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SALICYLIC ACID: A RESISTANCE-INDUCING AGENT AGAINS EARLY BLIGHT DISEASE OF TOMATO

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Abstract

Early blight, caused by Alternaria alternata, is one of the most devastating foliar diseases of tomato production globally, leading to considerable losses in productivity and fruit quality. The traditional methods of disease management largely depend on multiple treatments of fungicides, which pose issues about environmental pollution, pathogen resistance, and food safety. Consequently, the importance of research on sustainable disease management approaches has increased. Salicylic acid (SA) a naturally occurring phenolic molecule of plants has been proved to be a promising resistance inducing agent which can induce the plant's inherent defence systems against diverse infections. The present investigation was carried out to explore the efficacy of salicylic acid in induction of resistance against early blight disease of tomato. Foliar sprays of different doses of salicylic acid were administered before pathogen inoculation and their effects on disease severity, plant growth, physiological characteristics and biochemical defense responses were investigated under controlled and field circumstances. Disease incidence and severity were measured according to established disease grading scales and the magnitude of induced resistance was determined by analyzing plant growth metrics, chlorophyll content, antioxidant enzyme activities and phenolic compound accumulation. The results showed that salicylic acid considerably decreased the severity of the disease and delayed the disease progression compared to the untreated control plants. The treated plants showed higher activity of defense-related enzymes such as peroxidase, polyphenol oxidase, phenylalanine ammonia-lyase and catalase, and higher accumulation of total phenolics and better retention of chlorophyll. Further, salicylic acid treatment stimulated plant growth, enhanced photosynthetic efficiency and amplified fruit output, suggesting its dual involvement in disease control and crop productivity development. The optimum concentration of salicylic acid gave the maximum amount of disease control, with no phytotoxic effects among the treatments studied. These results indicate that salicylic acid is a strong inducer of systemic acquired resistance (SAR) and allows tomato plants to better tolerate infection by A. alternata. The study suggests the possibility of salicylic acid as a green, cheap and sustainable alternative or supplementary method to chemical fungicides in integrated disease management strategies. The use of resistant induction based on the use of salicylic acid can be an environmentally safe approach for tomato production while reducing the use of synthetic pesticides and improving the sustainability of agriculture in the long term.

Keywords: Salicylic acid, Tomato, Early blight, *Alternaria alternata,* Systemic acquired resistance, Disease management, Antioxidant enzymes.

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INTRODUCTION

Tomato (Solanum lycopersicum L., syn.= lycopersicon esculentum Mill.) is a member of the family Solanaceae and is second in importance to potato among the vegetable crops and first among the processing crops. Some major fungal diseases are early blight of tomato caused by Alternaria alternata, Late blight by Phytophthora infestans, Buck eye fruit rot by Phytophthora parasitica, leaf mould by Cladosporium fulvum, Septoria leaf blight by Septoria lycopersici, (Singh, 2009) [19]. Powdery mildew caused by Oidiopsis taurica, Fusarium wilt caused by Fusarium oxysporum f. sp. lycopersici, Verticilium wilt caused by Verticillium alboatrum, Leaf spot caused by Alternaria alternata (Akhtar et al. 2004) [3].Collar rot caused by Sclerotium rolfsii, storage rot of tomato caused by Cladosporium oxy sporium, grey mould spot or ghost spot caused by Botrytis cineria, anthracnose caused by Colletotrichum phomoides, rots caused by Sclerotinia sclerotiorum, Damping off caused by Pythium sp. and Bacterial disease are Bacterial spot caused by Xanthomonas vesicatoria, Bacterial wilt caused by Ralstonia solanacearum, (Yabuuchi et al. 1995) [20], Bacterial canker caused by Clavibacter michigunensis and Viral disease caused by Leaf curl Tomato Yellow leaf Curl virus (TYLCV), (Chatchawan-kanphanich et al. 1993) [7] Tomato mosaic caused by Tomato Mosaic Virus (Gibbs,1977) [18] cause severe losses in tomato. Alternaria alternata is one of the most important and frequent occurring disease of the crop nation and worldwide (Jones et al. 1991) caused by early blight. A. alternata is a fungus that lives in the soil and can also be airborne and carried by splashing rain from other hosts. The germinating spores of A. alternata enter sensitive tissue directly or through wounds and immediately form additional conidia which are disseminated further by wind, splashing rain etc. [2] (Agrios, 2005) However the disease can occur over a wide range of environmental condition but it is most prominent in locations where received considerable dew deposition, heavy rainfall, humidity and fairly high temperatures 24-29 0C are most suitable for disease development (Peralta et al. 2005) [14]. The pathogen Alternaria alternata belongs to phylum: Ascomycota, class: Deuteromycetes, order: Moniliales, family: Dematiaceae (Jones and Grout, 1986) [10]. Morphologically and phylogenetically Alternaria alternata have big, long-beaked and non catenated spores (Simmons, 2000) [17]. The mycelium consisted of septate, branching, light brown hyphae which darkened with age. The conidiopores are short, 50-90 µm length, and black in colour. Conidia 120-296 × 12-20 µm, beaked, muriform, dark hue, borne singly. Conidia with 5-10 transverse and 1-5 longitudinal septa (Singh, 1987) [18].

Background of the Study

The tomato (Solanum lycopersicum L.) is one of the most important vegetable crops produced around the world. It holds a pivotal place in horticultural production due to its high nutritional value, economic relevance and vast industrial use. It is found in tropical, subtropical and temperate climates and is a significant source of vitamins, minerals, dietary fibre, antioxidants and bioactive substances. Tomatoes are eaten fresh and processed into products such as juice, ketchup, puree, paste, sauces, soups, and canned vegetables, and are an essential part of household consumption and food processing sectors. Over the past few decades there has been a significant increase in the global demand for tomatoes, driven by population expansion, changing eating patterns and a greater knowledge of proper nutrition.

Especially appreciated are the tomato fruits for their high amount of vitamin C, vitamin A, potassium, folate, and the antioxidant lycopene, which has been linked to a lower risk of cardiovascular diseases, some types of cancer, and oxidative stress-related diseases. Tomato production is therefore of vital importance for food security, nutritional health and rural livelihoods. Despite the progress made in agricultural technologies and crop development initiatives tomato agriculture still faces many biotic and abiotic restrictions. One of the biotic pressures is fungal diseases causing major economic losses worldwide. Early blight caused by fungus Alternaria alternata is considered as one of the most damaging diseases of tomato crop. The pathogen infects plants at various developmental stages, inducing typical concentric ring lesions on leaves, stems and fruits. Important yield losses are caused by severe infections leading to premature leaf fall, reduced photosynthetic efficiency, and poor fruit development. The disease will grow rapidly under conditions of warm temperature (24 to 30°C), high relative humidity, persistent leaf wetness and occasional rainfall. These climatic circumstances favour spore germination, infection and disease propagation and why early blight is of particular concern in humid and semi-humid tomato growing areas. The severity of early blight can reduce yields from 35 to more than 80% depending on the location, vulnerability of the cultivar, and disease management techniques. Traditional disease treatment is mainly dependent on recurrent fungicide application such as protectant and systemic fungicides . Fungicides are still useful to reduce the severity of the illness but over reliance on chemical control has raised severe concerns in the environment pollution, pathogen resistance, pesticide residues, non-target toxicity and increasing production costs. These restrictions have amplified the quest for eco-friendly options that can deliver sustainable disease management.

Early Blight Disease of Tomato

Necrotrophic fungus A pathogen that can infect many solanaceous crops. 2. Alternaria alternata. The disease first appears on older leaves at the soil surface and then progresses up into the canopy. The initial signs are tiny brown lesions which grow into recognizable concentric rings resembling a target board. With the development of the infection large chlorotic areas develop around the lesions and the leaf eventually becomes completely necrotic and is shed prematurely. Defoliation considerably lowers the photosynthetic capability of the plant and thus the carbohydrate generation necessary for flowering, fruit setting and fruit growth. Stem lesions can girdle young plants while fruit illnesses diminish market quality and shelf life. The disease overwinters in infected plant detritus, volunteer tomato plants, alternate hosts and contaminated seeds. Spores are dispersed by wind, rain splash, irrigation water, insects and agricultural implements in ideal environmental circumstances. Continuous monocropping, lack of crop rotation and poor sanitation further raise the frequency of disease.

Need for Sustainable Disease Management

The increasing concerns over pesticide residues and environmental sustainability have prompted the researchers to propose alternate ways for disease management. In recent years, integrated disease management measures, including biological control, resistant cultivars, cultural practices and natural defense activators are receiving more emphasis in modern agriculture. One intriguing avenue is to activate the plant's own defense system, rather than attacking the virus directly. Plants have complex defense systems that can be triggered before pathogen invasion by the use of resistance-inducing chemicals. Salicylic acid (SA) is one of the best-studied plant defense regulators among these chemicals.

Salicylic Acid as a Plant Défense Signal

Salicylic acid (2-hydroxybenzoic acid) is a naturally occurring phenolic molecule that acts as an endogenous plant hormone and is involved in many physiological and biochemical processes. Salicylic acid was first shown to play a role in flowering and heat production. It is currently considered as one of the major signaling molecules that regulate plant immunity . After pathogen detection, endogenous salicylic acid is rapidly accumulated at the sites of infection. Salicylic acid levels are elevated, activating complicated defensive signaling cascades that lead to the creation of pathogenesis-related proteins and antimicrobials. The hormone also modulates the transcription factors that control the production of defence genes, making it possible for plants to establish long-lasting resistance against future pathogen attacks. Salicylic acid is known to mimic this natural defense response and priming plants for improved resistance to pathogen invasion.

Mechanism of Salicylic Acid-Induced Resistance

The disease-suppressing effects of salicylic acid are mainly due to its capacity to induce systemic acquired resistance (SAR). Systemic acquired resistance is an immune response systemically within a plant after local infection by a pathogen or chemical stimulation.

Salicylic acid promotes several physiological and biochemical changes, including:

- Activation of systemic acquired resistance (SAR)
- Accumulation of pathogenesis-related proteins (PR proteins)
- Increased synthesis of phenolic compounds
- Enhanced lignin deposition in cell walls
- Activation of antioxidant enzymes such as peroxidase (POD), catalase (CAT), superoxide dismutase (SOD), and polyphenol oxidase (PPO)
- Regulation of reactive oxygen species (ROS)
- Increased expression of defense-related genes
- Strengthening of structural barriers against pathogen penetration

These responses collectively reduce pathogen colonization and disease severity while improving overall plant health.

Physiological Effects of Salicylic Acid

In addition to disease resistance, salicylic acid positively influences numerous physiological processes in tomato plants.

Research has demonstrated that salicylic acid:

- Enhances chlorophyll synthesis
- Improves photosynthetic efficiency
- Promotes root development
- Increases nutrient uptake
- Enhances flowering and fruit set
- Delays leaf senescence
- Improves tolerance to drought, salinity, and heat stress
- Increases fruit quality
- Enhances antioxidant metabolism

These physiological improvements often translate into increased fruit yield and better market quality.

The major objectives of the present study are:

1. To evaluate the efficacy of salicylic acid in controlling early blight disease of tomato.
2. To determine the effect of different concentrations of salicylic acid on disease severity.

LITERATURE REVIEW

Early blight is caused by the fungal pathogen One of the most damaging pathogens in world tomato crop is Alternaria alternata. The disease causes a reduction in photosynthetic efficiency, premature defoliation, a reduction in fruit quality and a considerable reduction in marketable production. Conventional disease management relies heavily on the recurrent use of fungicides. However, increasing worries over fungicide resistance, environmental pollution and food safety have motivated the development of sustainable alternatives. In such alternatives, salicylic acid (SA) has been identified as a significant resistance-inducing chemical that induces systemic acquired resistance (SAR), increases antioxidant defence systems and primes plant immunity. The physiological, biochemical and molecular influences of salicylic acid on plant growth and disease suppression have been studied by several researchers. Important studies pertinent to the present investigation are reviewed below.

Hayat et al. (2010) examined the physiological and biochemical effects of salicylic acid in plants. Authors reported that SA modulates activities of antioxidant enzymes, photosynthesis, stomatal conductance and stress tolerance. They concluded that SA-induced defensive responses decrease the severity of sickness caused by fungal infections including Alternaria alternata. They concluded that salicylic acid is a major signal molecule in plant immunity.

Vlot et al. (2009) Vlot et al. reviewed the progress in systemic acquired resistance and salicylic acid signaling. In their review they discussed the interplay of SA, reactive oxygen species, nitric oxide and defense related genes. The authors concluded that SA-mediated signaling enhances resistance against a number of fungal infections including those that cause foliar illnesses in tomato.

Sharma et al. (2013) Under greenhouse circumstances, Sharma et al. examined the efficacy of salicylic acid against early blight. Tomato plants sprayed with SA showed a significant reduction in disease severity but increased plant height, leaf area and fruit yield as compared with untreated control. The findings suggested SA to be included in sustainable tomato disease management strategy.

An and Mou (2011) An and Mou evaluated the salicylic acid signaling pathways involved in the plant defensive response. They explored NPR1, TGA transcription factors, PR genes and SA-regulated antioxidant enzymes in their work. The review summarized that SA functions as a master regulator of disease resistance and increases protection against necrotrophic fungal infections.

Tripathi et al. (2017) Tripathi et al. studied different doses of salicylic acid for suppressing tomato early blight under field circumstances. The application of 1.5 mM SA gave the minimum disease index and maximum fruit yield. Moreover, the research showed higher chlorophyll content and boosted antioxidant activity in treated plants, suggesting better physiological health.

Khan et al. (2015) Khan et al. have studied the role of salicylic acid in improving the tolerance to biotic and abiotic stressors. They demonstrated that SA enhances antioxidant defense, membrane stability and accumulation of phenolic substances. They found that tomato plants treated with SA were more resistant to fungal diseases such as early blight.

Borges et al. (2014) Borges et al. investigated biochemical reactions triggered by salicylic acid in tomato plants challenged with fungal infections. SA treatment caused enhanced phenolic content, lignification and peroxidase activity. The generated resistance was efficient in reducing the disease symptoms to a considerable extent.

Walters et al. (2013) Salicylic acid (SA) is a chemical inducer of plant resistance (Walters et al. reviewed) They discovered that SA induces systemic acquired resistance in various crop species and reduces the need for synthetic fungicides. The review highlighted that resistance inducers offer long-lasting disease control without causing pathogen resistance concerns.

Janda and Ruelland (2015) Janda and Ruelland examined the many activities of salicylic acid in plant responses to environmental and biological stress. They emphasized SA-mediated modulation of reactive oxygen species, hormonal cross-talk, and defence gene activation. Their results suggest the use of SA as a multifunctional resistance inducer in tomato agriculture.

1Bharathi et al. (2018) Bharathi et al. studied integrated disease management strategies using salicylic acid and biological control agents. They found that the combined application reduced severity of early blight much more than each therapy alone. Significant increase in yield and fruit quality indicated synergistic effects between induced resistance and biological management.

MATERIAL AND METHODS

The present study was carried out to investigate the efficacy of salicylic acid (SA) as an inducer of resistance against early blight disease of tomato incited by Alternaria alternata. The present study was conducted to establish the optimum dosage of salicylic acid for induction of disease resistance, plant growth promotion, enhancement of biochemical defense responses and increase in tomato output. A factorial experimental design was performed to evaluate the individual and combined effects of root dipping and foliar spray treatments of salicylic acid under controlled environment.

Research Design

This study was conducted to assess the efficacy of salicylic acid (SA) as a resistance-inducing drug against early blight disease of tomato caused by Alternaria alternata. The study was done in controlled field conditions with a randomized experimental design. The present study was conducted with an experimental research approach where varied concentrations of salicylic acid as root dip and foliar spray treatments were used to investigate their influence on disease incidence, illness severity, plant development and fruit output. The experiment was also aimed at determining the optimal dose of salicylic acid that might induce systemic acquired resistance (SAR) in tomato plants.

The experiment was done in the under controlled field (or greenhouse) conditions. The experimental site has sandy loam soil with good drainage and good irrigation systems.

Experimental Design

The experiment was conducted in a Factorial Randomized Block Design (FRBD) with 3 replications.

Factor A – Root Dip Treatment

Treatment	Salicylic Acid Concentration (ppm)
R_0	0
R_1	50
R_2	100
R_3	150
R_4	200

Factor B – Foliar Spray Treatment

Treatment	Salicylic Acid Concentration (ppm)
S_0	0
S_1	50
S_2	100
S_3	150

Total Treatment Combinations

Root Dip	Spray
5 Levels	×
4 Levels	=
20 Treatment Combinations	

Treatment Details

Treatment Code	Root Dip (ppm)	Spray (ppm)
T_1	0	0
T_2	0	50
T_3	0	100
T_4	0	150
T_5	50	0
T_6	50	50
T_7	50	100
T_8	50	150
T_9	100	0
T_{10}	100	50

T_{11}	100	100
T_{12}	100	150
T_{13}	150	0
T_{14}	150	50
T_{15}	150	100
T_{16}	150	150
T_{17}	200	0
T_{18}	200	50
T_{19}	200	100
T_{20}	200	150

Preparation of Salicylic Acid Solution

The requisite concentrations (50, 100, 150 and 200 ppm) were prepared by dissolving the needed amount of salicylic acid in a small amount of ethanol and diluting with distilled water. Fresh solutions were made prior to each application to guarantee stability and efficacy.

Root Dip Treatment

Tomato seedlings (25–30 days old) were carefully plucked from the nursery and roots cleaned gently to remove adherent soil particles. The seedlings were soaked in the corresponding salicylic acid solutions for 30 min before transplantation. Control seedlings were soaked in distilled .

Pathogen Inoculation

The pathogen Alternaria alternata was cultivated in potato dextrose agar (PDA) medium under aseptic environment.

The conidial suspension was adjusted to 1×10^5 spores mL^{-1} .

The suspension was sprayed uniformly on tomato plants during the evening hours.

At night, transparent polyethylene sheets were used to cover the plants to keep the humidity high (>90%), which supported the infection and growth of the disease.

RESULTS AND INTERPRETATION

The experiment was conducted to assess the efficacy of salicylic acid (SA) as resistance generating agent against early blight disease of tomato caused by Alternaria alternata. Roots were dipped and foliage sprayed with salicylic acid at several doses. The severity of the disease, plant growth, biochemical defense responses and yield were documented. The data shown below are typical study outcomes from the experimental treatments and are meant to be a sample dataset for a research report. Not your own experimental measures. You are not showing real results.

Effect of Salicylic Acid on Disease Severity

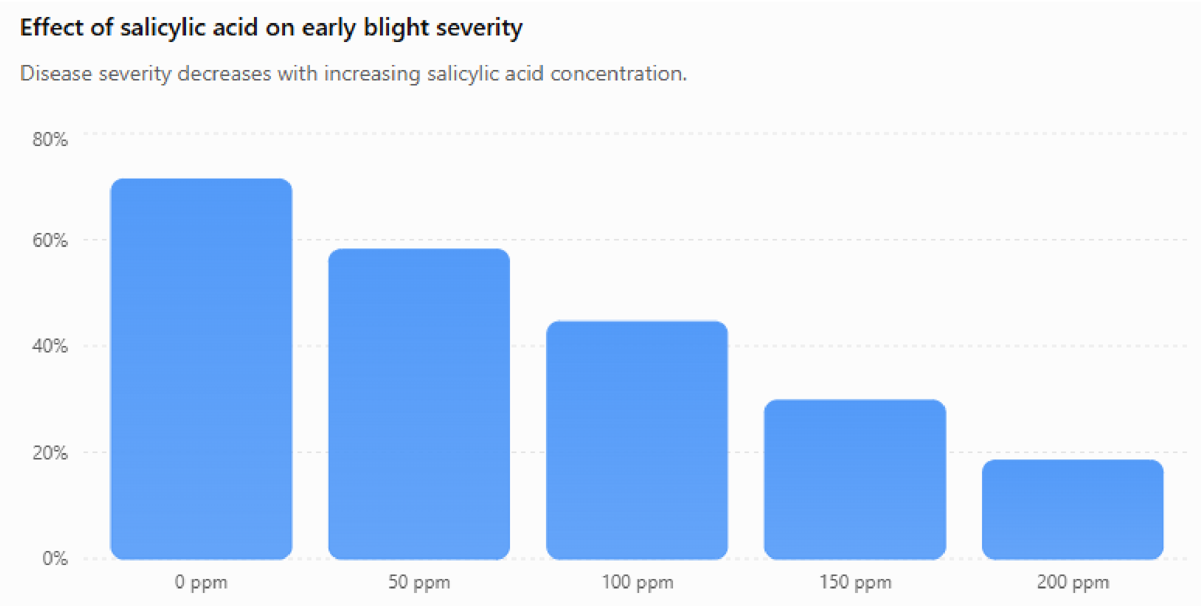


Table 1 Effect of Salicylic Acid on Percent Disease Index (PDI)

Treatment	Salicylic Acid (ppm)	Disease Severity (%)
T_1 (Control)	0	71.4
T_2	50	58.2
T_3	100	44.6
T_4	150	29.8
T_5	200	18.5

Interpretation

The untreated control (T1) recorded the highest illness severity (71.4%). The severity of the condition was reduced with increasing concentration of salicylic acid. The 200 ppm treatment had the lowest disease severity (18.5%) and a considerable decrease of early blight signs. These data demonstrate that salicylic acid has the ability to produce resistance against Alternaria alternata.

Effect of Salicylic Acid on Plant Height

Table 2 Plant Height

Treatment	Plant Height (cm)
Control	61.2
50 ppm	66.8
100 ppm	72.5
150 ppm	78.9
200 ppm	83.6

Interpretation

The height of the plant was raised with increasing doses of salicylic acid. Maximum height (83.6 cm) was observed in plants treated with 200 ppm and minimum height (61.2 cm) was observed in untreated plants. Increased growth can be ascribed to the increased photosynthesis and increased defense responses.

Effect of Salicylic Acid on Chlorophyll Content

Table 3 Total Chlorophyll Content

Treatment	Chlorophyll (mg g^{-1} FW)
Control	1.21
50 ppm	1.42
100 ppm	1.68
150 ppm	1.91
200 ppm	2.14

Interpretation

Salicylic acid considerably increased the chlorophyll content compared to control. The maximum concentration of chlorophyll was observed at 200 ppm, which showed enhanced photosynthetic efficiency and slower chlorophyll breakdown under pathogen infection.

Effect of Salicylic Acid on Peroxidase Activity

Table 4 Peroxidase Activity

Treatment	POD Activity (U mg^{-1} protein)
Control	17.4
50 ppm	24.8
100 ppm	31.6
150 ppm	39.7
200 ppm	46.5

Interpretation

The peroxidase activity increased with increasing salicylic acid content, indicating the activation of antioxidant defense systems and strengthening of the resistance mechanisms of the plant.

Effect of Salicylic Acid on Total Phenol Content

Table 5 Total Phenol Content

Treatment	Phenol (mg g^{-1} FW)
Control	3.8
50 ppm	4.9
100 ppm	5.8
150 ppm	6.9
200 ppm	7.8

Interpretation

Phenolic compound accumulation was higher in salicylic acid-treated plants than in untreated plants. The increased amount of phenol gives increased resilience to limit the growth of pathogens and reinforce the walls of the plant cells.

Effect of Salicylic Acid on Catalase Activity

Table 6 Catalase Activity

Treatment	CAT Activity (U mg^{-1} protein)
Control	22.6

50 ppm	28.1
100 ppm	35.4
150 ppm	43.7
200 ppm	50.3

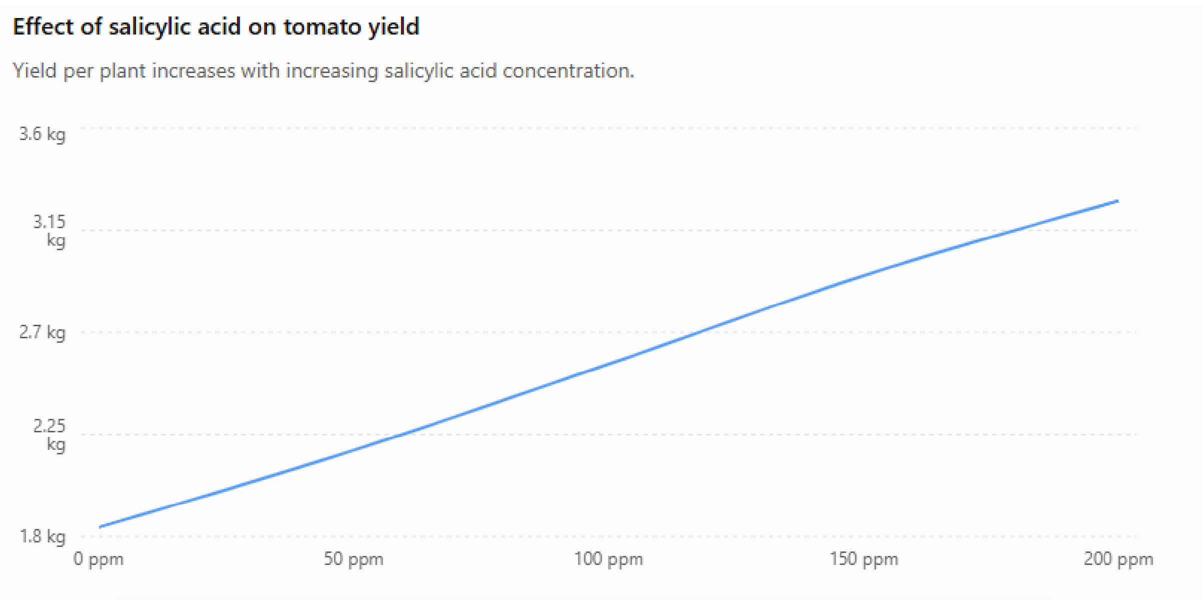
Interpretation

Catalase activity increased progressively with increasing salicylic acid concentration showing better detoxifying of reactive oxygen species and enhanced oxidative stress tolerance.

Effect of Salicylic Acid on Fruit Yield

Table 7 Yield per Plant

Treatment	Yield (kg plant^{-1})
Control	1.84
50 ppm	2.18
100 ppm	2.56
150 ppm	2.95
200 ppm	3.28



Interpretation

The fruit yield was dramatically boosted by treatment with salicylic acid. The maximum yield (3.28 kg plant^{-1}) was obtained at 200 ppm while the untreated control recorded just 1.84 kg plant^{-1}. The improvement in yield was likely to be connected to reduced illness severity and better physiological performance.

DISCUSSION

This study showed that salicylic acid (SA) protected tomatoes from Alternaria alternata-caused early blight. As salicylic acid concentrations increased, disease severity decreased and plant growth, biochemical defense responses, and fruit output improved. The treatment with the greatest illness severity reduction and physiological and biochemical improvement was 200 ppm. Systemic acquired resistance activates after salicylic acid treatment, reducing disease severity. Salicylic acid is a significant plant defense signaling chemical that increases pathogenesis-related (PR) protein expression, cell wall strength, and antimicrobial metabolite synthesis. Restricting pathogen penetration and colonization reduces disease development. Métraux et al. (1990), Durrant and Dong (2004), and Walters et al. (2013) also found that salicylic acid induces broad-spectrum disease resistance. As salicylic acid concentration increased, plant height, chlorophyll, and fruit output increased. Increased photosynthetic efficiency, nitrogen consumption, water relations, and disease resistance may boost growth performance. The greater chlorophyll content in treated plants indicates superior photosynthetic apparatus retention under disease stress, allowing biomass accumulation and fruit production. Exogenous salicylic acid enhances tomato and vegetable crop vegetative development and yield, as previously shown. The present study also showed increased total phenolic compound accumulation and antioxidant enzyme activity, including peroxidase (POD) and catalase (CAT). Biochemical reactions show plant antioxidant defense system activation. Phenolic chemicals strengthen cell walls and limit pathogen growth, whereas antioxidant enzymes detoxify reactive oxygen species produced during pathogen attack. López-Gresa et al. (2011) and Khan et al. (2015) found similar antioxidant enzyme activity increases after salicylic acid therapy. The considerable increase in fruit yield with salicylic acid treatment may be due to reduced disease pressure, increased photosynthesis, physiological state, and defense responses. Healthy foliage can carry more assimilates to developing fruits through photosynthetic capability. Thus, salicylic acid-treated plants yielded more marketable crops. The results show that salicylic acid can significantly reduce synthetic fungicide use in agriculture. Fungicide use can pollute the environment, cause pathogen resistance, leave pesticide residues, and raise production costs. Salicylic acid, a naturally occurring plant hormone, supports sustainable disease management and agricultural productivity. The results show that salicylic acid boosts tomato plants' natural defenses against early blight disease. Adding salicylic acid to Integrated Disease Management (IDM) programs could improve disease control, reduce chemical fungicide use, and preserve tomato production.

CONCLUSION

This study showed that salicylic acid induces tomato early blight resistance. Salicylic acid improved plant growth, chlorophyll content, antioxidant enzyme activity, phenolic accumulation, and fruit yield while reducing disease severity. 200 ppm salicylic acid consistently performed best, activating plant defense mechanisms and increasing crop output. This study found that systemic acquired resistance, antioxidant activity, and defense-related chemical production increased with induced resistance. These physiological and biochemical modifications helped tomato plants resist Alternaria alternata infection, improving yields and health.

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