Journal of Plant Physiology and Breeding

2021, 11(1): 75-85 ISSN: 2008-5168

Salicylic acid is associated with improved growth and resistance of olives (*Olea europaea* L.) to Verticillium wilt

Abdol Hossein Taheri*, Seyed Javad Sanei, and Seyed Esmael Razavi

Received: September 19, 2018 Accepted: June 23, 2021
Department of Plant Protection, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran.
*Corresponding author; Email: a.taheri@gau.ac.ir

Abstract
To improve the growth of olive and find a suitable approach for controlling *Verticillium dahlia* in this plant, treatment of different cultivars by salicylic acid (SA) was evaluated. Nine-month-old seedlings of Koroneiki, Marry, Rowghani, and Zard cultivars were pre-treated with 0, 5, and 10 mM SA at 15-days intervals, and then roots were inoculated by dipping into a defoliating isolate of *V. dahliae*. The dry weight of different tissues was measured separately at the end of the trial (14 weeks after inoculation). The response was assessed by grading the severity of symptoms on the 0-4 scale and calculating the area under the disease progress curve. Also, the concentration of phenolic compounds in the root tissues, the activity of the superoxide dismutase enzyme, the final intensity of symptoms, and the percentage of dead plants were measured. Foliar spray of 10 mM SA increased the vegetative growth of the olive cultivars. The results showed that treatment with SA decreases the severity of Verticillium wilt. The root phenol level and the activity of superoxide dismutase were significantly higher in the plants treated with 10 mM SA as compared to the control plants. Disease progression had a negative relationship with the superoxide dismutase activity and total phenols of the roots in olive cultivars.

Keywords: Olive cultivars; Salicylic acid; Superoxide dismutase; Total phenol; *Verticillium dahlia*

Citation: Taheri AH, Sanei SJ, and Razavi SE, 2021. Salicylic acid is associated with improved growth and resistance of olives (*Olea europaea* L.) to Verticillium wilt. Journal of Plant Physiology and Breeding 11(1): 75-85.

Introduction

Olive growth and productivity are limited by various diseases and pests. *Verticillium dahliae* Kleb. is one of the most devastating diseases of olive in Iran (Sanei *et al*. 2008) and the world, which reduces the quality and yield of olive cultivars (Montes-Osuna and Mercado-Blanco 2020). The defoliating pathotype of *V. dahliae* with high optimal growth temperature (27 °C) causes higher disease severity in olive cultivars (Sanei *et al*. 2008; Xu *et al*. 2012).

Plants have physical barriers and inducible defense mechanisms to limit pathogen development, such as induction of hypersensitive response (Maleck and Dietrich 1999), cell wall fortification, and production of pathogenesis-related molecules like phytoalexins with antipathogen activities (Ferreira *et al.* 2007). Induced resistance is defined as the increased expression of plants' defense mechanisms against pathogens, caused by elicitors and other factors (Mishra *et al.* 2012). Due to the negative effects of fungicides on the ecosystem, using elicitors is becoming an alternative method for the protection of plants (Vimala and Suriachandraselvan 2009).

Oligosaccharides, peptides, and lipids are some of the compounds that can act as elicitors (Mott *et al.* 2014). Changes in transcription (Nuhse *et al.* 2003). Salicylic acid (SA), a plant phenol, is used extensively as an elicitor, which regulates plant growth and development (Al-Absi *et al.* 2009) and contributes to the plant defense

against pathogens (Raskin 1992). SA has been shown to have a wide range of impacts on the growth and photosynthesis of plants (Pancheva *et al*. 1996). Based on Abo-Elyousr *et al*. (2009), the severity of onion leaf blight induced by *Stemphylium vesicarium* was considerably decreased when SA was sprayed on the leaves. Chaudhry *et al*. (2001) have reported the reduction of *Ascochtya rabiei* by applying SA on the susceptible chickpea cultivar C-727. Chitra *et al*. (2008) indicated the role of SA in developing resistance to *Alternaria alternata* in groundnut.

SA has been shown to alter bio productivity and crop growth (Fathi *et al*. 2019; Hayat *et al*. 2010). It may also generate several metabolites in plants, as well as changes in photosynthetic indices (Fariduddin *et al*. 2003; Hassannejad and Porheidar Ghafarbi 2018). Arfan *et al*. (2007) reported the stimulating effect of SA on the growth of olive plants under salinity. SA pre-treatment has decreased Verticillium wilt severity and suppressed the *V. dahliae* pathogenicity in olive plants (Gharbi *et al.* 2016).

The goal of this study was to investigate the effect of foliar SA spraying on the development of Verticillium wilt symptoms and progression of the disease severity and the role of polyphenols in the plants' defence in four olive cultivars.

Materials and Methods

Plant and fungal material

Nine-month-old olive cultivars Koroneiki, as resistant (Sanei and Razavi 2017b), and Marry, Rowghani, and Zard as susceptible (Sanei and Razavi 2017a) were used in the experiment. The fungal material was a highly virulent (defoliate, VCG1) strain of *V. dahliae* which was collected from the Zard cultivar in Golestan region by the Plant Pathology Laboratory of the Plant Protection Department, Gorgan University of Agricultural Sciences and Natural Resources, Iran.

Pathogen inoculum and inoculation

The inoculum was prepared by growing colonies of *V. dahliae* on potato dextrose agar (PDA) cultures for seven days at 25 ± 0.5 °C in the dark. The inoculum concentration was adjusted to 4×10^6 conidia per milliliter with sterile water (Colella *et al*. 2008). Plants were inoculated by dipping their bare root system into the inoculum for 30 minutes. The plants then were transferred into sterile plastic containers comprising 1000 ml of prior autoclaved silty-loam soil (Table 1) and incubated at 24 ± 4 ◦C (Lopez-Escudero *et al.* 2004). The experiment was carried out in a greenhouse with fluorescent tubes providing supplemental light for 16 hours per day at the air temperature ranging from 20 °C to 26 °C. Control plants that had not been inoculated were given the same treatment as the inoculated plants, but instead, the distilled sterile water was used. The seedlings were grown under well-watered irrigation conditions at five-day intervals from March to July.

Application of SA and experimental design

Olive plants were treated with SA (Sigma-Aldrich, Lyon, France) solutions (0, 5, and 10 mM) before inoculation at 15-days intervals. The experiment was arranged as factorial with three

factors (SA, inoculation, cultivar) based on randomized complete blocks with four replications.

Dry weight

The tips of all shoots of each plant were marked with an indelible marker at the final node to evaluate the influence of SA on the vegetative growth of olive plants. The fresh weight of the whole plants was measured with a balance, while the plant roots were naked and removed from the soil for dipping. Thirteen weeks following inoculation, the fresh weight of new green leaves and shoots grown from marked points at shoot tips and the whole root were recorded separately. These parts were placed individually in paper envelopes, dried at 70 °C for 48 hours, and then their dry weight was measured (Birem. *et al*. 2016).

Disease assessment

Two weeks after inoculation, the severity of the disease was assessed every week for 14 weeks. Wilt resistance was graded according to Lopez-Escudero *et al.* (2004) on a scale of 0 to 4 based on the percentage of plant tissue affected by chlorosis, leaf and shoot necrosis, or defoliation (0 = healthy plant or plant without symptoms; 1 = 1 - 33%, 2 = 34 - 66%, and 3 = 67 - 99% affected tissue; 4 = dead plant). To determine the severity of reactions, the percentage of dead plants (Lopez-Escudero and Blanco-Lopez, 2001) as well as other signs, such as marginal patches on the leaves and uneven twig growth, were observed (Lopez-Escudero *et al.* 2004). The area under the disease progress curve (AUDPC) was calculated for each cultivar in the period of 14 weeks as follows (Campbell and Madden 1990): AUDPC= $[(t/2 \times (S_2 + 2S_3 + \bullet\bullet\bullet + 2S_{i-1} + S_i)/4 \times n] *100$ (t = time between observations in days; S_i = final mean severity of the ith observation; 4 = maximal disease severity; *n* = number of observations). During the study, the fungus was isolated from the infected shoots or leaf petioles of affected plants to determine the plant infection (Lopez-Escudero *et al.* 2004). The frequency of *V. dahliae* reisolation was determined by disinfecting stem segments with 1 percent NaOCl for five minutes and culture of xylem chips on C'zapeck Dox Agar (supplemented with 100 ppm streptomycin sulfate) for 14 days at 25 ± 1 ºC (Tsror *et al.* 2001). The degree of resistance of olive cultivars was determined according to Table 2 (Lopez-Escudero *et al.* 2004).

Total phenols and superoxide dismutase enzyme

The content of total phenols in roots was measured using a colorimeter 100 days after inoculation by *V. dahlia* and its unit was milligrams of tannic acid equivalents per dry weight (Sofo *et al*. 2004). The superoxide dismutase (SOD; EC 1.15.1.1) enzyme activity was measured according to Giannopolitis and Ries (1977). Each assay was repeated four times.

Data analysis

The data for severity of Verticillium wilt, frequency of *V. dahliae* reisolation from the olive xylem, vegetative growth of olives, total phenols,

Table 1. Physical and chemical properties of the soil in the experiment

Texture	N (%)	Organic carbon (%)	P (ppm)	K (ppm)	pH	EC (dS.m -1)
Silty loam	0.21	2.39	14.7	275	7.55	1.24

Table 2**.** Resistance categories and disease parameters for the reaction of olive cultivars to *Verticillium dahliae* (Lopez-Escudero *et al.* 2007).

Resistance category	AUDPC[a]	FMS[b]	PDP[c]
Highly resistant	0-10	0.0-1.5	0
Resistant	11-30	0.0-1.5	0
Moderately resistant	31-50	1.5-2.5	0-30
Susceptible	51-70	2.5-3.0	31-50
Extremely susceptible	71-100	3.0-4.0	51-100

[a]AUDPC: area under the disease progress curve; [b]FMS: final mean severity of symptoms; [c]PDP: percentage of dead plants.

and SOD activity were subjected to analysis of variance and the means were compared by the Fisher's protected LSD at $p \leq 0.05$. Statistical analyses were performed by the R.3.3.1 program.

Results

Based on analyses of variance, effects of SA, inoculation, cultivar, and their interactions were significant for all characters under study, except for the main effect of inoculation on SOD (data not shown). At all concentrations of SA, inoculation with *V. dahliae* did not significantly reduce the dry weight of shoots, new green leaves, and roots in the Koroneiki cultivar as compared to non-inoculated plants, except for the dry weight of shoots at 10 mM SA (Table 3). For the sensitive cultivars (Marry, Rowghani, Zard), inoculation with *V. dahliae* decreased, in most cases, the dry weight of shoots, new green leaves, and roots at all SA concentrations as compared to the respective controls (Table 3). However, foliar spray of 10 mM SA significantly improved these characters on the inoculated sensitive cultivars as compared with the inoculated olive plants at 0 mM SA (Table 3).

There was a decrease in wilt incidence due to the foliar application of SA at 10 mM concentration (Table 4). The inoculated untreated plants showed 91% wilt incidence. By contrast, the inoculated SA-treated plants showed a significant reduction in disease severity, and the wilt incidence was around 29.33%.

The resistant cultivar Koroneiki had significantly higher root total phenols and SOD activity than all sensitive cultivars in both inoculated and non-inoculated olive plants at all SA concentrations. The application of 10 mM SA significantly increased the total phenol accumulation and SOD activity of inoculated and non-inoculated sensitive and resistant olive cultivars as compared with the respective controls when no SA was applied (Table 3). Total phenols and SOD activity had a negative relationship with AUPDC (Figure 1).

Table 3. Dry weight of the roots and new green leaves and shoots, SOD activity, and root phenol content of olive plants 100 days after inoculation with *Verticillium dahliae* and treated with salicylic acid

Factors		Dry weight (g)			Root total phenols (mg/g DW)	SOD activity (units per mg protein)
		Leaves	Roots	Shoots		
SA (0 mM)						
[a]Inoculation	Variety					
C	Koroneiki	2.41	6.38	2.71	25.82	54.2
	Marry	2.48	5.80	2.87	16.76	47.0
	Rowghani	2.56	5.71	2.87	16.45	45.4
	Zard	2.43	5.73	2.78	17.30	48.2
I	Koroneiki	2.40	6.40	2.68	25.12	52.0
	Marry	1.44	3.29	1.24	16.79	48.6
	Rowghani	1.35	4.04	1.53	16.33	47.6
	Zard	1.30	3.87	1.00	16.59	44.4
SA (5 mM)						
C	Koroneiki	2.44	6.20	2.80	25.64	55.8
	Marry	2.30	5.41	2.70	16.68	46.8
	Rowghani	2.44	5.74	2.87	16.68	46.4
	Zard	2.46	6.18	2.78	16.2	45.4
I	Koroneiki	2.63	6.36	2.70	25.90	56.2
	Marry	1.38	3.17	1.38	16.54	46.2
	Rowghani	1.28	4.09	1.61	22.16	51.8
	Zard	1.21	3.47	1.20	16.59	46.2
SA (10 mM)						
C	Koroneiki	2.96	6.42	3.12	33.96	70.8
	MarryC	2.84	5.42	2.87	24.78	54.4
	Rowghani	3.02	6.25	3.08	24.78	55.8
	Zard	2.92	5.78	2.91	24.42	54.4
I	Koroneiki	2.85	6.30	2.73	31.16	63.0
	Marry	2.52	5.32	2.85	22.84	57.2
	Rowghani	2.52	5.70	2.84	25.20	55.0
	Zard	2.53	5.66	2.76	22.22	52.0
LSD (0.05)		0.303	0.825	0.329	1.844	3.688

[a]Inoculation status: C = non-inoculated control, I = inoculated plants; SA: salicylic acid: SOD: superoxide dismutase

Discussion

The ability of a plant to prevent or restrict pathogen growth and multiplication is known as disease resistance (Chaudhary *et al.* 2001). Verticillium wilt resistance/tolerance has been reported in olive rootstocks and commercial cultivars (Bubici and Cirulli 2012; Erten and Yildiz 2011) and also in wild olives (Sanei and Razavi 2017a). Either resistant or susceptible plants respond to pathogens by inducing several strategies. Exogenous application of systemic elicitors can be a valuable alternative to the conventional methods of controlling pathogens (Desender *et al.* 2007). In this study, the foliar spray of 10 mM SA reduced the disease incidence in all cultivars, however, the reduction was much more pronounced in the sensitive cultivars. Hayat *et al*. (2010) in a review about the efficiency of SA foliar application on plants indicated the effects of this hormone on providing protection and tolerance against various biotic stresses, and alleviation of the toxic effects of abiotic stresses.

Table 4. Mean disease parameters assessed in the olive cultivars inoculated with the defoliating isolate of *Verticillium dahliae* and treated exogenously with salicylic acid.

Factors		Severity of Verticillium wilt external symptoms		Frequency of *V. dahliae* reisolation from the olive xylem (%)	Resistance level	Percentage of dead plants
		AUDPC[a]	100 DAI[b] (0-4 scale)			
Cultivar	SA					
Marry						
	0	60.04	3.00	1.70	S	40
	5 mM	53.78	2.70	1.70	S	0
	10 mM	42.84	1.00	1.50	MR	0
Rowghani						
	0 mM	65.88	3.10	1.75	S	0
	5 mM	64.76	3.00	1.75	S	0
	10 mM	45.48	2.00	1.10	MR	0
Koroneiki						
	0	9.14	0.80	0.60	HR	0
	5 mM	11.88	0.80	0.50	HR	0
	10 mM	6.34	0.60	0.15	HR	0
Zard						
	0	69.92	3.20	2.75	S	40
	5 mM	63.90	2.80	2.75	S	0
	10 mM	39.94	2.00	1.35	MR	0
LSD (0.05)		3.464	0.224	0.141		

[a]AUDPC: area under the diseas e progress curve; [b]DAI = days after inoculation; S = susceptible, MS = moderately susceptible, R = resistant, HR = highly resistant

Gharbi *et al*. (2016) reported the effect of foliar spraying of SA on induced resistance in olive.

The susceptibility level of the evaluated olive cultivars was linked to the growth reduction in this report and inoculation with *V. dahliae* reduced the dry weight of leaves, shoots, and roots of the susceptible olive varieties. On the other hand, resistant genotypes showed few symptoms and produced new leaves and shoots after inoculation. Birem *et al*. (2016) used the fresh and dry weights of plants as the main indicators to determine the differences in vegetative growth of olive cultivars with varying levels of resistance to *V. dahlia.* Several authors have shown the growth reduction induced by *V. dahliae* in olive (Birem *et al*. 2016), pepper (Goicoechea 2006), sunflower (Sadras *et al*. 2000), tomato, and eggplant (Karagiannidis *et al.* 2002). According to Sadras *et al*. (2000), the reduction in the growth of sunflower plants due to *V. dahliae* infection was attributed to the reduction in the leaf area, which was caused by the reduced leaf expansion early in the season and faster leaf senescence in older plants.

Our study showed that the application of 10 mM SA alleviated the adverse effects of inoculation with *V. dahliae* on new green leaves, shoots, and roots of the sensitive cultivars of olive. Hayat *et al.* (2010) indicated the effects of this hormone on enhancing the growth and productivity in plants. The influence of SA on carboxylation efficiency, photosynthesis, nitrate reductase activity, and seed yield has been reported in *Brassica juncea* (Fariduddin *et al.*

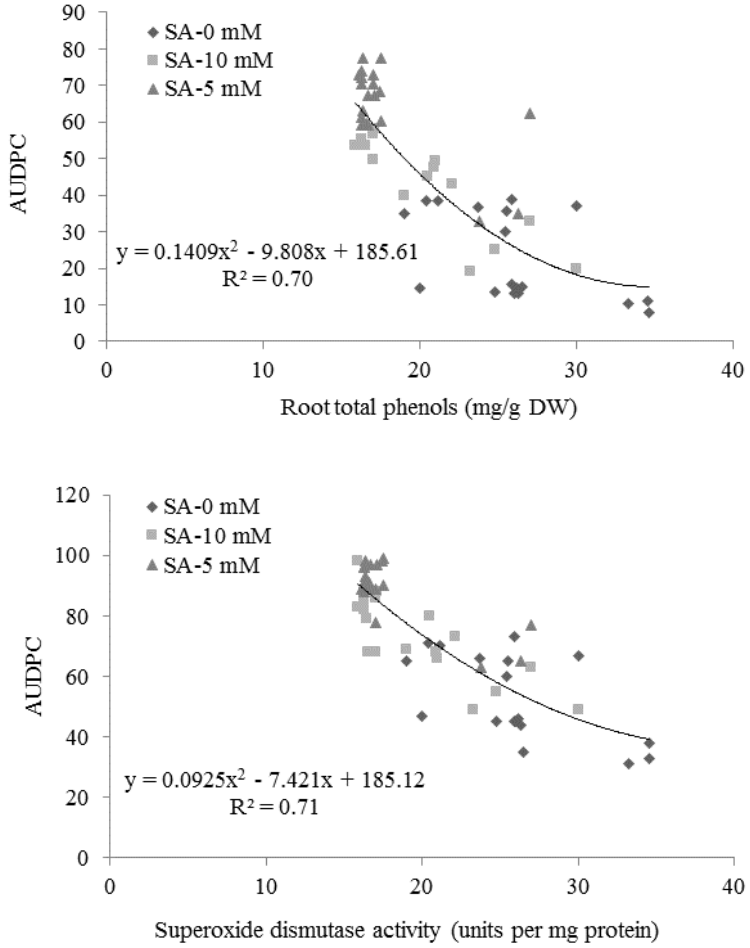

Figure 1. Relationship of root total phenols and superoxide dismutase activity with the area under the disease progress curve (AUDPC) of the olive cultivars infected with a defoliating isolate of *Verticillium dahliae*.

et al. 2003). The enhancement in photosynthetic activity in wheat (Arfan *et al.* 2007) and diminishing the inhibiting effect of salinity on the growth of olive plants (Al-Abasi 2009) have been attributed to the stimulating effect of SA treatment under salinity conditions.

The application of 10 mM SA increased the total phenol content and SOD activity in all cultivars at both inoculated and non-inoculated conditions. Resistance to pathogens increases the level of certain compounds, resulting in disease protection (Del Rio *et al*. 2003). Enhanced phenolic compounds buildup in plant tissue following pathogen attacks has been reported by many authors (e.g. Roussos *et al*. 2002; Del Rio *et al.* 2003; Baidez *et al.* 2007; Markakis *et al*. 2010). Baidez *et al*. (2007) reported that quercetin and luteolin aglycons followed by rutin, oleuropein, luteolin-7-glucoside, tyrosol, p-coumaric acid, and catechin have an antifungal effect against *V. dahliae* at in vitro conditions. Elicitor compounds trigger a cascade of defense responses such as the production of defense enzymes like chitinases and glucanases, and cell wall fortification (Desender

et al. 2007; Ferreira *et al.* 2007). SA is engaged in activating several compounds to defend plants against pathogen attacks (Chitra *et al*. 2008). Response to SA results in the production of secondary metabolites such as phytoalexins (Ahuja *et al*. 2012). Antioxidant defense enzymes, including SOD, are also important in the response of plants to various stresses and are induced by SA. For example, Xi *et al.* (2021) showed that the clubroot incidence rate and disease index were declined and the activities of antioxidant enzymes such as SOD, ascorbic acid-peroxidase, catalase, and glutathione reductase were increased after application of 0.6 mM exogenous SA.

Conclusion

This study showed the positive effect of SA on the growth and incidence of *V. dahliae* in olive cultivars under investigation. The substantial effect of SA on the root phenolic content and SOD activity was also observed in this study, which can protect the olive plants from the *V. dahliae* attack.

Conflict of Interest

The authors declare that they have no conflict of interest with any people or organization concerning the subject of the manuscript.

References

Abo-Elyousr KAM, Hussein MAM, Allam ADA, and Hassan MH, 2009. Salicylic acid induced systemic resistance on onion plants against *Stemphylium vesicarium*. Archives of Phytopathology and Plant Protection 42(11): 1042-1050.

Ahuja I, Kissen R, and Bones AM, 2012. Phytoalexins in defense against pathogens. Trends in Plant Science 17(2): 73-90.

Al-Abasi KM, 2009. Growth and ionic relations in 'Nabali' olive during salinity stress as affected by salicylic acid and relief treatments. Advances in Horticultural Science 23(2): 101-107.

Arfan M, Athar HR, and Ashraf M, 2007. Does exogenous application of salicylic acid through the rooting medium modulate growth and photosynthetic capacity in two differently adapted spring wheat cultivars under salt stress? Journal of Plant Physiology 164(6): 685-694.

Baidez AG, Gomez P, Del Rio JA, and Ortuno A, 2007. Dysfunctionality of the xylem in *Olea europaea* L. plants associated with the infection process by *Verticillium dahliae* Kleb. Role of phenolic compounds in plant defense mechanism. Journal of Agricultural and Food Chemistry 55(9): 3373-3377.

Birem F, Alcantara-Vara E, and Lopez-Escudero FJ, 2016. Water consumption and vegetative growth progress in resistant and susceptible olive cultivars infected by *Verticillium dahliae*. Agricultural Sciences 7(4): 230-238.

Bubici G and Cirulli M, 2012. Control of Verticillium wilt of olive by resistant rootstocks. Plant and Soil 352: 363-376.

Campbell CL and Madden LV, 1990. Introduction to Plant Disease Epidemiology. John Wiley and Sons, USA.

Chaudhary MHZ, Sarwar N, and Chaughati FA, 2001. Biochemical changes in chickpea plant after induction treatment with simple chemical for systemic resistance against ascochyta blight in the field. Journal of the Chemical Society of Pakistan 23(3): 182-186.

Chitra K, Ragupathi N, Dhanalakshmi K, Mareeshwari P, Indra N, Kamalakannan A, Sankaralingam A, and Rabindran R, 2008. Salicylic acid induced systemic resistance on peanut against *Alternaria alternata*. Archives of Phytopathology and Plant Protection 41(1): 50 -56.

Colella C, Miacola C, Amenduni M, D'Amico M, Bubici G, and Cirulli M, 2008. Sources of Verticillium wilt resistance in wild olive germplasm from the Mediterranean region. Plant Pathology 57(3): 533-539.

Del Rio JA, Baidez AG, Botia JM, and Ortuno A, 2003. Enhancement of phenolic compounds in olive plants (*Olea europaea* L.) and their influence on resistance against *Phytophthora* sp. Food Chemistry 83(1): 75-78.

Desender S, Andrivon D, and Val F, 2007. Activation of defense reactions in *Solanaceae*: where is the specificity? Cell Microbiology 9(1): 21-30.

Erten L and Yildiz M, 2011. Screening for resistance of Turkish olive cultivars and clonal rootstocks to Verticillium wilt. Phytoparasitica 39: 83-92.

Fariduddin Q, Hayat S, and Ahmad A, 2003. Salicylic acid influences net photosynthetic rate, carboxylation efficiency, nitrate reductase activity, and seed yield in *Brassica juncea*. Photosynthetica 41: 281-284.

Fathi S, Kharazmi M, and Najafian S. 2019. Effects of salicylic acid foliar application on morpho-physiological traits of purslane (*Portulaca olaracea* L.) under salinity stress conditions. Journal of Plant Physiology and Breeding 9(2): 1-9.

Ferreira RB, Monteiro S, Freitas R, Santos CN, Chen Z, Batista LM, Duarte J, Borges A, and Teixeira AR, 2007. The role of plant defence proteins in fungal pathogenesis. Molecular Plant Pathology 8(5): 539-711.

Gharbi Y, Bouazizi E, and Triki MA, 2016. Inductions of defense response in olive plants against *Verticillium dahliae* through application of salicylic acid as abiotic inducer. Journal of Advances in Biology and Biotechnology 5(4): 1-9.

Giannopolitis CN and Ries SK, 1977. Superoxide dismutases: I. Occurrence in higher plants. Plant Physiology 59(2): 309-314.

Goicoechea N, 2006. Verticillium-Induced wilt in pepper: physiological disorders and perspectives for controlling the disease. Plant Pathology Journal 5(2): 258-265.

Hassannejad S and Porheidar Ghafarbi S, 2018. Assessment of some chlorophyll a fluorescence parameters of different corn cultivars in response to clodinafop-propagrgyl herbicide and salicylic acid. Journal of Plant Physiology and Breeding 8(1): 47-57.

Hayat Q, Hayat S, Irfan M, and Ahmad A, 2010. Effect of exogenous salicylic acid under changing environment: a review. Environmental and Experimental Botany 68(1): 14-25.

Karagiannidis N, Bletsos F, and Stavropoulos N, 2002. Effect of Verticillium wilt (*Verticillium dahliae* Kleb.) and mycorrhiza (*Glomus mosseae*) on root colonization, growth and nutrient uptake in tomato and eggplant seedlings. Scientia Horticulturae 94(1): 145-156.

Lopez-Escudero FJ and Blanco-Lopez MA, 2001. Effect of a single or double soil solarization to control Verticillium wilt in established olive orchards in Spain. Plant Disease 85(5): 489-496.

Lopez-Escudero FJ, del Rio C, Caballero JM, and Blanco-Lopez MA, 2004. Evaluation of olive cultivars for resistance to *Verticillium dahliae*. European Journal of Plant Pathology 110: 79-85.

Markakis EA, Tjamos SE, Antoniou PP, Roussos PA, Paplomatas EJ, and Tjamos EC, 2010. Phenolic responses of resistant and susceptible olive cultivars induced by defoliating and nondefoliating *Verticillium dahliae* pathotypes. Plant Disease 94(9):1156-1162.

Mishra AK, Sharma K, and Misra RS, 2012. Elicitor recognition, signal transduction and induced resistance in plants. Journal of Plant Interactions 7(2): 95-120.

Montes-Osuna N and Mercado-Blanco J, 2020. Verticillium wilt of olive and its control: what did we learn during the last decade? Plants 9(6):735.

Mott GA, Middleton MA, Desveaux D, and Guttman DS. 2014. Peptides and small molecules of the plant-pathogen apoplastic arena. Frontiers in Plant Science 5: 677.

Nuhse TS, Boller T, and Peck SC, 2003. A plasma membrane syntaxin is phosphorylated in response to the bacterial elicitor flagellin. Journal of Biological Chemistry 278(46): 45248-45254.

Pancheva TV, Popova LP, and Uzunova AN, 1996. Effect of salicylic acid on growth and photosynthesis in barley plants. Journal of Plant Physiology 149(1-2): 57-63.

Raskin I, 1992. Role of salicylic acid in plants. Annual Review of Plant Physiology and Plant Molecular Biology 43: 439-463.

Roussos PA, Pontikis CA, and Tsantili E, 2002. Root promoting compounds detected in olive knot extract in high quantities as response to infection by the bacterium *Pseudomonas savastanoi* pv. *savastanoi*. Plant Science 163: 533-541.

Sadras VO, Quiroz F, Echarte L, Escande A, and Pereyra VR, 2000. Effect of *Verticillium dahliae* on photosynthesis, leaf expansion and senescence of field-grown sunflower. Annals of Botany 86(5): 1007-1015.

Sanei SJ and Razavi SE, 2017a. Sources of Verticillium wilt resistance in wild olive germplasm from the Golestan province, Northern Iran. Journal of Crop Protection 6(4): 457-470.

Sanei SJ and Razavi SE, 2017b. Resistance and vegetative growth analysis of some olive cultivars in response to a defoliating pathotype of *Verticillium dahliae* Kleb. International Journal of Horticultural Science and Technology 4(2): 239-250.

Sanei SJ, Waliyar F, Razavi SE, and Okhovvat SM, 2008. Vegetative compatibility, host range and pathogenicity of *Verticillium dahliae* isolates in Iran. International Journal of Plant Production 2: 37-46.

Sofo A, Dichio B, Xiloyannis C, and Masia A, 2004. Effects of different irradiance levels on some antioxidant enzymes and on malondialdehyde content during rewatering in olive tree. Plant Science 166: 293-302.

Tsror (Lahkim) L, Hazanovsky M, Mordechi-Lebiush S, and Sivan S, 2001. Agressivness of *Verticillium dahliae* isolates from different vegetative compatibility groups to potato. Plant Pathology 50(4): 477- 482.

Vimala R and Suriachandraselvan M, 2009. Induced resistance in bhendi against powdery mildew by foliar application of salicylic acid. Journal of Biopesticides 2(1): 111-114.

Xu F, Yang L, Zhang J, Guo X, Zhang X, and Li G, 2012. Effect of temperature on conidial germination, mycelial growth, and aggressiveness of the defoliating and nondefoliating pathotypes of *Verticillium dahliae* from cotton in China. Phytoparasitica 40(4): 319-327.

ارتباط اسید سالیسیلیک با بهبود رشد و تحریک مقاومت زیتون (*Olea europaea* L.) به پژمردگی ورتیسیلیومی

عبدالحسین طاهری*، سیدجواد صانعی و سید اسماعیل رضوی

گروه گیاهپزشکی، دانشگاه علوم کشاورزی و منابع طبیعی گرگان، گرگان
*مسئول مکاتبه؛ Email: a.taheri@gau.ac.ir

چکیده

به منظور بهبود رشد و پیدا کردن یک روش مناسب برای کنترل *Verticillium dahliae*، عامل پژمردگی ورتیسیلیومی، تیمار ارقام زیتون توسط اسید سالیسیلیک (SA) مورد مطالعه قرار گرفت. در این بررسی، نهال‌های نُه ماهه زیتون شامل کورونایکی، ماری، روغنی و زرد پس از تیمار توسط SA با غلظت‌های ۰، ۵ و ۱۰ میلی‌مولار با جدایه برگ‌ریز *V. dahliae*، جدا شده از زیتون از منطقه گرگان، به‌روش غوطه‌ور کردن ریشه مایه‌زنی شدند. محلول‌پاشی گیاهان زیتون هر ۱۵ روز یکبار توسط SA انجام شد. در پایان آزمایش، ۱۴ هفته پس از مایه‌زنی، وزن خشک بخش‌های مختلف گیاه به‌طور جداگانه اندازه‌گیری شد. مقاومت با تعیین شدت علائم با استفاده از مقیاس ۴-۰ و محاسبه سطح زیر منحنی پیشرفت بیماری ارزیابی شد. درصد گیاهان خشک شده، میانگین شدت علائم نهایی، فراوانی جداسازی *V. dahliae* از بافت آوندی، فنل کل و فعالیت آنزیم سوپراکسید دیسموتاز نیز مدنظر قرار گرفت. نتایج نشان داد که محلول‌پاشی برگ‌ها با غلظت ۱۰ میلی‌مولار SA با افزایش رشد رویشی همراه است. SA شدت بیماری را کاهش داد. گیاهان تیمار شده میزان فنل ریشه و فعالیت سوپراکسید دیسموتاز بیشتری نسبت به گیاهان شاهد داشتند. پیشرفت بیماری با میزان فنل ریشه و فعالیت سوپراکسید دیسموتاز رابطه منفی داشت.

واژه‌های کلیدی: اسید سالیسیلیک؛ ارقام زیتون؛ پژمردگی ورتیسیلیومی؛ سوپراکسید دیسموتاز؛ فنل کل