ISSN:2958-0420 Contents lists available at JJOAS-N

Jordan Journal of Applied Science - Natural Science Series
Applied Science Private University

Research Article *Vol. 19*

Integrated Management of *Alternaria alternata* in Tomato and Pepper: Leaf-Environment, and Cultivar Interactions.

Mohunnad Massimi[1,2*], Besarta Kabashi[1]

[1]Crop Production and Horticulture Doctoral School, Institute of Plant Protection, University of Debrecen, Böszörményi út 138, H-4032 Debrecen, Hungary.

[2]Jordan's Ministry of Agriculture, Amman, Jordan.

ARTICLE INFO

Article history:

Received 15 Dec 2024

Accepted 23 Apr 2025

Published 12 May 2025

DOI: https://doi.org/10.35192/jjoas-n.v19i1.2098

***Corresponding author:**

Crop Production and Horticulture Doctoral School, Institute of Plant Protection, University of Debrecen, Böszörményi út 138, H-4032 Debrecen, Hungary.

Email:

mohunnad.massimi@agr.unideb.hu.

ABSTRACT

Background: Previous studies have shown that foliar applications of organic acids, bio-fungicides, and ion-rich solutions can enhance mineral uptake and immunity in tomato and pepper plants, reducing fungal infections.

Methods: A factorial experiment was conducted in a controlled growth chamber to evaluate the effects of cultivar selection and prophylactic foliar treatments on *Alternaria alternata* infections. Tomato cultivars (Mobil, Korall, and Tyking F1) and bell pepper cultivars (Carma, Fokusz, and Bobita F1) were tested. The foliar treatments included 112.4 mmol.L^{-1} magnesium sulfate-hydrate, 2.17 mmol.L^{-1} acetylsalicylic acid, 112.4 mmol.L^{-1} sodium hydrogen carbonate, and 217.4 mmol.L^{-1} hydrogen peroxide. Disease incidence and severity indices were recorded, with three replicates for each treatment.

Results: The highest *A. alternata* infection rates were observed in the Mobil tomato cultivar treated with magnesium sulfate-hydrate (112.4 mmol.L^{-1}), whereas the lowest disease indices were recorded in the drought-sensitive Tyking F1 cultivar treated with 2.17 mmol.L^{-1} acetylsalicylic acid. Similarly, in bell peppers, Carma exhibited the lowest infection levels when treated with acetylsalicylic acid, while Bobita F1 showed the highest disease indices following magnesium sulfate hydrate application.

Conclusion: To mitigate *A.alternata* infections in protected horticultural systems, growers should consider cultivating Tyking F1 tomato and Carma pepper while implementing prophylactic foliar treatments with 2.17 mmol.L^{-1} acetylsalicylic acid. Optimal environmental conditions, including air temperatures above 25°C and relative humidity levels around 80%, should be maintained. Additionally, integrating supplementary yield-enhancing strategies from recent research can further improve disease management and crop productivity.

Keywords: Crop protection, Protected culture, Sustainable horticulture.

Introduction

Early blight and powdery mildew are among the most significant fungal diseases that impact plant leaves in the family of Solanaceae (1, 2) like tomatoes, and peppers. There is an argument that the crop varieties are drought and powdery mildew-resistant. However, most commercial tomato varieties are susceptible to early blight (2). Early blight is a fungal disease caused by the genus Alternaria. It is found in Solanaceae family plants, such as tomatoes, bell, and chili peppers. The fungal pathogen causes leaf lesions and leaves with concentric patterned rings. Leaf lesions usually appear on older leaves (2). Early blight can cause significant yield loss if left uncontrolled (2). In Jordan, yield loss estimates for tomatoes range from 20 to 80%, with an average of 50%, and for sweet peppers, 15 to 60%, with an average of 38%. The disease resulting in leaf spots, defoliation, seedlings may exhibit damping-off, and severe infections can impair the photosynthetic capacity of the plants. Crop breeders develop resistant cultivars that withstand early blight incidents in tomatoes. In Qatar 2021, a notable study finds that tomato cultivars TF-00175 and Syngenta have the lowest disease index and are more resistant to early blight infection than the other cultivars (3).

Recently, agrobiologists state that the significant ways to control this disease are foliar treatments applied to leaf surfaces to improve nutrient uptake and improve immunity. Major types of early blight pathogens on tomatoes and peppers are Alternaria alternata, and Alternaria solani. The use of foliar nutrition in previous research to reduce fungal pests in tomatoes and peppers varied widely. One of the most prominent studies showed that different calcium salt mixtures reduce powdery mildews, Erysiphe orontii, colonies on foliates as effectively as sulfur when sprayed on tomato plants (1, 4). Foliar calcium application inhibits the growth of powdery mildew on tomatoes due to ion-specific consequences. Furthermore, whereas highly resistant breeds have high calcium absorption, higher calcium richness promotes tomato resistance to

Published by Jordan Journal of Applied Science - Natural Science Series — This is an open access article under the CC BY 4.0 license.

Ralstonia solanacearum, which causes bacterial wilt (5). Experiments conducted in greenhouses and outdoors evaluate the efficacy of foliar applications of ammonium lignosulfonate (ALS) and potassium phosphate (KP) fertilizers in preventing bacterial spot disease in tomatoes and bell peppers. As a control treatment, acibenzolar-S-methyl was assigned. Xanthomonas campestris pv. vesicatoria inoculated greenhouse-grown tomato seedlings treated with acibenzolar-S-methyl, 434.8 mmol.L^{-1} or 869.6 mmol.L^{-1} ALS, 25 mmol.L^{-1} KP, or 434.8 mmol.L^{-1} ALS with 10 mmol.L^{-1} KP show much less infection than unprotected controls. On infected field-grown tomato and bell pepper plants, weekly foliar applications of acibenzolar-S-methyl, ALS, or KP reduce disease (6). When tomato plants are inoculated with Fusarium oxysporum f. sp. lycopersici and treated with salicylic acid at the roots 0.2 mmol.L^{-1} or foliar spray 0.2 mmol.L^{-1}, vascular browning and leaf yellowing wilting are dramatically reduced (7).

Research has shown that balanced foliar nutrition, which includes nitrogen, phosphorus, and potassium, can be more effective than single nutrient applications. This balance keeps plants from becoming excessively vegetative (which may stimulate fungal development) or overly stressed (which may reduce resistance). Calcium is required for maintaining cell wall stability and signaling during pathogen attack. It improves structural integrity, making it more difficult for diseases such as Alternaria alternata to enter plant tissues. Sulfur has natural antifungal effects and is utilized as both a nutrient and a therapeutic treatment for fungal diseases. Its role in generating sulfur-containing molecules (such as glutathione) helps the plant's immune system.

Organic acids, such as salicylic acid are well-known for their ability to induce systematic acquired resistance (SAR), a plant's broad-spectrum defensive mechanism against pathogens (8). Foliar application of salicylic acid has been demonstrated to increase pathogenesis-related protein synthesis and augment plant defenses. These studies show tomato and pepper foliar nourishment with macronutrients, calcium, sulfur, and salicylic acid can be used as an antifungal method to combat Alternaria alternata and Alternaria solani infections in tomatoes and peppers.

On the other hand, foliar spraying micronutrients has been the subject of prior investigations to prevent pests in tomatoes and peppers, such as blights, blossom end rots, as well as insects and viruses. Micronutrients have a considerable impact on the early blight disease in vitro tests on tomatoes at all tested dosages of 2.17, 4.35, and 6.52 mmol.L^{-1}, copper, and zinc have shown the most notable antifungal action for Alternaria blight of tomatoes caused by Alternaria alternata (9). At a 2174 mmol.L^{-1} concentration, garlic extract entirely prevented mycelial development in plants. In garden environments, two foliar sprays of copper sulfate 108.7 mmol.L^{-1} are the most effective in reducing disease intensity by 46.94% over control followed by zinc sulfate. Garlic extract 2174 mmol.L^{-1} reduces disease intensity by 58.16% over untreated control and is more effective than neem leaf extract (9). The incidence of blossom end rot in tomato plants is decreased when $CaCl_2$ used alone. But the lowest blossom end rot incidence 6.25% in tomatoes is produced by foliar sprays of $CaCl_2$ 130.2 mmol.L^{-1} and borax 43.4 mmol.L^{-1} (10). Also, due to the silicon content of Hebagreen in comparison to the typical granular NPK fertilizer, herbagreen-treated tomato plants show lower late blight disease incidence and severity in tomatoes as well as lower insect pest populations of Bemisia tabaci (11). Plants continued to be infected even after foliar calcium treatment reduced virus concentrations (12). In summary, diverse tomato pests such as blight fungal pathogen, insects, and viruses can be inhibited using foliar nourishment of micronutrients and natural plant extracts rather than using secondary essential nutrients of calcium alone which is more prominent for physiological disorder treatments.

A combination of zinc sulfate, manganese sulfate, and copper sulfate, combined with boric acid foliar treatments, reduces Alternaria solani tomato disease severity (5.85%) and disease incidence (23.15%) compared to the control (28.59%) (13). Even though the boric acid is not an organic acid, this study shows a positive combined impact of micronutrients and acid on early blight infection reductions in tomatoes (13).

Like tomato plants, pepper plants were tested for disease and pest management using the foliar application. One of the most significant research projects on the application of potassium and phosphorus macronutrients to pepper plants' foliar feeding was reported to prevent the powdery mildew pathogen (14). To combat powdery mildew Leveillula taurica pathogen, a 217.4 mmol.L^{-1} mono-potassium phosphate KH_2PO_4 foliar spray can be applied to the top surfaces of lower leaves of peppers cultivated in greenhouses. Plants exposed to the inoculum showed a reduction in spore generation on foliate tissue and a foliate area covered in sporulating colonization when lower leaves were sprayed with mono-potassium phosphate (14). This research reports that foliar nourishment phosphorus and potassium can solve pepper infection with a powdery mildew fungus. Furthermore, it has been demonstrated by other research that micronutrients are more successful in preventing diverse fungal infections in pepper plants.

For three different pepper varieties, the mean fruit weight was higher in plants treated with harpin plus Botrytis cinerea than in plants inoculated with Botrytis cinerea alone. According to these results, harpin may be able to strengthen pepper plants' resistance to Botrytis cinerea (15). Also, a recent study shows that chitosan may be an effective substitute for common fertilizers and fungicides in the fight against Phytophthora capsici in chili pepper plants (16). Chlorophyll content and physiological parameters like height and leaf number increments show that chitosan-foliar treated plants grow more quickly than control plants (16).

On chili pepper evaluated in vitro, Alternaria alternata growth was significantly inhibited as $ZnSO_4$ concentrations rose from 0.25 to 10.50 mmol.L^{-1}. $ZnSO_4$ foliar treatments of 0.009, 0.018, and 0.036 mmol.L^{-1} decreased Alternaria leaf spot disease in vivo while enhancing plant growth and physicochemical traits. A dose of 0.036 mmol.L^{-1} $ZnSO_4$ stimulates growth and physiological traits in both the presence and absence of the pathogen, highlighting the significance of zinc micronutrient for improved plant health. Consequently, $ZnSO_4$ be utilized as a cost-effective and accessible remedy to increase Alternaria leaf spot tolerance in chili pepper plants (17). These cases indicate the efficient use of bio-fungicides, sulfur, and zinc foliar treatments to combat several fungal pathogens on pepper species.

There are no formal documents and research reports on the impact of some common organic foliar extracts - other than acetylsalicylic acid - as pesticides against pests. Experts and growers effec-

tively use sodium hydrogen carbonate as a fungicide and insecticide. Also, the mineral salt of Epsomite displays positive results in combating soil-borne fungal pathogens and hydrogen peroxide in reducing fungal root rot pathogens. This test searched how drought -tolerant and non-drought-tolerant breeds of tomato and bell pepper plants react to several leaf treatments by scaling both indices of the early blight disease incidence and severity on plants.

Methodology

Alternaria alternata (Fries) Keissler pathogen was isolated from Lupinus angustifolius plants. Vials were obtained from the National Collection of Agricultural and Industrial Microorganisms (00969), Hungarian University of Agriculture and Life Sciences, and kept in a refrigerator at 4 °C. Dishes of potato dextrose agar with two suspension drops in each were covered with coverslips and placed in an incubator that was adjusted to 25.7 °C. The mother suspension spores solution was washed with NaCl-peptone of 206.5 $mmol.L^{-1}$ and the number of spores in it was determined using a Thoma cell counting chamber of 0.0025 $mm^2 \times 0.1$ mm.

Three tomato varieties; Mobil, Korall, and Tyking F1, and three bell pepper varieties; Carma, Fokusz, and Bobita F1 were seeded in a nursery under typical climatic conditions of 30.5 °C temperatures and 50% air humidity. 100 seeds of each breed were planted in plastic seedling trays, with the seeds sown in eight rows and seven columns. Each tray was 46 cm long and 28 cm wide.

After growth, the trays were transferred from the nursery, where the tomatoes and bell peppers were in the first true leaf stage. The six trays were incubated in a growth incubator PHCBI Model, MLR-352-PE. The temperature was fixed to 25℃. Three fluorescent lamps were run at right, left, and in front of the trays, each with a power of 37 watts. The lights were run for ten hours a day from 8 a.m. to 6 p.m., then stopped automatically for 14 hours the remainder of the day. The air moisture was raised to 80%, and up to 83%, using a pail of water with a gauge of six liters of tap moisture which was detected using a type of probe Extech 445702.

Each variety received an initial sole foliar nourishment spraying treatment. The foliar treatments were sprayed at a dose of 4 ml for each seedling after 23 days of emergence initiation for tomatoes, and 27 days for pepper first emergence, across each of the three adjacent columns; magnesium sulfate-hydrate 112.4 $mmol.L^{-1}$, 2.17 $mmol.L^{-1}$ acetylsalicylic acid (source was aspirin protect tablet), sodium hydrogen-carbonate 112.4 $mmol.L^{-1}$, and hydrogen peroxide of 217.4 $mmol.L^{-1}$. After 48 h of foliar nourishment, seedlings of both tomato and pepper plants were artificially inoculated once with Alternaria alternata at a dosage of 0.5 ml per seedling (2.050×10^9 spores L^{-1}). A sterilized gradual syringe was used to spray the top foliage growth. On the fifth day following inoculation, disease incidence was determined. The severity index, in addition, was calculated on the sixth day. Disease incidence ($I = \sum x/N$). The number of diseased plants (x) is divided by the total number evaluated (N) (18). Percent disease severity [$PDS= (\sum RT \times 100)/(SN)$], where T represents the total number of leaves in each category, R is the disease severity scale, N is the total number of leaves tested, and S is 5, the highest number in the scale (19).

The pH of each spray solution was recorded using a pH meter (HORIBA LAQUA-TWIN pH (11)) with four replicates. Further, two electronic ionic probes of the type of HORIBA LAQUA-TWIN devices were used to detect the calcium (Ca^{+2}) and nitrate (NO_3^-) ionic composition in $mmol.L^{-1}$ in the spraying solutions.

After foliar nourishment and pathogen inoculation, the variables were collected and processed using SPSS version 26 to test normality by the Shapiro-Wilk test. Related samples Friedman (2 way-ANOVA) by ranks of the factorial design was used, factor A was a variety with 3 varieties for each plant, and factor B was the foliar nutrition measure with 4 foliar solutions for each plant. Spearman correlation was plotted for disease incidence and severity index using Minitab 20. Further, Minitab 20's regression reaction optimizer was run to determine the highest and lowest reactions to each plant's disease incidence, and disease severity index variables, with only breed and leaf nourishment treatments used.

Results

Figure1 (A and B) show Spearman correlations for early blight disease incidence and severity index in both plants for tomato and bell pepper, respectively. In tomatoes, the amount of correlation r = 0.765 represents a strong positive correlation between early blight disease incidence and disease severity index Figure 1A. Further, a very robust positive correlation was recorded r = 0.899 between early blight disease incidence and severity percentage in bell peppers Figure 1B.

Plant varieties and foliar nourishment effects on disease incidence percentage are presented in Table 1. There were no considerable variations between tomato and bell pepper breeds. Tomato Korall and bell pepper Carma breeds showed the lowest disease incidences. Regarding the effect of foliar nourishment treatment on disease incidence, the acetylsalicylic $C_9H_8O_4$ of 2.17 $mmol.L^{-1}$ outperformed the other treatments and reduced incidence in both plants Table 1. Although acetylsalicylic caused a lower blight disease incidence than the other foliar treatments in tomatoes and peppers, there were no substantial differences between foliar treatments in tomatoes Table 1. In pepper, hydrogen peroxide H_2O_2 of 217.4 $mmol.L^{-1}$ was significantly the lowest effective foliar treatment against early blight incidence Table 1.

For tomatoes' disease severity index, the outcomes of Korall variety plants were significantly the lowest compared to other tomato varieties Table 1. The most efficient leaf treatment for reducing early blight severity in tomatoes of various varieties was acetylsalicylic 2.17 $mmol.L^{-1}$ without any significant variations. The severity of early blight infection does not significantly differ amongst pepper cultivars Table 1. Hydrogen peroxide 217.4 $mmol.L^{-1}$ was the worst treatment significantly for preventive foliar nutrition in peppers Table 1. Acetylsalicylic 2.17 $mmol.L^{-1}$ outperformed magnesium sulfate and sodium hydrogen-carbonate with no discernible differences. Acetylsalicylic acid 2.17 $mmol.L^{-1}$ produced the strongest early blight disease tolerance, predominately for Tyking F1 tomato. Magnesium sulfate 112.4 $mmol.L^{-1}$ produced the highest early blight disease sensitivity, mostly for the Mobil tomato. Also, the multiple minimum responses of early blight disease tolerance were recorded for the variety Carma of pepper.

Sprinkling the same variety with acetylsalicylic 2.17 $mmol.L^{-1}$ produced a minimum early blight disease incidence and severity. When the pepper Bobita F1 variety was sprinkled with magnesium sulfate 112.4 $mmol.L^{-1}$, the results of the early blight disease incidence and severity index percentage were the highest.

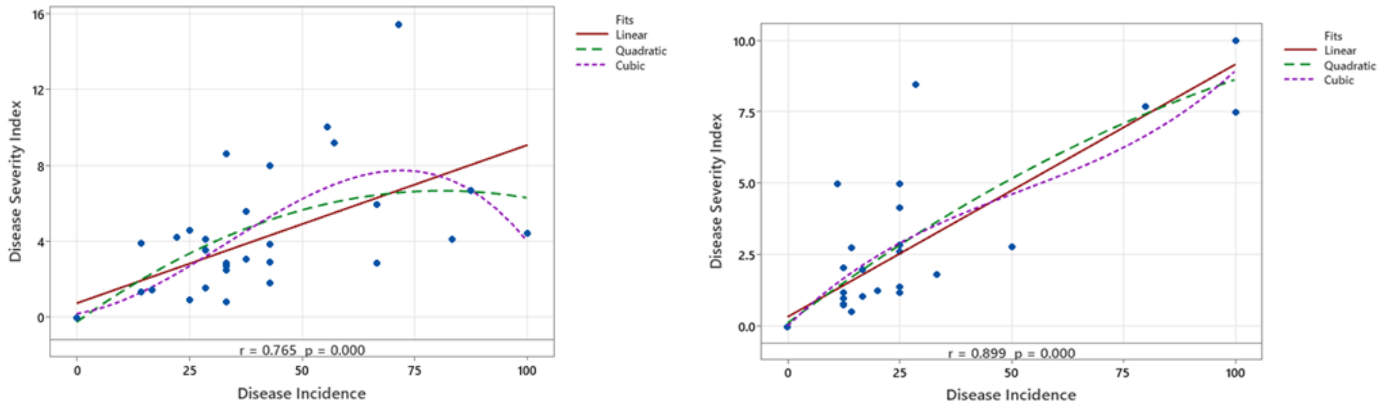

Figure 1. Spearman correlation between early blight disease incidence and severity index in (A) tomato and (B) bell pepper.

Table 1. Overall mean for the effect of plant cultivars and foliar nourishment on the early blight disease incidence (%) and severity index (%) after the artificial inoculation of *Alternaria alternata*.

Disease Incidence (%)			
Bell Pepper Cultivars		**Tomato Cultivars**	
13,43.a ± (11.27)	Carma	45,68a ± (21.95)	Mobil
16,34.a ± (24.45)	Fokusz	25,10a ± (34.69)	Korall
28,36.a ± (35.50)	Bobita F1	29,59a ± (18.76)	Tyking F1
Prophylactic Leaf Feeding		**Prophylactic Leaf Feeding**	
to Bell Pepper Cultivars		**to Tomato Cultivars**	
9.92^{ab} ± 10.49	$MgSO_4.7H_2O$	38,83a ± (34.33)	$MgSO_4.7H_2O$
3.61^{b} ± 7.41	$C_9H_8O_4$	21,72a ± (15.42)	$C_9H_8O_4$
15,59 ab ± (11.23)	$NaHCO_3$	31,68a ± (21.00)	$NaHCO_3$
48,38 a ± (35.82)	H_2O_2	41,60a ± (32.09)	H_2O_2
Disease Severity Index (%)			
Bell Pepper Cultivars		**Tomato Cultivars**	
1,90a ± (1.96)	Carma	4,67 a ± (3.80)	Mobil
1,48a ± (2.23)	Fokusz	1,27 b ± (1.65)	Korall
2,77a ± (3.66)	Bobita F1	4,65 a ± (3.53)	Tyking F1
Prophylactic Leaf Feeding		**Prophylactic Leaf Feeding**	
to Bell Pepper Cultivars		**to Tomato Cultivars**	
1.01 ab ± (1.38)	$MgSO_4.7H_2O$	4,11 a ± (4.83)	$MgSO_4.7H_2O$
0.25 b ± (0.50)	$C_9H_8O_4$	2,38 a ± (1.66)	$C_9H_8O_4$
1,79 ab ± (1.59)	$NaHCO_3$	4,12 a ± (3.14)	$NaHCO_3$
5.16 a ± (3.37)	H_2O_2	3,51 a ± (3.74)	H_2O_2

Discussion

Based on the regression reaction optimizer of early blight disease variables of both disease incidence and severity index on plant leaves, this case study supported farmers in screening the top tomato or bell pepper breed with the prophylactic foliar nourishment of acetylsalicylic acid 2.17 mmol.L^{-1} together before the expected exposure of seedlings to the protected culture of air microclimate of not lower than 25°C and 80% up to 83% humidity, which was considered very optimum to enhance Alternaria alternata growth.

The incidence percentage often provides information on a disease's prevalence in a particular region or host group (18). In general, tomato breeds of Korall followed by Tyking F1 appear to have lower percentages of disease incidence in protected horticulture than others. Moreover, pepper breeds that are tolerant to environmental impacts are Carma, and Fokusz sound to have lower proportions of early blight disease incidence in the protected horticulture than the drought-sensitive breed Bobita F1. At the same time, hydrogen peroxide 217.4 mmol.L^{-1} is the least effective leaf treatment, while prophylactic foliar nourishment with acetylsalicylic 2.17 mmol.L^{-1} against Alternaria alternata results in more tolerant seedlings with lower early blight incidence in both tomatoes and peppers. Disease incidence is mostly used for diseases that impact entire plants, like wilts, smuts, and rots, while they are in the early stages of an epidemic. The number of clearly diseased plants to all the other plants in the field is referred to as the disease incidence. Those results fit with previous results and proofs (20). When planted and treated with acetylsalicylic 1.087 mmol.L^{-1}, the Korall breed flourished and had greater chlorophyll and ionic levels of calcium, potassium, and nitrate concentrations, outperforming Tyking F1 (20). Cultivating pepper Carma with a supporting acetylsalicylic leaf feeding splash 1.087 mmol.L^{-1} also showed a similar superiority in comparison to the breed Bobita F1 that was treated with distilled

moisture regarding physiological plant health attributes (20). In addition to incidence, plant disease severity is measured by the amount of affected plant tissue, usually as a percentage of all plant tissue (19).

The percentage of essential host tissues or organs affected by a disease's symptoms and lesions is known as the disease's severity. It is more appropriate for diseases like rusts, mildews, leaf spots, and other similar diseases and depends on the number and size of the lesions. Disease severity provides information about the extent of the disease's damage. The considerable tolerance response of the tomato Korall to early blight disease severity and all leaf treatments, mainly acetylsalicylic 2.17 mmol.L^{-1} foliar nourishment can be observed. In this article, the plant tolerance against Alternaria alternata supports a previously published result (20). Seedlings of Korall were studied under similar optimal environmental conditions and acetylsalicylic small dosage of 1.087 mmol.L^{-1} (20). The plant health of tomato Korall outperformed other breeds, possibly due to the breed's vigor under a smaller level of acetylsalicylic 1.087 mmol.L^{-1} (20). These findings showed that tomatoes Korall positively affected plant growth and can be grown in open-air gardens (20).

Thus, by enhancing the plant's physiological reaction to Alternaria alternata, spraying Korall seedlings previously in protected cultures with acetylsalicylic 2.17 mmol.L^{-1} enhances immunity and stress tolerance to early blight disease. Further, the substantial susceptibility of pepper Bobita F1 seedlings to early blight disease severity treated with hydrogen peroxide 217.4 mmol.L^{-1} foliar nourishment can be noticed. Hydrogen peroxide was the only acidic spraying solution in this study, while the others were basic or neutral. The Soil microbiologists reported that the acidity is lowered by the enzymes that fungi create, which are acidic (21). However, bacterial slime makes the soil more basic, and most nitrogen-fixing bacteria need an acidity of above 7 (21).

This only explains why, in comparison to other prophylactic foliar nourishment treatments, the severity index of the early blight disease caused by Alternaria alternata has increased in leaves previously treated with hydrogen peroxide 217.4 mmol.L^{-1}. Under identical ideal climatic conditions and leaf feeding of distilled moisture, seedlings of Bobita F1 were investigated (20). Due to the breed's drought sensitivity, pepper Bobita F1 produced the lowest criteria for plant health. Based on these results, it could not be cultivated in open-air gardens (20). In conclusion, growing the pepper Bobita F1 in protected cultures, particularly with leaf treatments of hydrogen peroxide 217.4 mmol.L^{-1}, increases stress sensitivity to early blight disease.

The strong correlation coefficients between early blight disease incidence and severity index in both tested plants of tomato and pepper indicate a positive relation trend between the two variables. The strong relationship suggests that Alternaria alternta disease expansion in the host or geographical region mutually increases disease severity and intensity in plant leaf tissues. So, for general plant health response to early blight disease pathogen in protected cultures of tomatoes and peppers -based on breed choice and leaf nourishment treatment- a regression response optimizer is used as a statistical equalization to avoid singular comparisons and to focus on ultimately combined comparisons, i.e., minimum disease incidence and severity index variables simultaneously. The Tyking F1 tomato breed showed the lowest disease symptoms when treated with foliar nourishment of acetylsalicylic 2.17 mmol.L^{-1}. Spraying the tomato Mobil breed with magnesium sulfate 112.4 mmol.L^{-1} produced a relatively higher early blight disease incidence and severity index. The numerous minimum records of early blight disease infections were recorded for the breed Tyking F1, the breed that was classified as a non-drought tolerant breed (20). Growers were recommended to grow Mobil without any complementary leaf treatment in open-air gardens or to cultivate a Korall breed, that thrived physiologically when planted and splashed with acetylsalicylic 1.087 mmol.L^{-1} and in a better establishment than Tyking F1 in open-air gardens (20). But, in this study, gardeners shall consider growing tomatoes Tyking F1 with prophylactic leaf nutrition of acetylsalicylic 2.17 mmol.L^{-1} in protected cultures of high humidities (80-83%) and temperatures of a minimum 25°C threshold to avoid early blight occurrence due to Alternaria alternata. In addition, the pepper breed Carma produced several minimum responses of plant health attributes concerning early blight disease infection. The results of disease incidence and disease severity index percentages were the lowest when this breed was treated with acetylsalicylic prophylactic leaf feeding 2.17 mmol.L^{-1}. The pepper breed Bobita F1 showed a higher incidence and severity of early blight disease when leaves were treated previously with magnesium sulfate 112.4 mmol.L^{-1}. Close results were confirmed previously in similar environmental conditions of the growing chamber and displayed that the Carma breed treated with acetylsalicylic 1.087 mmol.L^{-1} produced the highest plant health physiological status (20). At the same time, pepper Bobita F1 performed the worst physiologically under distilled moisture leaf nourishment. Generally, it has been confirmed in previous research that Alternaria alternata fungus grew and thrived in media conditions supplemented with the magnesium sulfate-hydrate $MgSO_4.7H_2O$ (22). Consequently, tomato Tyking F1 and pepper Carma will thrive against early blight disease caused by Alternaria alternata fungal pathogen under foliar nourishment with acetylsalicylic 2.17 mmol.L^{-1} in the protected cultivation of tomatoes and peppers.

Specific doses of the active ingredient increased the concentrations of calcium, nitrates, or both in distilled moisture. These components, however, could become less in some other solutions because of binding or deposition. It is deserve observing that the concentrations of calcium combined with acetylsalicylic acid 2.17 mmol.L^{-1} reached the highest significant level in comparison to other solutions and remained an almost neutral acidic solution. The acetylsalicylic 2.17 mmol.L^{-1} solution had the lowest significant nitrate content compared to the sodium hydrogen-carbonate solution 112.4 mmol.L^{-1}. In any case, the hydrogen peroxide solution 217.4 mmol.L^{-1} had the highest acidic acidity (4.32) with no calcium content. Further, the magnesium sulfate 112.4 mmol.L^{-1} solution had the highest significant alkaline acidity of 8 with little calcium. In severely alkaline soils, lime, or a calcium supply was employed and necessary because, at high pH levels, magnesium inhibited other minerals uptake and competed with calcium absorption (23).

This could be the cause of the magnesium sulfate solution's failure to effectively treat the early blight disease in tomatoes and peppers. Acetylsalicylic 2.17 mmol.L^{-1} can reduce early blight because it has a larger calcium cation content 1.11 mmol.L^{-1} than oth-

er treatments. The production of pectin in plant cell walls, which limits the growth of Alternaria alternata fungus spores and mycelium and results in the deterioration cessation of the developed spots and lesions in the tissue of the leaves, is aided by calcium.

Those results come in fits with previous investigations. Acetylsalicylic was found to be the most effective treatment against Alternaria solani in tomatoes, with a root dip of 4.4 mmol.L^{-1} and a foliar spray of 3.3 mmol.L^{-1} resulting in a minimum of early blight disease intensity of 17.41%, and 20.43% at 45- and 60-days post-sowing, respectively (24). The most effective antioxidant therapy against Alternaria solani was salicylic acid 0.65 mmol.L^{-1}, followed by ascorbic acid 0.65 mmol.L^{-1} (25). Boric acid 0.33 mmol.L^{-1} had the least impact on early blight disease severity and incidence in tomatoes (25). In vitro tomato, salicylic acid effectively reduced the development of Alternaria alternata (8). Salicylic acid (SA) regulates several physiological processes in plants and plays a crucial role in systemic acquired resistance (SAR), which relies on complex signaling networks. Spraying tomato plants with SA has been shown to enhance the activity of key antioxidant enzymes, including superoxide dismutase (SOD), peroxidase (POX), catalase (CAT), ascorbate peroxidase (APX), and glutathione reductase (GR) (8).

These enzymes help mitigate oxidative stress caused by early blight (Alternaria alternata) by scavenging reactive oxygen species (ROS) and maintaining cellular redox balance. Additionally, calcium pectin strengthens cell wall integrity, making it more resistant to pathogen invasion. The ROS generated during this process act as signaling molecules to activate SAR, enhancing the plant's defense mechanisms. SA functions as a phytohormone that regulates both immunity and growth (26). In conclusion, this study demonstrates that aspirin (acetylsalicylic acid) at a concentration of 2.17 mmol.L^{-1} can effectively induce SAR and improve plant resistance to early blight.

Conclusion

Non-drought-tolerant tomato cultivar Tyking F1 requires a prophylactic dose of acetylsalicylic 2.17 mmol.L^{-1} leaf feeding in the protected culture of expected minimum temperatures of 25°C and relative air humidity of (80-83%). Prophylactic leaf nourishment is a deterrent practice in pest control that improves plant verdure in optimal climatic conditions and reduces pathogen pressure symptoms of early blight disease caused by a fungal pathogen called Alternaria alternata. Thus, organic horticulturists are advised to cultivate tomato Tyking F1 and bell peppers Carma in protected cultures with prophylactic leaf nourishment of acetylsalicylic acid 2.17 mmol.L^{-1} sprinkled just once per seedling at a dose ratio of 4 ml. In protected cultures, there is no need to splash the tomato Tyking F1 or bell pepper Carma cultivar with either magnesium sulfate 112.4 mmol.L^{-1} or hydrogen peroxide 217.4 mmol.L^{-1}. It is better to keep other tomato cultivars Mobil and Korall for open-air gardening.

Author Contributions

Mohunnad Massimi: conceptualization, investigation, project administration and writing. Mohunnad Massimi, Besarta Kabashi: methodology, and editing. All authors read and approved the final version of the manuscript.

Funding

This research was generously supported by the Stipendum Hungaricum scholarship.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We would like to express our heartfelt gratitude to our friends: Szakadát Gyula Zsolt, Dr. Arnold Szilágyi, and Gabriella Kovács for providing us with valuable bits of advice to achieve this work.

References

1. Ehret DL, Menzies JG, Bogdanoff C, Utkhede RS, Frey B. Foliar applications of fertilizer salts inhibit powdery mildew on tomato. Can J Plant Pathol. 2002;24(4):437-44. doi: 10.1080/07060660309507004.
2. Foolad MR, Zhang LP, Khan AA, Nino-Liu D, Lin GY. Identification of QTLs for early blight (Alternaria solani) resistance in tomato using backcross populations of a Lycopersicon esculentum × L. hirsutum cross. Theor Appl Genet. 2002;104(6-7):945-58. doi: 10.1007/s00122-002-0870-z.
3. Mazen M, Al-Shamari H, Al-Maliki SA, Al-Kuwari A, Thomas S, Elazazi E. Evaluation of tomato cultivars against early leaf blight (Alternaria solani) in net greenhouse Qatar. J Adv Agric. 2023;14:31-40. doi: 10.24297/jaa.v14i.9520.
4. Passam HC, Karapanos IC, Bebeli PJ, Savvas D. A review of recent research on tomato nutrition, breeding and post-harvest technology with reference to fruit quality. Eur J Plant Sci Biotechnol. 2007;1(1):1-21.
5. Yamazaki H, Kikuchi S, Hoshina T, Kimura T. Calcium uptake and resistance to bacterial wilt of mutually grafted tomato seedlings. Soil Sci Plant Nutr. 2000;46(2):529-34. doi: 10.1080/00380768.2000.10408806.
6. Abbasi PA, Soltani N, Cuppels DA, Lazarovits G. Reduction of bacterial spot disease severity on tomato and pepper plants with foliar applications of ammonium lignosulfonate and potassium phosphate. Plant Dis. 2002;86(11):1232-6. doi: 10.1094/PDIS.2002.86.11.1232.
7. Mandal S, Mallick N, Mitra A. Salicylic acid-induced resistance to Fusarium oxysporum f. sp. lycopersici in tomato. Plant Physiol Biochem. 2009;47(7):642-9. doi: 10.1016/j.plaphy.2009.03.001.
8. El-Garhy HAS, Abdel-Rahman FA, Shams AS, Osman GH, Moustafa MMA. Comparative analyses of four chemicals used to control black mold disease in tomato and its effects on defense signaling pathways, productivity and quality traits. Plants (Basel). 2020;9(7):808. doi: 10.3390/plants9070808.
9. Sharma RL, Ahir RR, Yadav SL, Sharma P, Ghasolia RP. Effect of nutrients and plant extracts on Alternaria blight of tomato

caused by Alternaria alternata. J Plant Dis Prot. 2021;128(4):951-60. doi: 10.1007/s41348-021-00485-4.

10. Rab A, Haq IU. Foliar application of calcium chloride and borax influences plant growth, yield, and quality of tomato (Lycopersicon esculentum Mill.) fruit. Turk J Agric For. 2012;36 (6):695-701. doi: 10.3906/tar-1112-7.
11. Camara J, Logah V, Osekre EA, Kwoseh C. Leaf nutrients content of tomato and incidence of insect pests and diseases following two foliar applications. J Plant Nutr. 2018;41(2):159-67. doi: 10.1080/01904167.2017.1382524.
12. Eraslan F, Akbas B, Inal A, Tarakcioglu C. Effects of foliar sprayed calcium sources on Tomato mosaic virus (ToMV) infection in tomato plants grown in greenhouses. Phytoparasitica. 2007;35:150 -8. doi: 10.1007/BF02981110.
13. Fatima A, Ali S, Azmat S, Amrao L, Ghani MU, Iftikhar Y, et al. Morphological assessment of resistance potential in tomato against early blight disease and its management. Pak J Agric Res. 2024;37(2):176-84. doi: 10.17582/journal.pjar/2024/37.2.176.184.
14. Reuveni R, Dor G, Reuveni M. Local and systemic control of powdery mildew (Leveillula taurica) on pepper plants by foliar spray of mono-potassium phosphate. Crop Prot. 1998;17(9):703-9. doi: 10.1016/S0261-2194(98)00077-5.
15. Akbudak N, Akbudak B, Seniz V. Foliar applied harpin effects on fruit quality of peppers. Acta Agric Scand B Soil Plant Sci. 2007;57 (1):82-6. doi: 10.1080/09064710600571622.
16. Esyanti RR, Dwivany FM, Mahani S, Nugrahapraja H, Meitha K. Foliar application of chitosan enhances growth and modulates expression of defense genes in chilli pepper (Capsicum annuum L.). Aust J Crop Sci. 2019;13(1):55-60. doi: 10.21475/ajcs.19.13.01.p1169.
17. Shoaib A, Akhtar M, Javaid A, Ali H, Nisar Z, Javed S. Antifungal potential of zinc against leaf spot disease in chili pepper caused by Alternaria alternata. Physiol Mol Biol Plants. 2021;27(6):1361-76. doi: 10.1007/s12298-021-01004-3.
18. Cardoso JE, Santos AA, Rossetti AG, Vidal JC. Relationship between incidence and severity of cashew gummosis in semiarid north-eastern Brazil. Plant Pathol. 2004;53(3):363-7. doi: 10.1111/j.0032-0862.2004.01007.x.
19. Esfahani MN. Analysis of virulence and genetic variability of Alternaria alternata associated with leaf spot disease in potato plants in Iran. Acta Mycol. 2018;53(1). doi: 10.5586/am.1105.
20. Massimi M. Foliar plant nutrition and plant health status interactions [dissertation]. Debrecen: University of Debrecen; 2024. Available from: https://hdl.handle.net/2437/369958.
21. Lowenfels J, Lewis W. Teaming with microbes: the organic gardener's guide to the soil food web. Revised ed. Portland (OR): Timber Press; 2010.
22. Wenderoth M, Garganese F, Schmidt-Heydt M, Soukup ST, Ippolito A, Sanzani SM, et al. Alternariol as virulence and colonization factor of Alternaria alternata during plant infection. Mol Microbiol. 2019;112(1):131-46. doi: 10.1111/mmi.14258.
23. Lowenfels J. Teaming with nutrients: the organic gardener's guide to optimizing plant nutrition. Portland (OR): Timber Press; 2013.
24. Meena R, Godika S, Yadav PD, Chand K, Gayithri M, Jajorira A. Management of early blight of tomato Solanum lycopersicum Mill. incited by Alternaria solani through salicylic acid in vitro and in vivo. J Pharm Innov. 2022;11:1-6.
25. El-Shennawy MZ, Abd El-All AM. Evaluation of some antioxidants against tomato early blight disease. Alex J Agric Sci. 2018;63 (3):157-64. doi: 10.21608/alexja.2018.81831.
26. Li A, Sun X, Liu L. Action of salicylic acid on plant growth. Front Plant Sci. 2022;13:878076. doi: 10.3389/fpls.2022.878076.