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Application of Humic and Fulvic Acids as Biostimulants to Improve Growth, Yield and Quality of Vegetable Crops. A review

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ABSTRACT
This review aims to evaluate the biostimulants, such as fulvic and humic acids, and their potential to improve the growth, yield and quality of vegetable crops. Most scientists have reported many positive effects of humic compounds, including fulvic and humic acids on plant growth and development, but it appears that these effects depend on several factors, such as the application rate and frequency, application method, plant species, type of humic substance, product formulation, growing substrate, and environmental conditions. Humic and fulvic acids are natural organic compounds derived from the decomposition of plant and microbial matter. Applying humic and fulvic acids as foliar or soil drench enhancing the growth and yield of vegetable crops through enhancing soil structure, increasing nutrient retention, and promoting root growth, improving cation exchange capacity, increasing the availability of essential nutrients such as nitrogen, phosphorus, and potassium, and facilitating better uptake by plants. As well as increasing photosynthetic efficiency and promoting cellular activity, leading to better growth and development. The application of fulvic and humic acids enhances the quality of vegetable crops by improving attributes such as size, color, texture, and flavor. Additionally, increase the concentration of bioactive compounds like vitamins, antioxidants, secondary metabolites and enhancing nutritional value.

Keywords: vegetable crops, humic acid, fulvic acid, yield, quality, abiotic stress.

Introduction

Humus is defined as organic material that has decomposed to the point where it can no longer be identified as plant, animal, or microbiological remains. Humus include: Humin is a black humic material with a high molecular weight that is insoluble in water at any pH. Natural components of soil organic matter, humic substances (HS) are produced by the breakdown of plant, animal, and microbial waste products as well as by the metabolic processes of soil microorganisms that use these substrates.

The water-soluble components of humus include fulvic and humic acids, whereas the insoluble portion is known as humin. While fulvic acid (FA) is soluble at any pH, humic acid (HA) is soluble at pH values greater than 2. (Maccarthy, 2001).

According to Schnitzer (1978) and du Jardin (2019), humic compounds, such as fulvic acid, humic acid, and humin, are produced as organic matter decomposition. Furthermore, can be extracted from a variety of materials, such as leonardite, compost, soil, and peat. The organic matter is formed by decomposition of lignin, polysaccharides, and proteins produces organic compounds that are carboxylic, phenolic, benzoic, and aliphatic. Additionally, between 70 and 90 percent of soil organic

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matter is composed of humic compounds, which are the biosphere's primary carbon storage. (Lipczynska-Kochany, 2018).

Humic substances (HS, fulvic and humic acids) are widely used as fertilizers or plant growth stimulants. Humic compounds include a few hundred to several hundred thousand atomic mass units (an atomic mass unit is the mass of one proton in an atom) (Gaffney *et al.,* 1996). Additionally, these compounds are important parts of humic substances, which are known to have a significant impact in improving plant growth and soil fertility. Fulvic and humic acids are often used in the formulation of plant biostimulants to promote plant growth, improve plant stress tolerance, and increase the substrate's capacity to store nutrients and the plant's ability to absorb them (Canellas *et al*., 2015; Xu *et al*., 2021).

Humic acid is a dark-brown humic material that has a larger molecular weight than fulvic acid and is only soluble in water at higher soil pH levels. Additionally, humic acid has a high-polyphenol a compound that has been effectively applied in agriculture, veterinary medicine, and ecological management (Luo *et al.,* 2022). In contrast, fulvic acid is a low molecular weight, yellow to yellow-brown humic material that dissolves in water at any pH. Fulvic acid, which has the lowest molecular weight and the highest solubility in water, is produced after humic acid is extracted from soil (Gaffney *et al.,* 1996; Piccolo, 2002; Simpson *et al.,* 2002; Sutton and Sposito, 2005).

Numerous studies have examined the application of HS as a foliar or soil drench. Commercial humic-based plant production products have been developed as a result of HS ability to improve plant growth (Rose *et al.,* 2014; Canellas *et al.,* 2015; Olk *et al.,* 2018). Commercial HS-based treatments are often able to be sprayed on leaves as well as the soil (root area) (Rose *et al.,* 2014; Canellas *et al.,* 2015). Several research focused on the mechanisms of action that explain the effect of soil-applied HS on increasing plant development. (Pinton *et al.,* 1999; Nardi *et al.,* 2002; Chen *et al.,* 2004; Berbara and García, 2013; Canellas *et al.,* 2015; García *et al.,* 2016; Olaetxea *et al.,* 2018), the positive effects of foliar-applied HS have not yet been thoroughly investigated. Indeed, it is assumed that foliar-applied HS promote plant growth by mechanisms similar to those involved in HS root application (Rose *et al.,* 2014). However, there are a lot of differences between foliar and root-applied HS in terms of how they interact, absorb, and transport. For example, compared to root HS application, a significantly smaller range of HS concentration is required for foliar application to enhance plant growth (Chen and Aviad, 1990). Similarly, humic materials that are given to the leaves have little effect on the rhizosphere and soil, which are crucial sites for interactions and reactions that result in increased nutrient bioavailability (Baigorri *et al.,* 2013; Urrutia *et al.,* 2014; Zanin *et al.,* 2019). Plants' reactions to foliar applications of humic compounds may differ from those to root applications in terms of nutrition, metabolism, and physiology. Humic substances (HS) from different origins applied to plant roots can improve plant growth and mineral nutrition (Chen *et al.,* 2004; Rose *et al.,* 2014) The influence of humic compounds on soil and rhizosphere characteristics, as well as their interactions with plant roots, are some of the mechanisms causing these beneficial benefits. On the other hand Turan *et al.* (2022) indicates that due to their low molecular weight, which allows for better penetration into the leaves, biostimulants containing fulvic acid are more effective against Fe deficiency when applied topically than those based on humic acid. Furthermore, in situations when crops lack iron, fulvic compounds applied topically in combination with iron fertilizers may enhance crop uptake of iron and yields.

Commonly recognized types of biostimulants include fulvic and humic acids, protein hydrolysates, seaweed extracts, chitosan and other biopolymers, inorganic substances, helpful fungus, and bacteria. Biostimulants are not just sources of nutrients but act on the natural processes of plants to enhance their growth, development, and yield with proven potential in improving plant growth, increasing crop production, and quality. As well as increase the tolerance of crops to these abiotic stress factors.

Prisa (2024) stated that the use of biostimulants in horticultural production, open fields, and protected crops is intended to accomplish one or more of the following goals, encourage the quick emergence of seedlings in crops that are sown directly or the quick resolution of the transplanting problem, to improve growth, flowering, fruit set, and fruit growth; to enhance the quality of the product; to enhance nutrient use efficiency; and to enhance resistance to environmental stressors. Furthermore, achieving these objectives is contingent upon the interaction between the biostimulant and environmental, agronomic, and genetic factors in addition to the biostimulant type, application technique, and dosage.

In agricultural practices, particularly in vegetable crop production, humic and fulvic acids have gained attention as effective biostimulants. One of the most crucial substances for increasing plant productivity, development, and yield is biostimulants such HA and FA. They also help in heavy metal detoxification, stimulate natural toxins, controlling pests and diseases, and improve water and nutrient efficiency. In addition, biostimulants are substances or microorganisms that improve plant growth, productivity, and resilience without acting as chemical fertilizers or pesticides. Humic and fulvic acids are valued for their multifaceted benefits, which include improving nutrient availability, enhancing soil structure, stimulating root development, and boosting plant metabolism.

Numerous studies have demonstrated that the use of humic and fluvic acids in vegetable growing has improved produce yield and quality, making them a crucial component of sustainable agriculture. Additionally, to increase crop uptake of nutrients while reducing chemical fertilizer use without affecting plant nutrition. However, biostimulants are substances or microbes that are administered to plants or the rhizosphere to promote natural processes that improve crop quality, nutrient absorption, nutrient usage efficiency, and tolerance to abiotic stress. Commercial products that contain combinations of these substances and/or microorganisms are also referred to as plant biostimulants (Stott and Martin, 1990; Mackowiak *et al.,* 2001; Nardi *et al.,* 2002; Berbara and García, 2014; Rose *et al.,* 2014; Malan, 2015; Van Oosten *et al.,* 2017).

Humic and flavic acids have a function as soil conditioners and can enhance plant uptake of nutrients. Plants benefit from humic compounds because they change the morphology of roots and improve nutrient uptake altering the metabolism of both primary and secondary plants, improving resistance to abiotic stress, and promoting advantageous interactions between microbes and plants. The effectiveness of humic compounds and their commercial derivatives, however, is dependent on a number of variables, including the frequency, rate and method of application, the type of humic substance, the plant species, the product formulation, growing substrate and environmental conditions (Puglisi *et al.,* 2013; Halpern *et al.,* 2015; Rose *et al.,* 2014; Olivares *et al.,* 2017; Canellas *et al.,* 2020; Cozzolino *et al.,* 2021 and Nardi *et al.,* 2021).

The physical, chemical, and biological properties of soil as well as agricultural production are enhanced by humic acid, particularly in alkaline-calcareous and inadequately fertile soils, also reducing the negative effects of stress. Additionally, humic acid improves protein synthesis, biomass development, membrane permeability, nitrogen usage efficiency, nutrient absorption, major and minor nutrient assimilation, and enzyme activation or inhibition all of which support plant growth.

It is also known that the humate moved from one area of the root system to another, enabling more effective iron absorption. Moreover, by promoting microbial activity, humic substances may help enhance mineral absorption (Schnitzer, 1986; MacCarthy *et al.,* 1990; Adani *et al.,* 1998; Doran *et al.,* 2003; Sharif *et al.,* 2004; El-Ghamry, *et al.,* 2009; Rajpar *et al.,* 2011; Chandrakant and Verm 2023).

Biostimulants based on humic and fulvic acids also improve the fertilization effectiveness of macronutrients including potassium, nitrogen, and phosphorus. Humic compounds are important in the soil, particularly for the plant-available mobilization of mineral-fixed phosphates. In the same way, humic materials mobilize vital trace elements like iron, zinc, copper, and manganese that crops would otherwise be unable to absorb directly, particularly in arid soils with low humus levels.

Numerous studies have focused on the effect of applying humic acids to increase the productivity and improve the quality of vegetable crops. Haider *et al*. (2017) on okra showed that increasing pod weight with soil application of HA at rates of 10, 20, and 30 kg/ha resulted in high yield. Also, Kumar *et al*. (2017) on tomato the highest total yield is obtained by applying a nutrient mixture (foliar) and several types of HC as foliar and soil applications.

Pillajo *et al*. (2024) indicated that to lower fertilization rates in tomato production while preserving growth and appropriate nutrition, humic compounds may be a viable substitute.

On broccoli, the highest head weight and marketable yield were found with a combination of biofertilizer (20g L) + HA (10 ml/L) as compared to biofertilizer alone (Al-Taey *et al*. (2019). In the same trend Dawood *et al*. (2019) Applying different levels of HA (ranging from 0% to 5%) to faba beans resulted in higher seed yields than the control.

Raheem *et al*. (2018) on Lettuce, plant height increased with 4.5 ml/L foliar application of HA at different concentrations, whereas head weight and total yield increased with 1.5 ml/L soil application. Elshamly and Nasser, (2023) said that foliar treatments of humic and potassium amendments increased carrot yield and nutrient uptake Fawzy, (2012). Reported that when humic acid was applied at a rate of 3g/L, the diameter of the cucumber fruits increased in comparison to the control, which increased the yield.

When humic or salicylic acids were applied as foliar application, sweet pepper growth, yield, and fruit nutritional quality all increased significantly. For the three cultivars that were studied, salicylic acid generally worked better than humic acid. As a result, we advise applying salicylic acid as a foliar spray to improve red sweet pepper yield and nutritional value (Ibrahim *et al*., 2024)

On a potato different NPK dosages (full and half dose) were combined with HA (0.03% and 0.5%), zinc, and boron. The highest tuber yield was obtained with a half dose of NPK at basal dose + Zn + B + HA, compared to other treatments (Shah *et al.,* 2016). Al-Fraihat *et al*. (2018) On onion, HA at several doses (0, 500, 750, and 1000 mg/L) and with varying numbers of sprays produced the highest number of leaves (10.5), leaf length (57.4 cm), and fresh weight of leaves (95.1 g) when compared to other treatments.

Significant improvements were noted in plant height, stem diameter, head width, percentage of nutrients in the leaf, Lettuce, Broccoli, and Cauliflower cultures of various groups after foliar application of humic compounds (Rachid *et al*., 2020; Raheem *et al*., 2018). In the same trend, bulb weight, number of leaves, tuber yield, Garlic, Onion, Potato, (Balmori *et al*., 2019; Kandil *et al*., 2012; Man-hong *et al*., 2020).

Leaf dry weight, vitamin C, calcium, total chlorophyll, and bulb flavonoids were all significantly impacted by the foliar or soil application of HA on onion plants. The addition of 4 kg fed^{-1} potassium humate to the soil also produced the highest significant values for growth parameters, yield, and its constituents, as well as for N, P, K, Fe, Mn, and Zn in the onion bulb and leaves. It also produced the highest significance in the chemical and physical quality of the onion bulb (Forotaghe *et al.,* 2021; El-Shaboury and Sakara 2021)

To increase the productivity and quality of vegetable crops, fulvic acid can be sprayed on the leaves or added to the soil. El-Sawy *et al*. (2020). examined the effects of applying fulvic acid at doses of 0, 3, and 6 g/L on three snap bean cultivars (Flantino, Bronco, and Giza 3). According to the results, snap bean production, quality, and vegetative development characteristics were enhanced when fulvic acid content was raised through foliar application. Applying FA at particular times of plant growth could increase plant productivity. The vegetative growth parameters of faba bean plants were enhanced by foliar application of FA (Chen *et al*., 2004).

Applying four fulvic acid concentrations (0, 3, 6, and 9g L^{-1}) as foliar on four faba bean varieties. The faba bean crop growth rate, leaf area and leaf area index, plant height, number of leaves per plant, and total fresh and dry weight per plant all increased as the FA concentrations increased (Abdel-Baky *et al.,* 2019). Furthermore, Mahmoud *et al*., (2019) showed that the most significant values of vegetative growth parameters and onion production were obtained at a rate of 3g/L of FA. Additionally, Application of FA enhanced the vegetative growth of faba bean and radish (Ismail and Fayed, 2020; Khang, 2011).

Kanabar and Nandwani, (2022) stated that under organic vegetable production fulvic acid was sprayed on the leaf surface at various rates and applied as a soil drench to the plant root area on bell pepper. Results indicated an increased number of fruits, fruit length, fruit diameter, fruit weight, and yield in response to foliar application of fulvic acid. Additionally, it indicates that fulvic acid used topically was successful and might be applied to organic bell pepper cultivation to increase marketable yield. Shi *et al.* (2023) working on tomato using fulivic acids as a foliar application under stress of copper and cadmium. Under various Cu and Cd stressors, the results indicated that 1000 $mg \cdot L^{-1}$ FA might somewhat increase tomato plant biomass. The amount of Cu and Cd in various organs as well as the overall accumulation reduced after FA was sprayed; at the same time, there was a little decrease in the transport efficiency of Cu and Cd.

Tables (1-4) provide a summary of how fulvic and humic acids affect growth, yield, and quality.

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Table 1: Impact of humic acid on growth and productivity of vegetable crops.

Biostimulants	Application method	Crop	Recorded Effects	References
Humic acid	Foliar spray	Carrot	Increased yield	Elshamy and Nasser, (2023)
	Foliar spray	Chilli	Increased yield	Pavani *et al*. (2022)
	Foliar spray	Cauliflower	Increased stem and floral diameters, plant length and yield	Rachid *et al.* (2020)
	Foliar spray	Carrot	Increased average root weight and yield	El-Helaly (2018)
	Foliar spray	Potato	Increased plant growth, leaf area and marketable tuber yield	Wadas and Dziugiel, 2019
	Foliar spray and Soil application	Tomato	Increased fruit diameter, fruit height, and fruit number and yield	Yildrim, 2007
	Soil application	Watermelon	Increased marketable and total yield	Salman *et al.* (2005)
	Foliar spray Soil application	Lettuce	Increased Plant Height, Head fresh weight and total yield	Raheem *et al.* (2018)
	Soil application	Garlic	Increased plant length, number of eaves/plant, fresh weight and total yield	Shafeek *et al.* (2015); Balmori, *et al.,* (2019)
	Foliar spray	Onion	Increased leaves number, leaf length, fresh weight of leaves and total yield	Al-Fraihat *et al*. (2018); Kandil *et al.,* (2012)
	Soil application & Foliar spray	Tomato	Increased total yield	Kumar *et al*. (2017)
	Soil application	Potato	Increased tuber yield	Shah *et al*. (2016), Man-hong *et al.,* (2020)
	Soil application	Okra	Increased seed germination, pod weight and total yield	Haider *et al*. (2017)
	Soil application	Broccoli	Increased head weight, marketable yield and total yield	Al-Taey *et al*. (2019)
	Foliar spray	Faba bean	Increased seed yield	Dawood *et al.* (2019)

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Table 2: Effect of humic acid on quality of vegetable crops.

Biostimulants	Application method	Crop	Recorded Effects	References
Humic acid	Foliar spray	Tomato	Increased total soluble substance, total acidity and reducing sugar , ascorbic acid, total carotene, total lycopene	Soare *et al.,* 2024
	Foliar spray	Carrot	Decreased the amount of sodium in carrot root while increasing the content of nitrogen, phosphorus, potassium, potassium/sodium ratio, and total sugar concentration.	Elshamy and Nasser, (2023)
	Foliar spray& Soil application	Onion	Increased Leaf dry weight, vitamin C, calcium, total chlorophyll, and bulb flavonoids, N, P, K, Fe, Mn, and Zn in the onion bulb and leaves.	Forotaghe, *et al.* (2021), El – Shaboury and Sakara 2021)
	Foliar spray	Chilli	Enhanced macro-nutrient content (N,P,KS) and uptake .	Pavani *et al.* (2022)
	Foliar spray	Cauliflower	Increased dry fruit weight and photosynthetic pigments content: chlorophyll a, chlorophyll b, and carotenoids	Rachid *et al.* (2020)
	Foliar spray	Carrot	Increased leaves chlorophyll content, roots dry matter, carbohydrates, carotenoids, nitrogen and phosphorus	El-Helaly (2018)
	Foliar spray& Soil application	Tomato	Increased dry matter content, total soluble solids (TSS), ascorbic acid content	Yildirim, (2007)
	Soil application	Watermelon	Increased mineral content (NPK), dry matter, fruit length, Dimater, cortex thick and firmness	Salman *et al.,* (2005)
	Foliar spray& Soil application	Lettuce	Increased mineral content (NPK), Head dry weight, Chlorophyll, T.S.S. (%),	Raheem *et al.* (2018)
	Soil application	Garlic	Increased bulb diameter, Neck of bulb, firmness, dry weight, total chlorophyll content	Shafeek *et al.* 2015; Balmori, *et al.,* 2019
	Foliar spray	Tomato	Increased TSS, Vitamin C and fruit lycopene	Kazemi (2014)
	Foliar spray	Lettuce	Increased chlorophl II content, dry matter content	Shahein *et al.* (2014)
	Soil application	Watermelon	Increased TSS and dry matter content	Salman *et al.* (2005)
	Foliar spray	Cucumber	Increased TSS and dry matter content	Al-Madhagi (2019)
	Foliar spray	Spinach	Increased TSS and protein	Dubey *et al.* (2019)
	Foliar spray	Cabbage	Increased ascorbic acid	Rodica *et al.* (2017)
	Foliar spray	Onion	Increased protein	Forotaghe *et al.* (2021)

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Table 3: Impact of fulvic acid on growth and productivity of vegetable crops.

Biostimulants	Application method	Crop	Recorded Effects	References
Fulvic acid	Foliar spray & seed priming	Pea	Increased growth parameters, seeds per pod, number of pods per plant, 100-seed weight and seed yield	Mahdy (2024)
	Foliar spray	Bell pepper	Increased no. fruit, fruit weight and yield	Kanabar and Nandwani, (2022)
	Foliar spray	Faba bean	Increased Plant height, No. leaves, fresh weight, leaf area index, crop growth rate seed and straw yield.	Abdel-Baky *et al.,* 2019
	Foliar spray	Snap bean	Increased plant height, No. of leaves and branches, total fresh weight and yield.	El-Sawy *et al.,* (2020)
	Foliar spray	Tomato	Increased plant height, fresh weight, Fruit number and yield	Suh *et al.,* (2015)
	Foliar spray	Spinach	Increased growth characteristics, and yield	Turan *et al.,* (2022)

Table 4: Effect of fulvic acid on quality of vegetable crops.

Biostimulants	Application method	Crop	Recorded Effects	References
Fulvic acid	Foliar spray & Seed priming	Pea	Increased leaf pigments, and total carbohydrates	Mahdy *et al.,* (2024)
	Foliar spray	Tomato	Increased total soluble substance, total acidity and reducing sugar , ascorbic acid, total carotene, total lycopene	Soare *et al.,* (2024)
	Foliar spray	Bell pepper	Increased Fruit length and fruit diameter	Kanabar and Nandwani, (2022)
	Foliar spray	Snap bean	Increased average pod length and diameter, dry weights of pods, total protein percentage, fiber percentage and total soluble solids (TSS).	El-Sawy *et al.,* (2020)
	Foliar spray	Faba bean	Increased levels of total carbohydrates, crude protein, minerals (potassium, phosphorus, and nitrogen), arginine, lysine, phenylalanine, and tryptophan improved the nutritional value and quality of seeds as well as the amount of total photosynthetic pigments in leaves.	Abdel-Baky *et al.,* (2019)
	Foliar spray	Tomato	Increased dry weight, contents of P and Ca	Suh *et al.,* (2015)
	Foliar spray	Spinach	Increased nutrient uptake, chlorophyll content	Turan *et al.,* (2022)

In conclusion, applying fulvic or humic acids as a soil drench or foliar application improves growth, yield, and quality of vegetable crops. Moreover, fulvic acid is more effective when used as a foliar spray due to the small molecular weight and high solubility. This allows for better absorption by the plant leaves, leading to enhanced nutrient uptake and improved overall plant health. As a result, growers can expect not only enhanced crop performance but also a potential reduction in the need for chemical fertilizers. This eco-friendly approach can lead to more sustainable farming practices, benefiting both the environment and the economy. Whereas, humic acid, with its larger molecular structure, is more beneficial when applied directly to the soil, where it can improve soil structure and increase microbial activity. This enhanced microbial activity fosters a healthier ecosystem for plants, leading to better nutrient uptake and overall growth. Additionally, integrating fulvic and humic acids into regular agricultural routines may help improve soil health over time, fostering long-term productivity.

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