, 616. https://doi.org/10.3390/agronomy9100616

Drobek M., Frąc M., Cybulska J., 2019. Plant biostimulants: importance of the quality and yield of horticultural crops and the improvement of plant tolerance to abiotic stress – a review. Agronomy 9, 335. https://doi.org/10.3390/agronomy9060335

Eckardt N.A., Cominelli E., Galbiati M., Tonelli C., 2009. The future of science: food and water for life. Plant Cell 21(2), 368–372. https://doi.org/10.1105/tpc.109.066209

Fornes F., Sánchez-Perales M., Guardiola J.L., 2005. Effect of a seaweed extract on the productivity of 'de Nules' clementine mandarin and Navelina orange. Botanica Marina 45(5), 486-489. https://doi.org/10.1515/BOT.2002.051

García-Martínez A.M., Díaz A., Tejada M., Bautista J., Rodríguez B., Santa María C., Revilla E., Parrado J., 2010. Enzymatic production of an organic soil biostimulant from wheat-condensed distiller solubles: Effects on soil biochemistry and biodiversity. Process Biochem. 45(7), 1127–1133. https://doi.org/10.1016/j.procbio.2010.04.005

Graziani G., Ritieni A., Cirillo A., Cice D., Di Vaio C., 2020. Effects of biostimulants on Annurca fruit quality and potential nutraceutical compounds at harvest and during storage. Plants 9, 775. https://doi.org/10.3390/plants9060775

Hasanuzzaman M., Parvin K., Bardhan K., Nahar K., Anee T.I., Masud A.A.C., 2021. Fotopoulos V. Biostimulants for the regulation of reactive oxygen species metabolism in plants under abiotic stress. Cells 10(10), 2537. https://doi.org/10.3390/cells10102537

Hellequin E., Monard C., Chorin M. Le bris N., Daburon V., Klarzynski O., Binet F., 2020. Responses of active soil microorganisms facing to a soil biostimulant input compared to plant legacy effects. Sci. Rep. 10. https://doi.org/10.1038/s41598-020-70695-7

Jannin L., Arkoun M., Ourry A., Lainé P., Goux D., Garnica M., Fuentes M., Francisco S.S., Baigorri R., Cruz F., Houdusse F., García-Mina J., Yvin J., Etienne P., 2012. Microarray analysis of humic acid effects on *Brassica napus* growth: Involvement of N, C and S metabolisms. Plant Soil 359, 297–319. https://doi.org/10.1007/s11104-012-1191-x

du Jardin P., 2015. Plant biostimulants: Definition, concept, main categories and regulation. Hortic. Sci. 196, 3–14. https://doi.org/10.1016/j.scienta.2015.09.021

Khan A.S., Ahmad B., Jaskani M.J., Ahmad R., Malik A.U., 2012. Foliar application of mixture of amino acids and seaweed (*Ascophylum nodosum*) extract improve growth and physicochemical properties of grapes. Int. J. Agric. Biol. 14(3), 383–388. http://www.fspublishers.org/published_papers/73501_..pdf [access: 8.04.2023].

Khattab M.M., Shaban A.E.A., Hassan A.E., 2016. Impact of foliar application of calcium, boron and amino acids on fruit set and yield of ewais and fagry kelan mango cultivars. J. Ornam. Hortic. 8(2), 119–124. https://doi.org/10.5829/idosi.jhsop.2016.8.2.1179

Kumaraswamy R.V., Kumari S., Choudhary R.C., Sharma S.S., Pal A., Raliya R., Biswas P., Saharan V., 2019. Salicylic acid functionalized chitosan nanoparticle: A sustainable biostimulant for plant. Int. J. Biol. Macromol. 123, 59–69. https://doi.org/10.1016/j.ijbiomac.2018.10.202

La Spada F., Aloi F., Coniglione M., Pane A., Cacciola S.O., 2021. Natural Biostimulants elicit plant immune system in an integrated management strategy of the postharvest green mold of orange fruits incited by *Penicillium digitatum*. Front. Plant Sci. 12. https://doi.org/10.3389/fpls.2021.684722

Lee S., Yoon J.Y., Jung, H.I., Lee D.J., Shin D.Y., Hyun K.H., Kuk Y.I., 2012. Ameliorative effects of squash (*Cucurbita moschata* Duchesne ex Poiret) leaf extracts on oxidative stress. Plant Growth Regul. 67, 9–17. https://doi.org/10.1007/s10725-011-9655-1

Ma Y., Freitas H., Celeste D.M., 2022. Strategies and prospects for biostimulants to alleviate abiotic stress in plants. Front. Plant Sci. 13. https://doi.org/10.3389/fpls.2022.1024243

Machado L.P., Matsumoto S.T., Jamal C.M., da Silva M.B., Centeno D.C., Colepicolo N.P., de Carvalho L.R., Yokoya N.S., 2014. Chemical analysis and toxicity of seaweed extracts with inhibitory activity against tropical fruit anthracnose fungi. J. Sci. Food Agric. 94(9), 1739–1744. https://doi.org/10.1002/jsfa.6483.

Maciejewski T., Szukała J., Jarosz A., 2007. Wpływ biostymulatora Asahi SL i Atonik SL na cechy jakościowe bulw ziemniaków [Influence of biostymulator Asahi SL i Atonik SL on qualitative tubers of potatoes]. J. Res. Appl. Agric. Eng. 52(3), 109–112 [in Polish].

Mancuso S., Azzarello E., Mugnai S., Briand X., 2006. Marine bioactive substances (IPA extract) improve foliar ion uptake and water stress tolerance in potted *Vitis vinifera* plants. Adv. Hortic. Sci. 20, 156–161. https://doi.org/10.1400/53262

Marfà O., Cáceres R., Polo J., Ródenas J., 2009. Animal protein hydrolysate as a biostimulant for transplanted strawberry plants subjected to cold stress. Acta Hortic. 842, 315–318. https://doi.org/10.17660/ActaHortic.2009.842.57

Marjańska-Cichoń B., Sapieha-Waszkiewicz A., 2012. The effect of Goëmar BM 86 on the yield of three apple varieties, and selected qualitative characteristics of Apple. Prog. Plant Prot. 52(4). http://dx.doi.org/10.14199/ppp-2012-205

Morris M., Kelly V.A., Kopicki R.J., Byerlle D., 2007. Fertilizer use in African agriculture, lessons learned and good practice guidelines. Directions in Development, Agriculture and Rural Development. World Bank, Washington, DC. http://hdl.handle.net/10986/6650

Moussa A., Passera A., Torcoli S., Serina F., Quaglino F., Mori N., 2021. Evaluation of biostimulant effectiveness in grapevine "bois noir" management. 8. convegno Incontro Nazionale sui Fitoplasmi e le Malattie da Fitoplasmi tenutosi a Catania nel 2021. https://hdl.handle.net/2434/884290

Mueller L., Schindler U., Mirschel W., Shepherd T.G., Ball B.C., Helming K., Rogasik J., Eulenstein F., Wiggering H., 2010. Assessing the productivity function of soils. A review. Agron. Sustain. Dev. 30, 601–614. https://doi.org/10.1051/agro/2009057

Nabti E., Jha B., Hartmann A., 2017. Impact of seaweeds on agricultural crop production as biofertilizer. Int. J. Environ. Sci. Technol. 14, 1119–1134. https://doi.org/10.1007/s13762-016-1202-1

Nascimento T., Rego C., Oliveira H., 2007. Potential use of chitosan in the control of grapevine trunk diseases. Phytopathol. Mediterr. 46, 218–224. https://doi.org/10.14601/Phytopathol_Mediterr-2156

Navarro-León E., López-Moreno F.J., Borda E., Marín C., Sierras N., Blasco B., Ruiz J.M., 2022. Effect of l-amino acid-based biostimulants on nitrogen use efficiency (NUE) in lettuce plants. J. Sci. Food Agric. 102(15), 7098–7106. https://doi.org/10.1002/jsfa.12071

Pankratz T.M., 2000. Environmental engineering dictionary and direktory. CRC Press, FL, Boca Raton. https://doi.org/10.1201/9781420032536

Povero G., Mejia J.F., Di Tommaso D., Piaggesi A., Warrior P., 2016. A systematic approach to discover and characterize natural plant biostimulants. Front. Plant Sci. 7. https://doi.org/10.3389/fpls.2016.00435

Pylak M., Oszust K., Frąc M., 2019. Review report on the role of bioproducts, biopreparations, biostimulants and microbial inoculants in organic production of fruit. Rev. Environ. Sci. Biotechnol. 18, 597–616. https://doi.org/10.1007/s11157-019-09500-5

Romanazzi G., Nigro F., Ippolito A., Di Venere D., Salerno M., 2002. Effects of pre and postharvest chitosan treatments to control storage grey mould of table grapes. J. Food. Sci. 67, 1862–1867. https://doi.org/10.1111/j.1365-2621.2002.tb08737.x

Rouphael Y., Colla G., 2018. Synergistic biostimulatory action: designing the next generation of plant biostimulants for sustainable agriculture. Front. Plant Sci. 9, 1655. https://doi.org/10.3389/fpls.2018.01655

Samuels L.J., Setati M.E., Blancquaert E.H., 2022. Towards a better understanding of the potential benefits of seaweed based biostimulants in *Vitis vinifera* L. cultivars. Plants 11, 348. https://doi.org/10.3390/plants11030348

Sharma H.S.S., Fleming C., Selby C., Rao J.R., Martin T., 2014. Plant biostimulants: a review on the processing of macroalgae and use of extracts for crop management to reduce abiotic and biotic stresses. J. Appl. Phycol. 26, 465–490. https://doi.org/10.1007/s10811-013-0101-9

Shekhar S.H.S. G., Lyons C., McRoberts D., McCall E., Carmichael F., Andrews F., McCormack R., 2012. Brown seaweed species from Strangford Lough: compositional analyses of seaweed species and biostimulant formulations by rapid instrumental methods. J. Appl. Phycol. 24, 1141–1157. https://doi.org/10.1007/s10811-011-9744-6

Shukla P.S., Mantin E.G., Adil M., Bajpai S., Critchley A.T., Prithiviraj B., 2019. *Ascophyllum nodosum*-based biostimulants: sustainable applications in agriculture for the stimulation of plant growth, stress tolerance, and disease management. Front. Plant Sci. 10. https://doi.org/10.3389/fpls.2019.00655

Soppelsa S., Kelderer M., Casera C., Bassi M., Robatscher P., Matteazzi A., Andreotti C., 2019. Foliar applications of biostimulants promote growth, yield and fruit quality of strawberry plants grown under nutrient limitation. Agronomy 9, 483. https://doi.org/10.3390/agronomy9090483

Spann T.M., Little H.A., 2011. Applications of a Commercial extract of the brown seaweed *Ascophyllum nodosum* increases drought tolerance in container-grown 'Hamlin' sweet orange nursery trees. Hortic. Sci. 46(4), 577–582. https://doi.org/10.21273/HORTSCI.46.4.577

Spinelli F., Fiori G., Noferini M., Sprocatti M., Costa G., 2010. A novel type of seaweed extract as a natural alternative to the use of iron chelates in strawberry production. Sci. Hortic. 125(3), 263–269. https://doi.org/10.1016/j.scienta.2010.03.011

Świerczyński S., Antonowicz A., 2021. The effects of reduced mineral fertilisation combined with the foliar application of biostimulants and fertilisers on the nutrition of maiden apple trees and the contents of soil nutrients. Agronomy 11, 2438. https://doi.org/10.3390/agronomy11122438

Świerczyński S., Antonowicz A., Bykowska J., 2021. The effect of the foliar application of biostimulants and fertilisers on the growth and physiological parameters of maiden apple trees cultivated with limited mineral fertilisation. Agronomy 11(6), 1216. https://doi.org/10.3390/agronomy11061216

Tarantino A., Lops F., Disciglio G., Lopriore G., 2018. Effects of plant biostimulants on fruit set, growth, yield and fruit quality attributes of 'Orange rubis®' apricot (*Prunus armeniaca* L.) cultivar in two consecutive years. Hortic. Sci. 239, 26–34. https://doi.org/10.1016/j.scienta.2018.04.055

Taskos D., Stamatiadis S., Yvin J., Jamois F., 2019. Effects of an *Ascophyllum nodosum* (L.) Le Jol. extract on grapevine yield and berry composition of a Merlot vineyard. Hortic. Sci. 250, 27–32. https://doi.org/10.1016/j.scienta.2019.02.030

Tavarini S., Passera B., Martini A., Avio L., Sbrana C., Giovannetti M., Angelini L.G., 2018. Plant growth, steviol glycosides and nutrient uptake as affected by arbuscular mycorrhizal fungi and phosphorous fertilization in *Stevia rebaudiana* Bert. Ind. Crops Prod. 111, 899–907. https://doi.org/10.1016/j.indcrop.2017.10.055

Turan M., Köse C., 2006. Seaweed extracts improve copper uptake of grapevine, Acta Agric. Scand. – B Soil Plant Sci. 54(4), 213–220. https://doi.org/10.1080/09064710410030311

Ugolini L., Cinti S., Righetti L., Stefan A., Matteo R., D'Avino L., Lazzeri L., 2015. Production of an enzymatic protein hydrolyzate from defatted sunflower seed meal for potential application as a plant biostimulant. Ind. Crops Prod. 75(A), 15–23. https://doi.org/10.1016/j.indcrop.2014.11.026

Van Oosten M.J., Pepe O., De Pascale S., Silletti S., Maggio A., 2017. The role of biostimulants and bioeffectors as alleviators of abiotic stress in crop plants. Chem. Biol. Technol. Agric. 4, 5. https://doi.org/10.1186/s40538-017-0089-5

Yakhin O.I., Lubyanov A.A., Yakhin I.A., Brown P.H., 2017. Biostimulants in plant science: a global perspective. Front. Plant Sci. 7. https://doi.org/10.3389/fpls.2016.02049

Zulfiqar F., Casadesús A., Brockman H., Munné-Bosch S., 2020. An overview of plant-based natural biostimulants for sustainable horticulture with a particular focus on moringa leaf extracts. Plant Sci. 295. https://doi.org/10.1016/j.plantsci.2019.110194

Source of funding: The research was supported by project no. SD/70/RiO/2023 provided by the University of Life Sciences in Lublin.

Received: 6.07.2023
Accepted: 16.11.2023
Published: 18.04.2024