

# Original Research Article

## Effects of Salicylic Acid Concentration and Exposure Time on The Surface Fungal Load of Tulip Bulbs

### ABSTRACT

**Aims:** The purpose of this study was to determine the impact of various SA concentrations and exposure times on the surface fungal load (SFL) of tulip bulbs.

**Place and Duration of Study:** Department of Plant Protection, Kocaeli University, in the year of 2022.

**Methodology:** The tulip bulb (*Tulipa gesneriana* L. cv. Royal Ten) used in the study was obtained from an officially registered flower bulb company in Türkiye. SA solutions ranging from 0 to 1600 ppm were prepared and used to treat tulip bulbs for 1, 6, 12, and 24 hours. Microbiological analysis involved assessing fungal growth inhibition through colony counts on potato dextrose agar plates after incubation. Statistical analysis, employing ANOVA and Scheffe tests, evaluated significant differences in fungal growth inhibition across different SA concentrations and exposure times.

**Results:** According to the results, the SFL of tulip bulbs decreased with increasing SA concentrations. Additionally, SA treatment significantly lowered SFL according to the initial log CFU at all exposure times except for one-hour exposure. The EC50 of SA values changed as a function of the exposure times, which ranged from 194 to 23 ppm against the SFL of tulip bulbs. These results suggest that SA may be a promising candidate for the treatment of fungal diseases in tulips.

**Conclusion:** SA demonstrated effective antifungal properties compared to synthetic fungicides, suggesting it could mitigate storage diseases in tulip bulbs. Recommendations included using 1600 ppm SA for six hours or 800 ppm SA for 24 hours to manage fungal contamination before storage or planting of tulip bulbs.

*Keywords: Tulipa spp., salicylic acid, antifungal effect, surface fungal load*

### 1. INTRODUCTION

Natural beauty and distinctiveness are two qualities that distinguish ornamental plants. These plants' beautiful blooms, foliage, and fruits draw a lot of attention due to their attractive colors and shapes. Grown for a variety of decorative uses, ornamental crops include potted plants, woody ornamentals, cut flowers or cut leaves, bulbs, and corms [1].

Plant diseases greatly reduce the quantity and/or quality of a variety of ornamental crops, therefore have severe economic consequences. The appearance of ornamental plants is extremely important, especially for cut flowers and potted plants. Visual disease symptoms, as well as pathogen-induced growth inhibition, have a significant impact on the quality and market value of flowers. As a result, ensuring quality features in these plants is critical as demand for industrial uses grows [2]. In plants, fungi are responsible for around 70% of the diseases, the rest are brought on by bacteria, viruses, and viroids. Fungal diseases frequently result in a substantial decrease in crop quality and production, up to 30–40% of the total yield potential [3]. According to estimates, fungi cause the greatest harm and are

mostly responsible for pathogen-driven host losses, deteriorating ornamental flower market prices, and visual quality.

Tulip is one of nature's most attractive flowers and the world's greatest ornamental geophyte crop. Tulip belongs to the family Liliaceae and has 100-150 species. It is the most popular bulbous ornamental due to its vivid color and beautiful blossoms. Tulips are ideal for cut flowers, beds, and pots, and are planted in both open and closed locations [4]. Tulips can be grown from seeds, but the bulb is where most of the flowers are grown for commerce. Vegetative commercial propagation is slow. Therefore, once they are introduced into the production cycle, soil-borne diseases and pests can infect and result in significant losses. Major fungal diseases in tulips are caused by *Botrytis tulipae* [5], *Fusarium oxysporum* f.sp. tulipae [6], *Penicillium* spp. [7], *Pythium* spp. [8], *Rhizoctonia solani* [9], and *R. tuliparum* [10], *Corticium rolfsii*, *Sclerotinia bulborum*, *Phytophthora* spp., *Gloeosporium thumenii* Sacc. f. tulipae [11]. Fungal diseases are frequently controlled through the use of chemical fungicides that are only effective for a few diseases and are occasionally non-specific [2]. Furthermore, excessive chemical use leads to microbial resistance to these chemicals, which is extremely undesirable owing to health and environmental safety concerns [12]. Therefore, alternative control methods should be developed. In terms of sustainable methods of plant disease control, natural fungicides are gaining popularity due to their favorable environmental characteristics, availability, and cost.

The use of salicylic acid (SA) in crop protection has received a lot of attention in recent years. Many laboratories have investigated SA's antifungal properties [13-15]. SA has been found to be effective at controlling fungi such as *Fusarium* and *Rhizoctonia* when applied as a foliar spray [16-19]. It appears to be a reasonable approach because SA is a natural phenolic hormone generated in plants as a signaling molecule that plays an important role in plant defense against many fungi and other diseases via the phenylpropanoid pathway [20]. Its mild application to vulnerable plants may boost their resistance to fungus. SA previously exhibited antifungal activity against *Penicillium expansum* by causing protein and lipid leakage [14]. Other investigations have shown that SA has antifungal efficacy against a variety of postharvest diseases, including *B. cinerea* [21], *F. oxysporum* [18], *R. stolonifer* [22], *R. solani*, *S. rolfsii* [23], *Macrophomina phaseolinae* [24], *Pythium* sp. [25], and *Phytophthora* sp. [26]. In addition to its antifungal properties, SA has been shown to have several other effects on plants. It can stimulate the production of hormones that play a role in plant growth and development, and it has been shown to have a positive effect on the root system of plants. It is important to note that SA should be used with caution, as it can cause phytotoxicity in some plants when used in high concentrations [27].

Moreover, SA applications to tulip bulbs can be effective against possible diseases encountered during their storage. According to several studies, SA treatments in various fruits diminish the prevalence of fungal diseases [21-22, 28-30]. This decrease can be attributed to two factors: first, the antifungal impact of SA [31], and second, the defensive mechanism activated by SA in the plant [32-34]. SA also inhibits the formation of ethylene [35] and lowers disease susceptibility [36]. The main effects of ethylene on tulip bulbs are gummosis (extrusion of amber-colored polysaccharides from bulb scales), flower bud abortion, bulb splitting, increased respiration, poor roots, and accelerated blooming. Axillary bud growth, excessive root hair, a reduction in the deposition of leaf wax, a reduction in height, and a reduction in vigor are further impacts [37]. In addition to the ethylene production of the plant, *Fusarium* spp. in the plant also produces ethylene [38], causing the infection to develop faster. SA increases the resistance of tulip bulbs by preventing the germination and growth of *Fusarium* spores.

The effects of SA treatment on the growth of tulips were investigated in our previous research [27]. Herein, the purpose was to determine the impact of various SA concentrations and exposure times on the surface fungal load (SFL) of tulip bulbs. Once the influence of SA on the SFL has been demonstrated, the effective concentration and exposure time may be advised to the manufacturer prior to tulip bulb planting or storage. Disease occurrences under storage conditions after SA treatment of tulip bulbs can be investigated in a future study.

## 2. MATERIAL AND METHODS

### 2.1 Plant material and chemicals

The tulip bulb (*Tulipa gesneriana* L. cv. Royal Ten) used in the study was obtained from an officially registered flower bulb company in Türkiye. This cultivar was chosen since it is known to be an ethylene sensitive variety [38]. All chemicals used to prepare solutions and media were obtained from Merck (Darmstadt, Germany).

### 2.2 Experimental design and microbiological analysis

The bulbs were compared for similarity at the beginning of the study, and several variables, such as circumference, diameter, and weight, were recorded based on the mean of all used bulbs. In average, a bulb was 9.67 cm in circumference, 3.08 cm in diameter, and 17.62 g in weight, according to the measurements. For each SA concentration and exposure time, three bulbs of tulips with similar sizes and shapes were chosen at random.

The molecular weight of the SA ( $C_7H_6O_3$ ) was 138.12 g mol<sup>-1</sup> with in ≥99.5 purity. SA solutions were prepared at concentrations of 50, 100, 200, 400, 800, and 1600 ppm, transferred to 380 mL glass jars (Figure 1a) and sterilized in an autoclave at 121°C for 20 minutes. The jars containing only distilled and sterilized water were used as controls. pH measurements were performed prior to autoclaving and recorded as 4.46, 3.40, 3.20, 3.08, 2.93, 2.75, and 2.57 for distilled water and SA solutions of 50, 100, 200, 400, 800, and 1600 ppm, respectively.

The tulip bulbs were kept in the jars for 1, 6, 12, and 24- hour to see the effect of exposure time (Figure 1b). At the end of these specified times, each of the tulip bulbs was taken into sterile bags (Figure 1c) containing 80 mL of sterile saline-peptone solution (8.5 g/L NaCl and 1 g/L peptone) and shaken in a shaker-incubator at 100 rpm for 10 minutes. The tulip bulbs were immersed in and out of SA solutions or sterile-distilled water as the exposure time control group before being transferred to the saline-peptone solution. All treatments were done at room temperature.

Microbiological analysis was performed on the SA-treated and control group of tulip bulbs to evaluate the antifungal effect of the SA on the tulip bulbs. One ml of each sample was taken and serially diluted with saline peptone solution from 10<sup>0</sup> to 10<sup>5</sup> using a sterile injector. Then one mL of each diluted sample was inoculated on potato dextrose agar (PDA) plates by the spreading method. The plates were incubated at 25 °C for 6 days. After incubation, the colony count was done (Figure 1d). The fungal load was expressed as a log CFU/ml. CFU/ml was calculated using the equation:

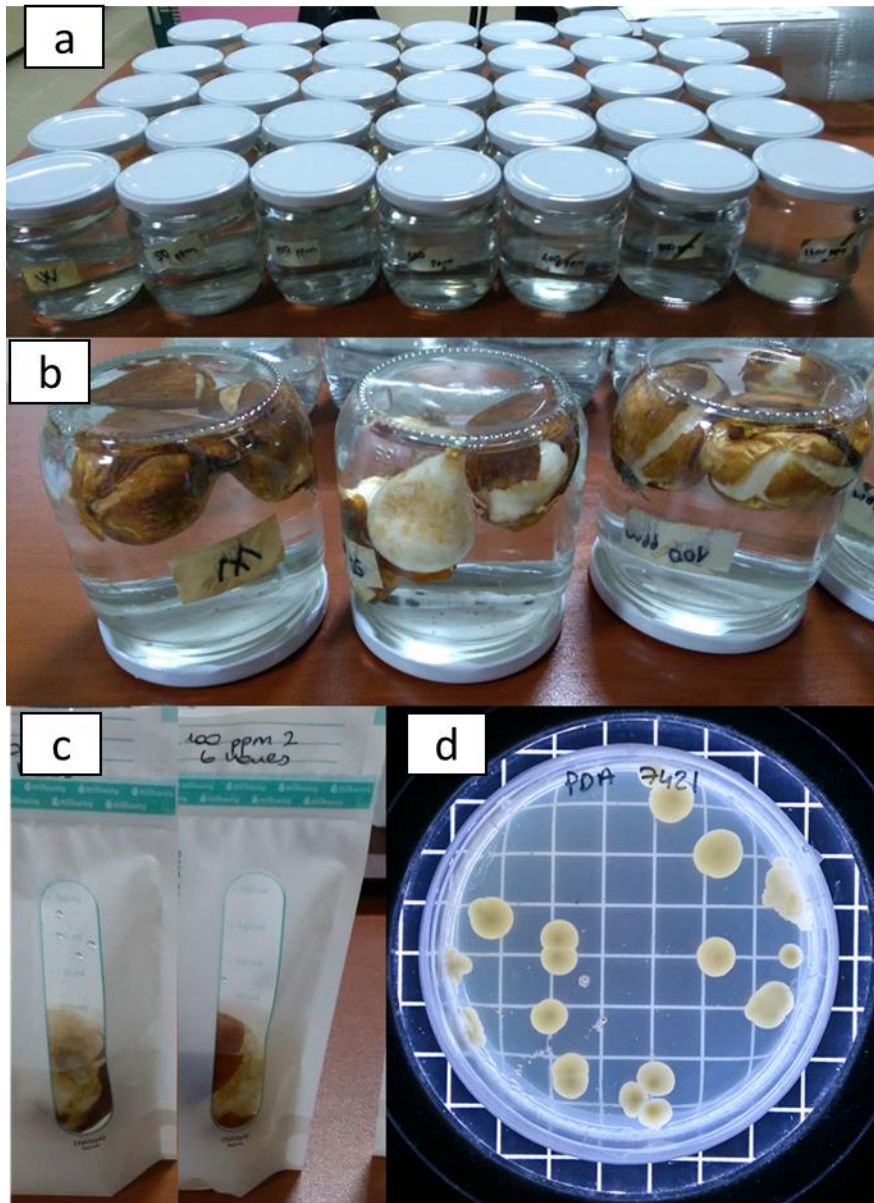
$$\text{CFU/ml} = (\text{number of colonies} \times \text{dilution factor}) / \text{volume of the culture plate.}$$

Additionally, the percentage inhibition of fungal growth (IFG) was estimated using the equation:

$$IFG = [(N_0 - N_{SA}) \times 100] / N_0$$

in which  $N_0$  and  $N_{SA}$  represent the number of the colonies of the fungi in the no SA treatment and in the SA treatment, respectively.

EC50 values (50% maximal effective concentration) were determined as the lowest concentration of SA that inhibited fungal growth and germination in 50% of SFL of tulip bulbs, which was expressed in ppm. EC50 values computed by using Quest Graph™ EC50 Calculator (AAT Bioquest, Inc., Sunnyvale, CA, United States, 2023).



**Figure 1. Experimental design and microbiological analysis a) SA solutions at different concentration (left to right; 0, 50, 100, 200, 400, 800 and 1600 ppm) in 380 mL jars. b) Incubation of the tulip bulbs in SA solutions. c) The sterile bags containing**

sterile saline-peptone solution and a tulip bulb d) The colonies after 6-days incubation on PDA plates of the samples treated with 800 ppm SA for 24 hours.

### 2.3 Statistical analysis

The study included seven SA concentrations and five SA exposure times with three repetitions. Furthermore, each repeat was diluted serially six times, resulting in a total of 630 Petri plates to count. Statistical software was used to assess the numbers that were counted (SPSS Statistics 25.0). When significant differences between samples were discovered after performing a variance analysis (ANOVA), the means were compared using the Scheffe test at a  $P = .05$ .

### 3. RESULTS AND DISCUSSION

The tulip bulb flora is important for the overall health and development of the bulbs. Some of the microorganisms present on the surface of the bulbs are beneficial, providing a range of functions such as improving the soil quality and helping to suppress the growth of harmful pathogens. Other microorganisms, however, can be harmful to the bulbs and cause diseases such as rot. The reduction in the SFL on the tulip bulbs was investigated in this study using various SA concentrations and exposure times (Table 1).

**Table 1. Effect of SA concentrations on fungal surface load of tulip bulbs (log CFU/ml) exposed for 1, 6, 12, 24-hour, and no exposure (0 hours). Values show the means  $\pm$  SD of the replicates.**

SA concentration (ppm)	Exposure time (hours)*, **				
	0	1	6	12	24
0	3,59 $\pm$ 0,53aA	3,37 $\pm$ 0,94aA	3,87 $\pm$ 0,74aA	3,65 $\pm$ 0,59aA	3,69 $\pm$ 0,84aA
50	2,81 $\pm$ 0,53aABC	3,17 $\pm$ 0,80aA	3,64 $\pm$ 0,54aAB	3,30 $\pm$ 0,49aA	3,62 $\pm$ 0,88aA
100	3,33 $\pm$ 0,53aABC	3,31 $\pm$ 0,63aA	3,62 $\pm$ 0,46aAB	3,03 $\pm$ 0,64aAB	3,37 $\pm$ 0,60aAB
200	3,50 $\pm$ 0,37aAB	3,04 $\pm$ 0,57abA	3,25 $\pm$ 0,48abAB	2,63 $\pm$ 0,62bAB	2,88 $\pm$ 0,48abABC
400	2,56 $\pm$ 0,81aBC	3,07 $\pm$ 0,51aA	3,24 $\pm$ 0,61aAB	2,48 $\pm$ 0,55aAB	2,02 $\pm$ 0,98aBCD
800	2,89 $\pm$ 0,45aABC	2,66 $\pm$ 0,38aA	2,76 $\pm$ 0,43aB	2,11 $\pm$ 0,67abBC	1,40 $\pm$ 0,85bCD
1600	2,33 $\pm$ 0,60aC	2,09 $\pm$ 0,73aA	1,53 $\pm$ 0,29aC	1,23 $\pm$ 0,48aC	1,42 $\pm$ 0,61aD

\*Means followed by a common lowercase letter in each row are not significantly different by the Scheffe's test at the  $P = .05$  level of significance.

\*\* Means followed by a common uppercase letter in each column are not significantly different by the Scheffe's test at the  $P = .05$  level of significance.

One-way ANOVA test is intended to determine the differences between the treatment groups. According to one-way ANOVA, the effect of salicylic acid concentrations on the SFL of tulip bulbs was found to be statistically significant ( $p < 0.05$ ) at concentrations of 200 ppm and above. The SFL decreased with increasing SA concentrations. There was no significant decrease in the SFL of tulip bulbs between no SA, 50, and 100 ppm SA concentrations. The next test was post-hoc Scheffe's multiple comparisons to look at a couple of different groups. The results of the Scheffe test showed that 1600 ppm SA treatment significantly

lowered SFL according to the initial log CFU/ml at all exposure times except for one- hour exposure. There was no significant difference between the different SA concentration treatments at one-hour exposure.

One-way ANOVA test results also showed that there was a significant difference between the groups treated with different exposure times ( $P < 0.05$ ). However, the Scheffe test showed that there was no significant difference between the interaction of treatment no SA, 50, and 100 ppm SA concentrations and all exposure times. The exposure times of 12 hours and 24 hours were significantly different from other exposure times at 200 ppm SA and 400 ppm concentrations, respectively. It can be concluded that the factor of SA concentration and exposure time x SA concentration interaction types affect the decrease in the number of colonies of fungi. The maximum decreases in log CFU/ml were seen at 1600 ppm SA concentrations for all exposure times: 1.26, 1.28, 2.34, 2.42, and 2.29 for no SA exposure, 1, 6, 12, and 24-hour exposures; respectively.

The types of fungal species found on tulip bulbs can be quite variable [14, 18, 21-25]. The values in Table 1 show the decrease in the total SFL for tulip bulbs. The minimum concentration at which no visible growth was observed was defined as the Minimum Inhibition Concentration (MIC). MIC could not be calculated for SA by looking at the values in Table 1 for the SFL of tulip bulbs. However, in the literature, there are some studies that determine the MIC value for possible pathogenic fungi in tulip bulbs, for example, Kong et al. (2016) determined the MIC value of SA against *Fusarium solani* as 1300 ppm [39]. In another study, SA completely inhibited the germination of *Penicillium expansum* conidia at 345 ppm [14]. Other pathogens, such as *R. stolonifer*, *F. oxysporum*, *Rhizoctonia solani*, *Sclerotium rolfsii*, *Macrophomina phaseolinae*, *Pythium* sp., and *Phytophthora* sp., showed similar results, with SA reducing nearly 70% of conidial germination and growth at a minimum concentration of 345 ppm [22,24]. It was shown that all concentrations of SA ranging from 0 to 690 ppm decreased the fungal growth of *R. stolonifer*. At a concentration of 690 ppm SA, there was a 100% of growth inhibition [22].

The percentages of inhibition (%) were calculated for each concentration according to Table 1, and EC50 values (concentration causing 50% inhibition of growth) were obtained from fitting data to a dose-response curve (Figure 2). The EC50 values of SA for all exposure times were given in Figure 3.

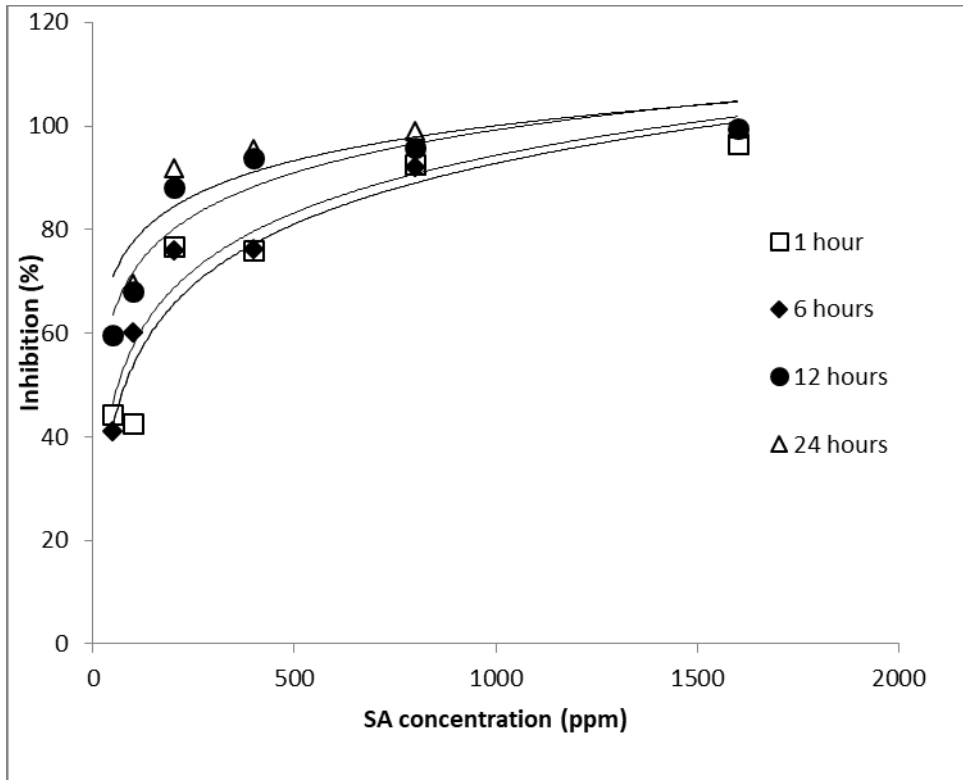


Figure 2. Dose-response profiles of SA for different exposure times. □: 1 hour, ◆: 6 hours, ●: 12 hours, and △: 24 hours.

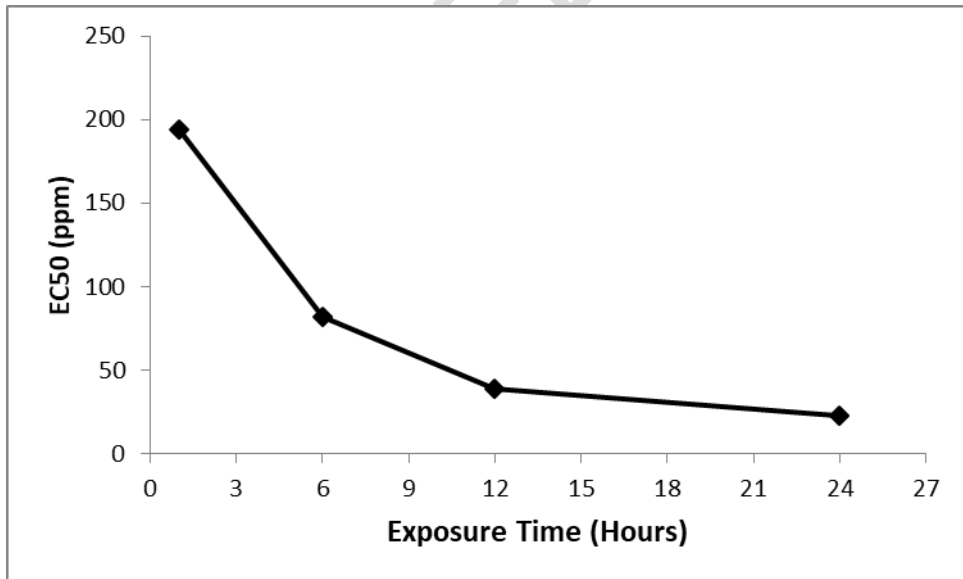


Figure 3. EC50 values of SA over exposure time based on inhibition percentages calculated using the integral method.

The EC50 of SA against surface fungi of tulip bulbs ranged from 194 to 23 ppm. EC50 values were less than 100 ppm which means SA showed strong antifungal activity against the SFL of tulip bulbs at higher exposure times. These findings indicate that SA may get its

antifungal activity through giving damage to biological membranes [22, 39], and by inhibiting or deactivation specific enzymes [40]. These biological changes could happen simultaneously or independently. Moreover, the antimicrobial effect of SA may be related to cellular respiration disturbances, such as shifting electron flow from the cytochrome pathway to an alternate cyanide-related pathway, partially blocking the primary cellular respiration pathway, and altering the cell energy-generating process [40]. SA can also attach to proteins that can affect the breakdown of intracellular hydrogen peroxide, causing this chemical to accumulate in the cell and inactivate the conidia [41]. Amborabé et al. (2002) revealed that the fungicidal properties of SA derivatives on the growth of *Eutypa lata* and all concentrations of this agent were poisonous for *E. lata*, low (138 ppm) and high concentrations of SA (>276 ppm) showed fungistatic and fungicidal properties; respectively and they found that SA behaves as a dissociating agent causing a change in the trans-membrane pH gradient in membranes of organelles and in the plasma membrane, possibly causing cellular energy loss [13]. In another study it was demonstrated that SA affects directly *P. expansum* conidia by breaking through the cell wall and starting a number of interactions with the plasma membrane. This action disrupts the lipid bilayer and/or damages the proteins that control cellular permeability, which raises the level of reactive oxygen species [14].

#### 4. CONCLUSION

In the current study, the effects of SA concentration and exposure time on the surface fungal load of tulip bulbs were evaluated, and the following conclusions were drawn:

The SFL of tulip bulbs decreased as SA concentrations increased. Aside from one-hour exposure, SA treatments considerably decreased the SFL of tulip bulbs according to the initial log CFU/ml at all exposure durations.

As a function of the exposure periods, the EC<sub>50</sub> of SA values against the SFL of tulip bulbs varied from 194 to 23 ppm.

SA revealed promising antifungal activity against the SFL of tulip bulbs instead of synthetic fungicides.

The tulip bulb storage disease risks can be greatly reduced when SA is applied prior to entering the storage conditions of the tulip bulbs.

We propose to the manufacturer that 1600 ppm SA for a 6-hour exposure or 800 ppm SA for a 24-hour exposure be used to control SFL of tulip bulbs at room temperature prior to planting or storage of the tulip bulbs.

#### REFERENCES

1. Lecomte C, Alabouvette C, Edel-Hermann V, Robert F, Steinberg C (2016) Biological control of ornamental plant diseases caused by *Fusarium oxysporum*: A review. *Biological Control*, 101, 17–30. <https://doi.org/10.1016/j.biocontrol.2016.06.004>
2. Mekapogu M, Jung JA, Kwon OK, Ahn MS, Song HY, Jang S (2021) Recent progress in enhancing fungal disease resistance in ornamental plants. *International Journal of Molecular Sciences*, 22: 7956. <https://doi.org/10.3390/ijms22157956>

3. Nazarov PA, Baleev DN, Ivanova MI, Sokolova LM, Karakozova MV (2020) Infectious Plant Diseases: Etiology, Current Status, Problems and Prospects in Plant Protection. *Acta Naturae*, 12(3), 46–59. <https://doi.org/10.32607/actanaturae.11026>
4. Nayeem M, Qayoom A (2015) Inside greenhouses for cultivation of tulip flowers. *International Journal of Advances in Production and Mechanical Engineering*, 1(2), 34–44.
5. Doornik AW, Bergman BHH (1974) Infection of tulip bulbs by *Botrytis tulipae* originating from spores or contaminated soil. *Journal of Horticultural Science*, 49, 203–207. <https://doi.org/10.1080/00221589.1974.11514570>
6. Saniewska A, Dyki B, Jarecka A (2005) Morphological and Histological Changes in Tulip Bulbs During Infection By *Fusarium oxysporum* F. sp. *tulipae*. *Phytopathol. Pol.*, 34(6), 21–39.
7. Prince TA, Stephens CT, Herner RC (1988) Pathogenicity, fungicide resistance, and ethylene production of *Penicillium* spp. isolated from tulip bulbs. *Phytopathology*, 78(6), 682–686.
8. Mukobata H, Yamamoto T, Nahata K, Suzui T (1989) Occurrence of *Pythium* blight caused by *Pythium* spp. in tulips. *Annals of the Phytopathological Society of Japan*, 55(5), 594–602. <https://www.ptonline.com/articles/how-to-get-better-mfi-results>
9. Schneider JHM., Schilder MT, Dijst G (1997) Characterization of *Rhizoctonia solani* AG 2 isolates causing bare patch in field grown tulips in the Netherlands. *European Journal of Plant Pathology*, 103, 265–279. <https://doi.org/10.1023/A:1008643311984>
10. Coley-Smith JR, Humphreys-Jones DR, Gladders P (1979) Long-term survival of sclerotia of *Rhizoctonia tuliparum*. *Plant Pathology*, 28, 128–130.
11. Gould CJ, Byther RS (1979) Diseases of tulips. *Washington State University Cooperative Extension Bulletin*, 711, 23.
12. Shahid M, Khan MS (2022) Tolerance of pesticides and antibiotics among beneficial soil microbes recovered from contaminated rhizosphere of edible crops. *Current Research in Microbial Sciences*, 3, 100091. <https://doi.org/10.1016/j.crmicr.2021.100091>
13. Amborabé BE, Fleurat-Lessard P, Chollet JF, Roblin G (2002) Antifungal effects of salicylic acid and other benzoic acid derivatives towards *Eutypa lata*: Structure-activity relationship. *Plant Physiology and Biochemistry*, 40, 1051–1060. [https://doi.org/10.1016/S0981-9428\(02\)01470-5](https://doi.org/10.1016/S0981-9428(02)01470-5)
14. da Rocha Neto AC, Maraschin M, Di Piero RM (2015) Antifungal activity of salicylic acid against *Penicillium expansum* and its possible mechanisms of action. *International Journal of Food Microbiology*, 215, 64–70. <https://doi.org/10.1016/j.ijfoodmicro.2015.08.018>
15. Wodnicka A, Huzar E, Krawczyk M, Kwiecień H (2017) Synthesis and antifungal activity of new salicylic acid derivatives. *Polish Journal of Chemical Technology*, 19(1), 143–148. <https://doi.org/10.1515/pjct-2017-0019>
16. El-mougy NS, Abd-El-kareem F, El-gamal NG, Fatooh YO (2004) Application of Fungicides Alternatives for Controlling Cowpea Root Rot Disease under Greenhouse and Field Conditions. *Egypt. J. Phytopathol.*, 32(1-2), 23–35.

17. Al-Hakimi AMA, Alghalibi SMS (2007) Thiamin and salicylic acid as biological alternatives for controlling broad bean rot disease. *Journal of Applied Sciences and Environmental Management*, 11(4), 125–131.
18. Mandal S, Mallick N, Mitra A (2009) Salicylic acid-induced resistance to *Fusarium oxysporum* f. sp. *lycopersici* in tomato. *Plant Physiology and Biochemistry*, 47, 642–649. <https://doi.org/10.1016/j.plaphy.2009.03.001>
19. Xue RF, Wu J, Wang LF, Blair MW, Wang XM, De Ge W, Zhu ZD, Wang SM (2014) Salicylic Acid Enhances Resistance to *Fusarium oxysporum* f. sp. *phaseoli* in Common Beans (*Phaseolus vulgaris* L.). *Journal of Plant Growth Regulation*, 33(2), 470–476. <https://doi.org/10.1007/s00344-013-9376-y>
20. Murphy AM, Zhou T, Carr JP (2020) An update on salicylic acid biosynthesis, its induction and potential exploitation by plant viruses. *Current Opinion in Virology*, 42, 8–17. <https://doi.org/10.1016/j.coviro.2020.02.008>
21. Fatemi H, Mohammadi S, Aminifard MH (2013) Effect of postharvest salicylic acid treatment on fungal decay and some postharvest quality factors of kiwi fruit. *Archives of Phytopathology and Plant Protection*, 46(11), 1338–1345. <https://doi.org/10.1080/03235408.2013.767013>
22. Panahirad S, Zaare-Nahandi F, Safaralizadeh R, Alizadeh-Salteh S (2012) Postharvest Control of *Rhizopus stolonifer* in Peach (*Prunus persica* L. Batsch) Fruits Using Salicylic Acid. *Journal of Food Safety*, 32, 502–507. <https://doi.org/10.1111/jfs.12013>
23. El-Mohamedy RSR, Jabnoun-Khiareddine H, Daami-Remadi M (2014) Control of root rot diseases of tomato plants caused by *Fusarium solani*, *Rhizoctonia solani* and *Sclerotium rolfsii* using different chemical plant resistance inducers. *Tunisian Journal of Plant Protection*, 9(1), 45–55.
24. Rehman HU, Ghazanfar MU, Goraya MS (2021) Comparative Efficacy of Fungicides and Salicylic Acid Against *Macrophomina phaseolina* Causing Charcoal Rot Under Laboratory Conditions. *Pakistan Journal of Phytopathology*, 33(2), 245–250. <https://doi.org/10.33866/PHYTOPATHOL.033.02.0609>
25. Radhakrishnan N, Balasubramanian R (2009) Salicylic acid induced defence responses in *Curcuma longa* (L.) against *Pythium aphanidermatum* infection. *Crop Protection*, 28, 974–979. <https://doi.org/10.1016/j.cropro.2009.07.010>
26. El-Mohamedy RSR, Abdel-Kader MM, Abd-El-Kareem F, El-Mougy NS (2013) Essential oils, inorganic acids and potassium salts as control measures against the growth of tomato root rot pathogens in vitro. *Journal of Agricultural Technology*, 9(6), 1507–1520.
27. Cavusoglu A, Özer Uyar GE, Ünal F (2022) An Abiotic Stress Factor: Phytotoxicity of High Doses of Salicylic Acid on Growth Parameters of *Tulipa* sp. Under Glasshouse and Outdoor Conditions. *Applied Ecology and Environmental Research*, 20(6), 4925–4934. [https://doi.org/10.15666/aeer/2006\\_49254934](https://doi.org/10.15666/aeer/2006_49254934)
28. Cao J, Yan J, Zhao Y, Jiang W (2013) Effects of postharvest salicylic acid dipping on *Alternaria* rot and disease resistance of jujube fruit during storage. *Journal of the Science of Food and Agriculture*, 93(13), 3252–3258. <https://doi.org/10.1002/jsfa.6167>

29. Haider STA, Ahmad S, Khan AS, Anjum MA, Nasir M, Naz S (2020) Effects of salicylic acid on postharvest fruit quality of “Kinnow” mandarin under cold storage. *Scientia Horticulturae*, 259(September 2019): 108843. <https://doi.org/10.1016/j.scienta.2019.108843>
30. Qin GZ, Tian SP, Xu Y, Wan YK (2003) Enhancement of biocontrol efficacy of antagonistic yeasts by salicylic acid in sweet cherry fruit. *Physiological and Molecular Plant Pathology*, 62, 147–154. [https://doi.org/10.1016/S0885-5765\(03\)00046-8](https://doi.org/10.1016/S0885-5765(03)00046-8)
31. Lu YY, Chen CY (2005) Molecular analysis of lily leaves in response to salicylic acid effective towards protection against *Botrytis elliptica*. *Plant Science*, 169, 1–9. <https://doi.org/10.1016/j.plantsci.2005.01.019>
32. Asghari M, Aghdam MS (2010) Impact of salicylic acid on post-harvest physiology of horticultural crops. *Trends in Food Science and Technology*, 21, 502–509. <https://doi.org/10.1016/j.tifs.2010.07.009>
33. Tian S, Qin G, Li B, Wang Q, Meng X (2007) Effects of salicylic acid on disease resistance and postharvest decay control of fruits. *Stewart Postharvest Review*, 6(2), 1-7. <https://doi.org/10.2212/spr.2007.6.2>
34. Urban L, Lauri F, Ben Hdech D, Aarouf J (2022) Prospects for Increasing the Efficacy of Plant Resistance Inducers Stimulating Salicylic Acid. *Agronomy*, 12: 3151 <https://doi.org/10.3390/agronomy12123151>
35. Leslie CA, Romani RJ (1986) Salicylic acid: A new inhibitor of ethylene biosynthesis. *Plant Cell Reports*, 5, 144–146. <https://doi.org/10.1007/BF00269255>
36. Babalar M, Asghari M, Talaei A, Khosroshahi A (2007) Effect of pre- and postharvest salicylic acid treatment on ethylene production, fungal decay and overall quality of Selva strawberry fruit. *Food Chemistry*, 105, 449–453. <https://doi.org/10.1016/j.foodchem.2007.03.021>
37. Kamerbeek GA, De Munk WJ (1976) A review of ethylene effects in bulbous plants. *Scientia Horticulturae*, 4, 101–115. [https://doi.org/10.1016/S0304-4238\(76\)80001-5](https://doi.org/10.1016/S0304-4238(76)80001-5)
38. Miller WB (2019) Tulips, Fusarium and ethylene: Changing the paradigm. *Acta Horticulturae*, 1237, 153–159. <https://doi.org/10.17660/ActaHortic.2019.1237.20>
39. Kong J, Xie YF, Guo YH, Cheng YL, Qian H, Yao WR (2016) Biocontrol of postharvest fungal decay of tomatoes with a combination of thymol and salicylic acid screening from 11 natural agents. *LWT - Food Science and Technology*, 72, 215–222. <https://doi.org/10.1016/j.lwt.2016.04.020>
40. Kapulnik Y, Yalpan N, Raskin I (1992) Salicylic acid induces cyanide-resistant respiration in tobacco cell-suspension cultures. *Plant Physiology*, 100, 1921–1926. <https://doi.org/10.1104/pp.100.4.1921>
41. Chen Z, Silva H, Klessig DF (1993) Active Oxygen Species in the Induction of Plant Systemic Acquired Resistance by Salicylic Acid. *Science*, 262 (5141), 1883-1886 <https://www.science.org/doi/abs/10.1126/science.8266079>