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Review

Impact of Organic Acids and Biological Treatments in Foliar Nutrition on Tomato and Pepper Plants

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Abstract: As a result of global warming related to the development of industry and agriculture, the proportion of atmospheric carbon dioxide has increased, and temperatures have risen to unprecedented levels. As a result, heat stress, aridity, and salinity in soil has increased, leading to significant research focused on soil deterioration and reduced agricultural productivity. Therefore, it is necessary to provide the means to maintain crop productivity. Agricultural research is seeking novel solutions that guarantee stability and increase the production and quality of crops, including innovative models for feeding crops using non-traditional methods, the most important of which is nourishing plants via their leaves to ensure the cessation of their soil consumption. It is considered an integrated pest-control method, and the technique could be included in plant nutrition. Foliar nutrition has been shown to be a perfect substitute for providing secondary nutrients and micronutrients to plants; however, it cannot be substituted for the fertigation or the fertilization of maintain the soil's macronutrients (nitrogen, phosphorus, and potassium). This study shed light on the most important research, conclusions, and generalizations on the technique of foliar feeding using organic acids and biological treatments, especially for tomato and pepper plants.

Keywords: crop quality; foliar feeding; integrated pest management; precision nutrient replenishment

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1. Introduction

When the concept of integrated pest management was first suggested, it failed to utilize chemical pesticides to control pests, instead focusing on the use of biological controls and improved agricultural practices. However, irrigation management, soil fertility, and drainage management are also essential components of any type of effective integrated pest control.

The strong association between plant nutritional fertilizer and pest resistance has been well documented in previous research [1]. This association has been highly beneficial, as pest control and the importance of adequate nutrient supplies have become significant concerns for sustainable plant protection. The authors of [1] found that their positive results prompted the invention and manufacturing of liquid foliar fertilizers, including the Bulgarian Fixal and Laktofol series, and their recommended use in tomato farming. The benefits of the foliar application of fertilizer preparations, in certain locations and under specific conditions, to rapidly ameliorate nutritional deficiency [2] are the following:

1. They swiftly remedy any nutrient shortage.
2. They can be integrated with pesticides and other sprays.
3. They can be used to improve poor-quality soil with low levels of nutrients.
4. They can be sprayed if a rapid growth response is required.
5. They can mitigate high potassium and phosphorus fixations.
6. They are effected for biotic and abiotic conditions, such as root-rot disease, dryness, etc.

7. They can be sprayed if the topsoil does not have enough moisture to absorb the plant's nutrients.
8. They enable practitioners to use smaller, more efficient amounts of fertilizer.
9. They have been shown to enhance efficiency and yield factors.

Fertilizer applications in soil have been primarily determined by soil testing, whereas foliar nutrient application have been primarily determined on observable foliar symptoms and plant tissue analyses. For effective foliar fertilization, an accurate diagnosis of nutrient deficiency is required.

Foliar feeding, especially in horticultural crops, has been widely employed and acknowledged as an important aspect of crop production. However, foliar applications have proven to be an excellent method for providing secondary nutrients (calcium, magnesium, and sulfur) and micronutrients to plants (zinc, manganese, iron, copper, boron, and molybdenum).

The method also improves the rapid absorption of mineral nutrients while avoiding soil interactions that reduce root uptake due to soil immobilization. It has assisted with nutrient-deficiency-related physiological issues. For the growth of many vegetable varieties, foliar treatments have been employed as integrated pest-control methods. Furthermore, it has also been shown to potentially boost crop yields, lower costs related to plant protection, and reduce soil and water pollution.

Because nutrients can be delivered to plant tissues during critical periods of plant growth, foliar fertilization is theoretically focused, and thus, more environmentally friendly, than broad-spectrum soil nutrient fertilization.

Light, humidity, and temperatures can affect foliar absorption due their impact on a plant's metabolism, which then impacts photosynthesis, stomatal opening, respiration, leaf expansion, and sink activity. This, in turn, affects the energy and metabolic activity involved in the uptake, assimilation, and subsequent transport of foliar-applied nutrients [3].

To summarize, both short-term and long-term environmental interactions affect the physical and chemical features of plant leaves over the plant's lifetime. The long-term interactions between abiotic impacts and biotic pressures, such as pests, could affect the efficacy of foliar treatments, as has been observed. It influences plant nutritional status, changes the structure and physiology of leaves, and alters foliar-applied nutrient assimilation.

This paper outlines and summarizes the research on foliar applications (those that use organic acids and biological treatments) and sprays on pepper and tomato crops as a plant nutritional method, as well as an integrated pest-management practice.

2. Tomatoes and Peppers (Bio-Environmental Description)

The tomato (*Solanum lycopersicum*) is a member of the Solanaceae family, which also includes peppers, potatoes, and eggplants. Tomato is now one of the most important vegetable crops, with significant economic influences on many farms throughout the world. Jordan, Israel, Spain, Morocco, Mexico, and Peru are among the primary producers in the Mediterranean and South American regions.

Tomatoes are divided into two categories based on their developmental traits: indeterminate and determinate [4]. Determinate growth by tomato plants is compact and only reaches a particular height. They flower and produce their fruits within a short period of time. After several nodes, the main stem and lateral branches culminate in two sequential inflorescences. Indeterminate growth by tomato plants, however, is characterized by constant growth, producing flowers and fruits over a long period of time, until the crop is terminated by the grower or weather conditions. Tomato is a summer/warm-season plant in terms of crop ecology, with the ideal temperature for growing tomatoes between 22 and 26 °C during the day and between 14 and 17 °C at night. The pH of the soil should remain around 6. When soil salinity is around 5 dS m^{-1}, tomato production decreases by 25% [5].

The pepper (*Capsicum* spp. L.) is another member of the Solanaceae family. Peppers are classified into two types: the bell pepper (sweet pepper) and the hot pepper (chili peppers).

One of the pepper's most important components is capsaicin, which yields an excitatory sensation of heat that causes a burning sensation when it encounters other tissues.

Pepper cultivation and production is regarded as critical, as it is one of the most important vegetable crops, with an economic impact on the income of many growers around the world. Mexico, as a center for chili pepper domestication and genetic diversity, has cultivated many species.

In terms of botany, the pepper is a plant that differs from tomatoes in terms of growth habits. Pepper (*Capsicum* spp. L.) is an indeterminate species with infinite shoot development. The stem and branches are constantly growing.

The root systems of pepper plants are shallow. There are usually a few major lateral roots that penetrate the soil to a depth of 2 m. The white flower is primarily hermaphroditic (both sexes in one flower). Pepper is a summer/tropical plant that cannot withstand frost in terms of crop ecology. It cannot survive if the temperature falls below 12 °C. A mild winter climate is critical. The pH of the soil should be between 5.5–6. When soil salinity is around 3.3 dS m^{-1}, pepper and bell pepper production decreases by 25% [5].

3. Foliar Nutrition with Organic Acids

3.1. Salicylic Acid Foliar Nutrition Experiments in Tomatoes and Peppers

The foliar application of salicylic acid and salicylic acid/$KMnO_4$ had neither a significant effect on tomato fruit yield, the content of soluble sugars in fruits, nor the nutritional status of leaves in terms of macro- and micro-nutrients. Following the foliar application of salicylic acid and salicylic acid/$KMnO_4$, tomato fruits had a higher concentration of ascorbic acid and a lower buildup of phenolic compounds and free amino acids. There was no effect from the exogenous foliar application of salicylic acid on the prevention of fruit production decline due to high salt stress [6]. However, it was proved that to recover the lowered growth characteristics of tomato plants under the salinity stress of sodium chloride (100 mmol dm^{-3} NaCl), the most effective methods of salicylic acid application were leaf pretreatment, root pretreatment, and leaf treatment. The concentration used in each method was salicylic acid (2.17 mmol dm^{-3}) [7].

However, the severity of vascular browning and leaf yellowing were significantly reduced in tomato plants treated with root (0.2 mmol dm^{-3}) or leaf foliar spray (0.2 mmol dm^{-3}) with salicylic acid and inoculated with *Fusarium oxysporum* f. sp. *lycopersici* (one of the soil-borne fungal pathogens of tomato wilt) [8].

During low-temperature periods on fall plantations, foliar spraying for sweet peppers with salicylic acid at 2.17 mmol dm^{-3} and chelated zinc at 1.087 mmol dm^{-3} were utilized to boost the ultimate production and fruit quality of sweet pepper plants. With 2.17 mmol dm^{-3} salicylic acid, plus 1.087 mmol dm^{-3} chelated zinc, the maximum values of the early, marketable, and total yields, as well as the physical characteristics of sweet pepper fruits, were obtained, followed by the results found with 1.087 mmol dm^{-3} salicylic acid with 2.17 mmol dm^{-3} zinc [9]. It was reported that three red sweet pepper cultivars grew faster, yielded more, and had better fruit nutritional quality after the foliar application of humic or salicylic acids. Depending on the cultivar, salicylic acid (32.61 mmol dm^{-3}) increased fruit weight, flesh thickness, and total yield. Salicylic acid was found to be more efficient than humic acid in [10]. It was concluded that spraying 2 sweet pepper cultivars with salicylic acid at 2.17 mmol dm^{-3} or 1.087 mmol dm^{-3} boosted production more than that of the untreated plants [11].

In a field experiment, *Bacillus amyloliquefaciens* strain 5B6 (phyllosphere bacteria) was shown to protect pepper plants against cucumber mosaic virus (CMV) by boosting the defense priming through salicylic acid and jasmonic-acid signaling [12]. As compared to the effects on the controls, spraying 1.8 mmol dm^{-3} salicylic acid enhanced sweet pepper plant height, stem diameter, fruit number, weight, length, diameter, vitamin-C content, total soluble solid content, and fruit production [13]. As compared to the untreated controls, the foliar treatment of 0.20 mmol dm^{-3} salicylic acid (30 days after transplantation), followed by 0.00010 mmol dm^{-3} Epibrassinolide (EBR) (60 days after transplantation), dramatically improved bell pepper growth and yield characteristics. By enhancing growth characteristics (plant height, spread, and leaf area), as well as photosynthetic efficiency, these treatments alleviated heat stress on bell pepper growth [14]. The results from these studies are summarized in (Table 1).

Table 1. The most important studies in salicylic acid foliar spraying in tomatoes and peppers.

Treatment *	Concentration	Impact of Foliar Application
Salicylic Acid [7]	2.17 mmol dm^{-3}	Restored the reduced growth characteristics of tomato plants subjected to the salinity of sodium chloride stress (100 mmol dm^{-3} NaCl)
Salicylic Acid [8]	0.2 mmol dm^{-3}	The severity of vascular browning and leaf yellowing was significantly reduced in tomato plants treated with a salicylic acid leaf foliar spray and inoculated with *Fusarium oxysporum* f. sp. *Lycopersici* (soil-borne fungal pathogen of tomatoes wilt)
Salicylic Acid + Chelated Zinc [9]	2.17 mmol dm^{-3} + 1.087 mmol dm^{-3}	To increase the quantity and quality of sweet pepper fruits, foliar spraying with salicylic acid and chelated zinc could be used
Salicylic Acid [10]	32.61 mmol dm^{-3}	Red sweet pepper cultivars with increased fruit weight, flesh thickness, and total yield
Salicylic Acid [11]	2.17 mmol dm^{-3} or 1.087 mmol dm^{-3}	Sweet pepper plant production was increased
Salicylic Acid [13]	1.8 mmol dm^{-3}	Increased the number, weight, length, and diameter of sweet pepper fruits, as well as their vitamin-C content, total soluble solid content, and fruit production
Salicylic Acid [14]	0.20 mmol dm^{-3}	Salicylic acid (30 days after transplantation) followed by Epibrassinolide (EBR) 0.00010 mmol dm^{-3} (60 days after transplantation) increased bell pepper yield, photosynthetic efficiency, and heat tolerance

* Measurement conversions are as follows: 1 mg L^{-1} equals 0.0217391 mmol dm^{-3}, 1 g L^{-1} equals 21.7391304 mmol dm^{-3}, and 1 µM equals 0.001 mmol dm^{-3}.

3.2. Tomato Foliar Application in Humic Acid, Fulvic Acid, and Gibberellic Acid Trials

The foliar spraying of the gibberellic acid GA_3 (0.01 mmol dm^{-3}) as a growth regulator exhibited a growth-promoting impact on unstressed tomato seedlings and was successful in enhancing the salinity of the sodium-chloride tolerance of tomato seedlings, up to 25 mmol dm^{-3} NaCl, with foliar treatments [15]. It was concluded that humic acid sprays with a concentration of 434.78 mmol dm^{-3} could be used successfully to improve tomato growth and yield [16]. The results reported by Kazemi revealed that spraying tomatoes with humic acid (0.65 mmol dm^{-3}) and calcium chloride (15 mmol dm^{-3}), either alone or in combination (0.65 mmol dm^{-3} humic acid + 15 mmol dm^{-3} calcium), had a substantial effect on vegetative and reproductive growth, as well as the chlorophyll content. Calcium (15 mmol dm^{-3}) + humic acid (0.65 mmol dm^{-3}) foliar sprays resulted in the highest vitamin C, yield (25.36 t ha^{-1}), fruit firmness, and lowest blossom end-rot incidence (5%) [17]. Researchers have tested individual and combined foliar sprays of humic acid (86.96 mmol dm^{-3}), fulvic acid (869.57 mmol dm^{-3}), and chelated calcium (54.35 mmol dm^{-3}) on tomato plants 4 times (after 2, 4, 6, and 8 weeks post-transplanting). All foliar sprays of humic acid, fulvic acid, and calcium, either individually or in combination, boosted vegetative growth, production, and fruit quality [18,19]. Furthermore, these therapies reduced the prevalence of blossom end-rot in tomato fruits [18,19].

In recent years, there has been an increased focus on the performance of humic acid-based products, particularly potassium humate. Humustim, a foliar fertilizer, has been particularly useful in tomatoes (Table 2).

Table 2. Impact of foliar application trials of humic acid, fulvic acid, and gibberellic acid applied to tomato plants.

Treatment *	Concentration	Impact of Foliar Application
Gibberellic Acid GA_3 [15]	0.01 mmol dm^{-3}	Foliar treatment improved tomato seedling salinity of sodium chloride tolerance up to 25 mmol dm^{-3} NaCl
Humic Acid [16]	434.78 mmol dm^{-3}	Foliar humic acid sprays were used successfully to improve tomato growth and yield
Humic Acid + Calcium [17]	0.65 mmol dm^{-3} + 15 mmol dm^{-3}	Foliar tomato spray produced the most chlorophyll, vitamin C, yield (25.36 t ha^{-1}), fruit firmness, and had the lowest incidence of blossom end rot (5%)
Humic Acid, Fulvic Acid, Chelated Calcium Solutions [18]	86.96 mmol dm^{-3} 869.57 mmol dm^{-3} 54.35 mmol dm^{-3}	All foliar sprays of humic, fulvic acid, and calcium, used four times (after 2, 4, 6, and 8 weeks post-transplanting), either individually or in combination, increased vegetative growth, production, and fruit quality. In addition, the prevalence of blossom end rot in tomato fruits was reduced

* Measurement conversions are as follows: 1 M equals 1000 mmol dm^{-3}, and 1 ml L^{-1} equals 1000 mg L^{-1} and equals 21.7391304 mmol dm^{-3}. Each 1% equals 10,000 mg L^{-1} and equals 217.39 mmol $dm^{-3.}$

3.3. Foliar Application of Humic and Ascorbic Acid Trials in Peppers

A study conducted by Karakurt found humic acid treatment had a considerable effect on the total chlorophyll content in organically produced peppers, primarily on the chlorophyll-b content. The highest total chlorophyll concentration was found with a foliar application of 434.78 mmol dm^{-3}. As compared to the controls (0 mmol dm^{-3}), the foliar humic acid treatment resulted in significant increases in the mean fruit weight as well as the early and total yields [20].

In an experiment that compared different spray treatments for pungent pepper, it was concluded that spraying humic acid (10.87 mmol dm^{-3}) and zinc (10.87 mmol dm^{-3}), or spraying zinc (10.87 mmol dm^{-3}) and boron (4.34 mmol dm^{-3}), together, were the most promising treatments for improving the physiological and biochemical qualities, respectively, of peppers, in a study based on average values [21]. Adding humic acid (3260.87 mmol dm^{-3}) to the foliar fertilizer at a rate of 0.01 t ha^{-1} yielded the highest seedling height, stem diameter, number of leaves, both shoot fresh-and-dry weights, and root dry weight, as well as macronutrient percentage (NPK%) [22]. Under cold conditions, the foliar application of Biomin aminochelate (an organic aminochelate fertilizer) improved chili pepper growth and quality attributes, followed by Humifolin fertilizer (a humic-acid-based fertilizer). The foliar application of Biomin and Humifolin resulted in higher values for leaf area, leaf number, chlorophyll index, root-and-shoot biomass, and leaf concentrations of soluble sugars, nitrogen, potassium, calcium, and zinc [23].

When comparing the effects of foliar applications on sweet peppers, seaweed extract at 54.35 mmol dm^{-3} and yeast extract at 108.7 mmol dm^{-3} recorded the highest significant values of most plant parameters, such as plant height, number of leaves, number of branches, leaf area, fresh-and-dry weights, and the chemical constituents of leaves, such as the chlorophyll (chlorophyll a, chlorophyll b, and total chlorophyll a + b), nitrogen, phosphorus, and potassium percentages. In addition, spraying 32.61 mmol dm^{-3} humic acid ranked second and considerably enhanced various parameters, such as the number of branches, fresh-and-dry weights, and leaf area. Plants treated with chicken manure and sprayed with either seaweed extract at 54.35 mmol dm^{-3} or yeast extract at 108.87 mmol dm^{-3}, in the presence of biofertilizers over two seasons, produced the most significant results in terms of plant metrics and chemical contents [24]. Chelators (humic acid: HA1 (0 mmol dm^{-3}) and HA2 (10.87 mmol dm^{-3})) and micronutrients (manganese: Mn1 (0 mmol dm^{-3}); Mn2 (10.87 mmol dm^{-3}) and molybdenum: Mo1 (0 mmol dm^{-3}); Mo2 (2.17 mmol dm^{-3}))

as foliar applications showed that HA2Mn2 and HA2Mo2 had significant results in all variables, suggesting that it could improve the quality of the green pungent pepper by increasing carbohydrate contents, antioxidant constituents, and antioxidant activities [25].

Another study conducted by Khazaei and Estaji found that the foliar spray of ascorbic acid (1 mmol dm^{-3}) considerably enhanced the shoot fresh weight, root dry weight, antioxidant characteristics, ascorbate, polyphenol oxidase, and ascorbate peroxidase, in plants under drought stress [26]. The results of these studies are outlined in Table 3.

Table 3. Impact of tests of humic and ascorbic acid foliar application in peppers.

Treatment *	Concentration	Impact of Foliar Application
Humic Acid [20]	434.78 mmol dm^{-3}	The total chlorophyll-b content in organically grown peppers increased as well as mean fruit weight and early total yield
Humic Acid and Zinc or Zinc and Boron together [21]	10.87 mmol dm^{-3} and 10.87 mmol dm^{-3},10.87 mmol dm^{-3} 4.35 mmol dm^{-3}	Enhanced the physiological and biochemical properties of pungent pepper
Humic Acid added to the foliar fertilizer [22]	3260.87 mmol dm^{-3}	The highest pepper seedling height, stem diameter, the number of leaves, shoot fresh-and-dry weights, root dry weight, and (nitrogen-phosphorus-potassium %) were produced
Biomin (0.2%) and Humifolin (0.2%) [23]	43.478 mmol dm^{-3} 43.478 mmol dm^{-3}	Chili peppers with higher values for leaf area, leaf number, chlorophyll index, root, and shoot biomass, and soluble sugar, nitrogen, potassium, calcium, and zinc concentrations in the leaves
Seaweed Extract (2.5 ml L^{-1}) + Yeast Extract (5 g L^{-1}) [24]	54.35 mmol dm^{-3} + 108.7 mmol dm^{-3}	Most sweet pepper plant parameters and chemical constituents of leaves, such as chlorophylls (chlorophyll a, chlorophyll b, and total chlorophyll a + b), nitrogen, phosphorus, and potassium percentages, had the highest significant values
Humic Acid and Manganese or Humic Acid and Molybdenum [25]	10.87 mmol dm^{-3} 10.87 mmol dm^{-3} 10.87 mmol dm^{-3}, 2.17 mmol dm^{-3}	Increased the carbohydrate content, antioxidant constituents, and antioxidant activities and quality of green pungent pepper
Ascorbic Acid [26]	1 mmol dm^{-3}	When combined with drought stress, it improved sweet pepper shoot fresh weight, root dry weight, antioxidant characteristics, ascorbate, polyphenol oxidase, and ascorbate peroxidase

* Measurement conversions are as follows: 1 g L^{-1} equals 21.7391304 mmol dm^{-3}, and 1 ml L^{-1} equals 1000 mg L^{-1} and equals 21.7391304 mmol dm^{-3}. Each 1% equals 10,000 mg L^{-1} and equals 217.39 mmol $dm^{-3.}$

3.4. Foliar Application of Growth Regulators in Peppers

Although the gibberellic-acid (GA_3) and abscisic-acid (ABA) treatments (2.17 mmol dm^{-3}) reduced sweet pepper yield, GA_3 (0.70 mmol dm^{-3}) increased plant height and the levels of tyrosine, phosphate, sulfate, iron, and phosphorus while decreasing glucose and fructose. As compared to the control plants, the foliar spraying of indole-3-acetic acid (IAA) (0.70 mmol dm^{-3}) had no effect, whereas plants treated with ABA had lower levels of sucrose but higher levels of iron. When sprayed every two weeks, GA_3 dramatically improved the quality of sweet pepper fruits while not affecting total yield [27]. On unstressed sweet pepper seedlings, a foliar treatment of GA_3 (0.01 mmol dm^{-3}) exhibited a growth-promoting effect and was successful in increasing the salinity tolerance of sodium chloride up to 50 mmol dm^{-3} NaCl [14].

The effect of foliar applications of different concentrations of morphactin on the pepper root mycoflora (*Capsicum annuum*) was investigated. In response to increasing morphactin concentrations, the root mycoflora was shown to diminish. This effect was attributed to a change in the root exudate pattern in response to the foliar administration of the chemical, as well as a retardation of lateral root growth. Morphactins are a class of synthetic growth regulators (fluorene-9-carboxylic acid derivatives) that have been shown to limit or modify new plant growth [28]. The foliar application of growth regulators in peppers are shown in (Table 4).

Table 4. Impact of foliar application of growth regulators on pepper.

Treatment *	Concentration	Impact of Foliar Application
Abscisic Acid (ABA) [27]	2.17 mmol dm^{-3}	Plants had lower sucrose levels and higher iron levels
Gibberellic Acid (GA_3) [27]	0.70 mmol dm^{-3}	Plant height and tyrosine, phosphate, sulfate, iron, and phosphorus levels increased while glucose and fructose levels decreased
Indole-3-Acetic Acid (IAA) [27]	0.70 mmol dm^{-3}	No effect
GA_3 [14]	0.01 mmol dm^{-3}	Salinity sodium chloride tolerance increased up to 50 mmol dm^{-3} NaCl
Morphactin [28]	0.217 or 2.17 or 21.7 mmol dm^{-3}	Limited plant growth

* Measurement conversions are as follows: 1 mg L^{-1} equals 0.0217391 mmol $dm^{-3,}$ and 1 M equals 1000 mmol $dm^{-3.}$

3.5. Experiments of Foliar Application of Amino Acids in Tomatoes and Peppers

Because of the differences in their free-amino-acid composition, the effect of commercial items on the iron (Fe) nutrition of tomato seedlings varies greatly depending on their origin. A product comprising animal-derived amino acids appeared to be poisonous and had negative impacts on iron nutrition. Exogenous treatments of the product (through roots or foliar applications) containing plant-derived amino acids, however, boosted plant growth and improved the iron nutritional levels of tomato seedlings cultivated with lime-induced iron deficiency, especially when the product had been applied directly to roots [29]. In another experiment, foliar treatments were applied, and it was discovered that applying the amino acids together (in this case, aspartic acid and glutamic acid) had better results than applying them separately. Tomato plants were poisonous when 15 mmol dm^{-3} of alanine was applied, and this toxicity was not reversed by applying an aspartic + glutamic + alanine mixture at the same time [30]. Another study found that an aminochelate foliar spray on tomatoes was superior, as compared to a soil application, in terms of the vitamin-C concentration and the total soluble solids in fruits; however, the soil application of aminochelate outperformed the foliar spray. Aminochelate therapy, particularly via foliar application, greatly increased plant growth, biomass production, and the yield in moderately calcareous soil [31]. Two tomato cultivars were administered a foliar spray of an organic amino acid (proline) at a concentration of 0.22 mmol dm^{-3}. Heinz-2274 had a 63.5% increase in the above-ground biomass, but the Rio Grande had only a 38.9% increase [32].

The foliar spraying of sweet pepper plants with 1.087 or 2.17 mmol dm^{-3} of folic acid and a mixture of methionine, lysine, and cysteine resulted in the highest total protein and total sugars in the dry-weight leaves. In addition, the foliar spraying of sweet pepper plants with a 1.087 mmol dm^{-3} folic acid mixture, including lysine and cysteine amino acids, increased flowering and reduced fruit shedding by 17.2%. Finally, a foliar application of 1.087 mmol dm^{-3} folic acid combined with a mixture of methionine, lysine, and cysteine amino acids resulted in the highest significant averages of fruit weight, diameter, dry weight, total soluble solids, and vitamin-C content [33]. A bio-stimulant treatment involving a ratio of glutamic acid + glutamine/aspartic acid corrected an imbalance induced by the pepper mosaic virus (PepMV), improving all measured parameters, as compared to those of uninfected plants [34].

A study performed by Khan found showed that, under hydroponic circumstances, the foliar application of amino acids and rockweed (*Ascophylum nodosum*) seaweed extract improved the growth and production of two bell pepper cultivars while maintaining biochemical fruit quality under long-term cold storage. A total of 65.22 mmol dm^{-3} of amino acids and 86.96 mmol dm^{-3} of seaweed performed well in terms of vegetative and reproductive parameters while 108.70 mmol dm^{-3} of amino acids and 43.48 mmol dm^{-3} of seaweed treatment maintained improved biochemical fruit quality under cold storage [35].

As compared to the controls, the combination of 130.44 mmol dm^{-3} seaweed extract and 17.39 mmol dm^{-3} amino acids had the highest values for plant height, the number of branches, and the percentage of dry matter of shoots in sweet pepper cultivars [36]. Treatments with glutathione and arginine, especially at 2.17 mmol dm^{-3}, had a stronger boosting impact on hot pepper plants due to its beneficial effect on yield, endogenous growth promoters, ascorbic acid, anthocyanins, tannins, phenolic compounds, carbohydrate, protein, and amino acid levels in yielding fruits, as compared to treatments with tryptophan [37]. The foliar application of amino acids to bell pepper plants increased the fruit diameter and length. Fruit morphologic alterations were also caused by high levels of urea [38]. The most prominent results are displayed in Table 5.

Table 5. Impact of experiments with foliar amino acid applications on tomato and pepper plants.

Treatment *	Concentration	Impact of Foliar Application
Organic Amino Acid (Proline) [32]	0.22 mmol dm^{-3}	Increased aboveground tomato plant biomass (Heinz-2274 increased aboveground biomass by 63.5%, while the Rio Grande increased by only 38.9%)
Folic Acid and a Mixture of Methionine, Lysine, and Cysteine [33]	1.087 or 2.17 mmol dm^{-3}	The most significant total protein and total sugars were found in the dry-weight leaves of sweet pepper plants
Folic Acid Mixture of Lysine and Cysteine Amino Acids [33]	1.087 mmol dm^{-3}	More flowering and 17.2% less fruit shedding in sweet pepper plants
Folic Acid with a Mixture of Methionine, Lysine, and Cysteine Amino Acids [33]	1.087 mmol dm^{-3}	The most significant average sweet pepper fruit weight, diameter, dry weight, total soluble solids, and vitamin-C content were obtained

Table 5. *Cont.*

Treatment *	Concentration	Impact of Foliar Application
Amino Acids + Seaweed (*Ascophylum nodosum)* [35]	65.22 mmol dm^{-3} + 86.96 mmol dm^{-3}	Improved vegetative and reproductive parameters in bell pepper plants
Amino Acids + Seaweed (*Ascophylum nodosum)* [35]	108.70 mmol dm^{-3} + 43.48 mmol dm^{-3}	Under cold storage conditions, improved biochemical bell pepper fruit quality was maintained
Seaweed Extract + Amino Acids [36]	130.44 mmol dm^{-3} + 17.39 mmol dm^{-3}	Had the highest significant values for plant height, branch number, and shoot dry matter percentage in sweet pepper cultivars
Glutathione and Arginine [37]	2.17 mmol dm^{-3}	In hot pepper, treatments had a greater boosting effect than tryptophan treatments, because of its beneficial effect on yield, ascorbic acid, anthocyanins, tannins, phenolic compounds, carbohydrate, protein, and amino acid levels in yielding fruits

* Measurement conversions are as follows: 1 mg L^{-1} equals 0.0217391 mmol dm^{-3}, and 1 ml L^{-1} equals 1000 mg L^{-1} and equals 21.7391304 mmol dm$^{-3.}$

4. Foliar Nutrition and Biological Treatments

Bio-stimulants are plant growth regulators that improve root growth, nutrient uptake, and biotic and abiotic stress tolerance. Farmers can use bacterial spraying since it is safe, effective, and simple to implement. *Pantoea agglomerans* FF (ubiquitous Enterobacteriaceae), *Acinetobacter baumannii* CD-1 (Gram-negative coccobacillus), *Bacillus subtilis* BA-142, and MFD-2 (hay bacillus or grass bacillus, a Gram-positive, catalase-positive bacterium), were found to have excellent potential for increasing tomato yield, growth, and mineral content. As compared to the control treatment, the bacterial treatments boosted the mineral content of tomato plants. As compared to the other applications, *Pantoea agglomerans* FF treatments in tomatoes produced the highest average fruit weight, fruit weight per plant, and plant length. However, fruit number per plant was higher with the *Acinetobacter baumannii* CD-1 application, whereas fruit breadth, length, and dry matter were higher in the *Bacillus megaterium-GC subgroup A.* MFD-2 treatment (Gram-positive, mainly aerobic spore-forming bacterium) than in the other tomato applications [39]. A research group concluded that overall production and mean fruit weight of tomato plants were enhanced by the foliar application of plant-based bio-stimulants, especially when legume-derived protein hydrolysates and seaweed extract had been used. The favorable effect of these bio-stimulants on the nitrogen utilization efficiency was most likely the reason for their influence on yield (nitrogen uptake and nitrogen use). As a result, using legume-derived protein hydrolysates (65.22 mmol dm^{-3}) and *Ecklonia maxima* extract (sea bamboo) (43.48 mmol dm^{-3}) to improve the yield and quality of processing tomatoes appeared to be a feasible long-term strategy [40].

The application of bio-stimulants (Viva, which is a product that has 12% organic matter and 12.5% proteins) on two tomato hybrid plants growing under reduced nitrogen–phosphorus–potassium (NPK) nutrition prevented the development of oxidative stresses in both hybrids studied, without compromising fruit yield or quality. Even when the necessary NPK nutrition was reduced by 40%, the foliar nutrition inhibited superoxide dismutase and peroxidase activity in tomato leaves. When a bio-stimulant was introduced to a reduced macronutrient fertilization, the fruit quality metrics and yield were also maintained. The use of a bio-stimulant in conjunction with a lower NPK fertilizer enabled tomato plants to maintain cell homeostasis and better react to stress [41]. Bio-stimulants were found to boost characteristics of tomato seedling development (plant height, stem thickness, shoot weight, and leaf number), as compared to untreated seedlings [42].

For most of the seedling growth characteristics evaluated, the foliar application of dry yeast extract at a concentration of 43.48 mmol dm^{-3} produced the best results [42]. Another experiment considered the impact of varying treatment rates of an enzyme-hydrolyzed animal protein bio-stimulant (Pepton) on the growth metrics and yield in gold cherry tomato plants [43]. After the initial application, 20 plants were measured for height; stem diameter; fruit set distance between the complete cluster and cluster flowering fruit set; leaf length; and the number of leaves per plant. Cherry tomato root length and diameter were measured at harvest from 20 randomly selected plants. As compared to the control group, Pepton improved all vegetative metrics. For all parameters, the Pepton application rate had a positive linear effect. When the Pepton was treated at 0.004 t ha^{-1}, the calculated yield was 7.8 t ha^{-1} higher, representing a 27% increase in production, as compared to the controls.

During the growing cycle, tomato plants were sprayed 4 times with a solution containing 21.74, 65.22, and 65.22-mmol dm^{-3} of PE, SWE, and PH, respectively. PE (Auxym) is a commercial plant bio-stimulant made by extracting water from tropical plant biomass and fermenting it. SWE (Kelpak) is made from *Ecklonia maxima* (Osbeck) Papenfuss, a brown seaweed gathered off the west coast of South Africa, and PH (Trainer) also contains a root-hair-promoting peptide, a soluble peptide with auxin-like action. As compared to untreated plants, PE, SWE, and PH increased the overall yields by 11.7%, 6.6%, and 7.0%, respectively. The nutritional value of the fruits was boosted by legume-derived PH, which increased lycopene, total soluble solids, potassium, and magnesium content. The SWE and, to a lesser extent, PH treatments increased the calcium content in the fruit tissue [44].

Secondary metabolites are important in the antagonistic activities of some *Trichoderma* (filamentous fungus) biocontrol species. In tomato plants, the metabolites of harzianolide and 6-n-pentyl-6H-pyran-2-one (6PP) were studied. Foliar spray treatments for growing plants were used to investigate the effect of 6PP and harzianolide on tomato plants. Plant height and leaf area increased significantly in 0.001 mmol dm^{-3} 6PP-treated plants, which appeared much more developed and vigorous after 20 days, as compared to the controls. Furthermore, the root systems of plants treated with 6PP were larger and more developed than that of untreated plants [45]. The results of these studies are outlined in Table 6.

Table 6. Impact of foliar nutrition with biological treatments in tomatoes.

Treatment *	Concentration	Impact of Foliar Application
Pantoea agglomerans FF [39]	10^{11} CFU per dm^{-3}	The highest average tomato fruit weight, fruit weight per plant, and plant length were produced
Acinetobacter baumannii CD-1 [39]	10^{11} CFU per dm^{-3}	Produced the higher tomato fruit number per plant
Bacillus megaterium-GC subgroup A., MFD-2 [39]	10^{11} CFU per dm^{-3}	Produced the higher tomato fruit breadth, length, and dry matter
Legume-derived Protein Hydrolysates + *Ecklonia maxima* Extract [40]	65.22 mmol dm^{-3} + 43.48 mmol dm^{-3}	A combination of bio-stimulants was used to increase the yield and quality of processing tomatoes

Table 6. *Cont.*

Treatment *	Concentration	Impact of Foliar Application
Dry Yeast Extract [42]	43.48 mmol dm^{-3}	When compared to untreated seedlings, bio-stimulant improved tomato seedling development characteristics (plant height, stem thickness, shoot weight, and leaf number)
PE (Auxym) is a plant bio-stimulant made by extracting water from tropical plant biomass and fermenting it [44]	21.74 mmol dm^{-3}	As compared to untreated plants, this treatment increased tomato overall yield by 11.7%
SWE (Kelpak) is made from *Ecklonia maxima* (Osbeck) Papenfuss, a brown Seaweed gathered off the west coast of South Africa [44]	65.22 mmol dm^{-3}	As compared to untreated plants, this treatment increased tomato overall yield by 6.6%. The calcium content in tomato fruit tissues was increased by seaweed extract treatments
PH (Trainer) contains a root-hair-promoting peptide, a soluble peptide with Auxin-like action [44]	65.22 mmol dm^{-3}	As compared to untreated plants, this treatment increased tomato overall yield by 7.0%. Legume-derived PH increased the nutritional value of the tomato fruits by increasing lycopene, total soluble solids, potassium, and magnesium content
Trichoderma Metabolites of 6-n-pentyl-6H-pyran-2-one (6PP) [45]	0.001 mmol dm^{-3}	After 20 days, tomato plant height and leaf area increased significantly, and the plants appeared much more developed and vigorous than controls. Furthermore, the root systems of treated plants were larger and more developed than the root system of untreated plants

* Measurement conversions are as follows: 1 M equals 1000 mmol dm^{-3}, and 1 ml L^{-1} equals 1000 mg L^{-1} and equals 21.7391304 mmol dm^{-3}, 1 g L^{-1} equals 21.7391304 mmol dm^{-3}. CFU: Colony Forming Units.

Soil additions of effective microorganisms, yeast extract, fulvic acid, and compost tea, alone or in combination with seaweed at 65.22 mmol dm^{-3} (Alga 600 or Technogreen, commercial seaweed extracts that are a blend of three seaweeds: the rockweed of *Ascophyllumnodosum*, the kelp of *Laminaria* spp., and the gulfweed of *Sargassum* spp.) as a foliar application, improved sweet pepper development and its biochemical components (mineral elements and some bio-constituents, such as endogenous phytohormones and enzyme activity). Sweet pepper plants supplemented with compost tea and a foliar spray of seaweed extract at 65.22 mmol dm^{-3} had the best results in terms of fruit fresh-and-dry weights, fruit length and diameter, and nitrogen-rich leaves [46]. Sweet pepper plants with 0.048 t ha^{-1} of compost tea and 130.44 mmol dm^{-3} of dry yeast had the best vegetative development, yield, and physical and chemical properties. Furthermore, as compared to all other treatments, this level had the highest benefit-to-cost ratio. The combination of 0.048 t ha^{-1} compost tea and 130.44 mmol dm^{-3} dry yeast generated the highest net-income, followed by a mixture of 0.048 t ha^{-1} compost tea and 65.22 mmol dm^{-3} dry yeast.

The concentration enhanced the vegetative growth, fruit physical quality (length, diameter, and fresh weight), total yield, leaf mineral content (nitrogen, phosphorus, and potassium), and fruit nutritional value considerably (calcium and vitamin C) [47]. Bio-stimulants such as amino acids (43.48 mmol dm^{-3}) and yeast extract (217.39 mmol dm^{-3}) have been recommended for foliar spraying on hot pepper plants because they increase productivity while also safeguarding the environment as eco-friendly and cost-effective alternatives for farmers. As compared to the controls, the foliar application of amino acid or yeast extract increased phenol, flavonoid, anthocyanins, ascorbic acid, lycopene, and ß-carotene [48]. In main plots, 4 compost rates were employed on hot pepper plants: control (no compost), 12, 24, and 36 t ha^{-1}; in the additional subplots, 4 foliar sprays were utilized: tap water (control), seaweed extract at 10.87 mmol dm^{-3}, yeast extract at 108.7 mmol dm^{-3}, and liquorice extract at 217.39 mmol dm^{-3}. It was discovered that among the stimulants, seaweed extract was the most effective in terms of vegetative growth of plant height, number of leaves, leaf area, fresh-and-dry weights, chlorophyll content, and yield components of fruits, as well as the total yield and fruit quality parameters, such as phenol and vitamin C, carotene, dry matter, nitrogen, phosphorus, and iron [49].

A foliar spray of seaweed extract rockweed (*Ascophyllum nodosum*) has been recommended for pepper plants at a rate of 0.00034 t ha^{-1} to improve the yield and quality of the fruits [50]. In a black pepper experiment, using the plant addition of *Trichoderma harzianum* (filamentous fungus) and 326 mmol dm^{-3} of foliar fertilizer (tradename Lestari Green) resulted in 26% longer shoot length and 54% more leaves, as well as a 10-day-early appearance of shoots, as compared to plants not subjected to *Trichoderma* and foliar fertilizer [51]. As compared to the control treatment of 6.9-t ha^{-1}, the foliar fertilizers such as 6522 mmol dm^{-3} on farm-fermented organic matter and Alopes Forte at 108.7 mmol dm^{-3}, a fishmeal fermented commercial product, yielded 9.1-t ha^{-1} and 8.9-t ha^{-1}, respectively. The use of foliar fertilizer also increased the production of yellow chili peppers [52]. Table 7 summarizes the biological treatments of pepper plants.

Table 7. Impact of foliar nutrition with biological treatments in peppers.

Treatment *	Concentration	Impact of Foliar Application
Foliar Spray of Seaweed (Alga 600 or Technogreen, commercial product comprising three different seaweeds: *Ascophyllumnodosum*, *Laminaria* spp., and *Sargassum* spp.) + Soil Addition of Compost Tea [46]	65.22 mmol dm^{-3}	The best results in terms of fresh-and-dry weights of sweet pepper fruits, fruit length, and diameter, and nitrogen-rich leaves
Foliar Spray Mixture of Dry Yeast + Compost Tea [47]	130.44 mmol dm^{-3}	The concentration increased sweet pepper vegetative growth, fruit physical quality (length, diameter, and fresh weight), total yield, leaf mineral content (nitrogen phosphorus, and potassium), and fruit nutritional value content (calcium and vitamin C)
Foliar Spray Mixture of: Amino Acids + Yeast Extract [48]	43.48 mmol dm^{-3} + 217.39 mmol dm^{-3}	It increased the hot pepper content of phenol, flavonoid, anthocyanins, ascorbic acid, lycopene, and ß-carotene levels As compared to the control

Table 7. *Cont.*

Treatment *	Concentration	Impact of Foliar Application
Foliar Spray of Seaweed Extract at + Soil addition of Compost of Plant Residues [49]	10.87 mmol dm^{-3}	Improved hot pepper vegetative growth, fruit number, and total yield, as well as fruit quality parameters such as phenol and vitamin C, carotene, dry matter, total soluble solids, nitrogen, phosphorus, and iron
Foliar Fertilizer (Lestari Green) + Soil Addition of *Trichoderma harzianum* [51]	326 mmol dm^{-3}	This resulted in a 26% longer shoot length, 54% more leaves, and 10 days earlier shoot appearance of the black pepper plant
Foliar Fertilizers such as Biol and Alopes Forte [52]	6522 mmol dm^{-3}, and 108.70 mmol dm^{-3}	As compared to the control treatment, which yielded 6.9 t ha^{-1}, foliar fertilizers, such as Biol and Alopes Forte, yielded 9.1 t ha^{-1} and 8.9 t ha^{-1}, respectively, in yellow chili peppers

* Measurement conversions are as follows: 1 g L^{-1} equals 21.7391304 mmol dm^{-3}. Each 1% equals 10,000 mg L^{-1} and equals 217.39 mmol dm$^{-3.}$

5. Conclusions

This article focused on the importance of foliar nutrition in integrated pest management (IPM) and integrated crop management (ICM). The reviewed research focused on the scientific advancements in the use of organic acids in foliar nutrition processes, such as salicylic acid, humic acid, fulvic acid, ascorbic acid, amino acid, and organic plant-growth hormones. The interest in organic acids has increased because they contain the elements of carbon, hydrogen, and oxygen, which are the main components of chlorophyll resulting from photosynthesis, as well as environmental concerns regarding reducing pesticides and chemical fertilizers derived from industrial sources, particularly organic salicylic acid. However, organic acids can be manufactured and derived from unnatural sources, which make them unsuitable for use in environmentally safe and healthy crops. As a result, this paper referred to studies in which biological treatments (including beneficial bacterial strains, the fungus of *Trichoderma* spp., legume-derived protein hydrolysates, seaweed extracts, dry yeast extracts, and hydrolyzed animal protein bio-stimulants) were used in foliar applications on tomato and pepper crops, where microorganisms can be used in foliar spraying. This enables the agricultural production to be considered organic while maintaining environmental and human health safety requirements. Researchers have divided amino acids into two categories: organic acids and biological stimulants. This paper sought to direct the attention of the scientific research community and agricultural manufacturers toward the use of organic farming techniques and biological controls that improve tomato and pepper production while reducing and limiting the use of pesticides and manufactured chemical fertilizers.

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