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Exogenous Application of Defence Signalling Compounds Stimulate Natural Defence Responses against Alternaria Blight and Seed Quality in Radish

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ABSTRACT

The present study was conducted in the Department of Seed Science and Technology, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India during 2017–2019 to test the efficacy of plant defence signalling compounds to manage alternaria blight and improve seed quality of radish cv. Japanese white . The experiment was composed of 13 treatments which included three different concentrations of four plant defence activators viz., salicylic acid (50, 75 and 100 ppm), methyljasmonate (55, 110 and 165 ppm), β-aminobutyric acid (250, 500 and 750 ppm), potassium nitrate (1%, 1.5% and 2%) and untreated control. The treatments were applied in the form of foliar applications at three growth stages of the crop viz., initiation of flowering stalk, flowering and pod development. The results highlighted that lowest severity of alternaria blight i.e. 9.44% and11.31% was recorded from the plants sprayed with 750 ppm β-aminobutyric acid and 100ppm salicylic acid respectively. The maximum seed yield was observed with foliar application of 100ppm salicylic acid (379.71 g plot^{-1}) followed by 2% potassium nitrate (352.72 g plot^{-1}). The other parameters related to seed yield and quality such as number of silique plant^{-1}, length of siliqua, number of seeds siliqua^{-1}, 1000 seed weight, seed germination, speed of germination, SVI-I and SVI-II were observed significantly higher with the foliar application of salicylic acid at 100 ppm as compared to other treatments. The results indicated the potential use of salicylic acid at 100 ppm in radish seed crop for management of alternaria blight and production of good quality seeds.

KEYWORDS: Alternaria, BABA, defence activators, KNO_3, MeJA, SA

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Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

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1. INTRODUCTION

Radish (*Raphanus sativus* L.) is cultivated throughout the world, fits well in multiple cropping systems and brings lucrative returns to farmers. In India, radish owns 2,06,000 ha area and production of 29,27,000 mt of roots (Anonymous, 2017). Alternaria blight caused by *Alternaria raphani* deteriorates seed quality and yield in mid hills of Himachal Pradesh causing heavy losses to seed producers and gets established in new area with infected seeds (Gupta and Thind, 2006). Plant defence elicitors like salicylic acid (SA), methyljasmonate (MeJA) and β-aminobutyric acid (BABA) are signalling compounds present inside the plant system and are responsible for generating powerful responses in the plants during biotic and abiotic stresses, hence can be used as environment friendly alternative to combat this disease.

Salicylic acid (SA) is phytohormone that mediates plant immunity and plays a role in plant growth regulation.SA influences seed germination, thermogenesis, plant growth promotion, flowering, fruit yield, root growth, ethylene biosynthesis, nutrient transport, plant water relations, photosynthesis and defence responses (Hashempour et al., 2014; Miura and Tada, 2014; Zhang et al., 2017). Some of these are induced by SA in a dose-dependent manner, triggered by application with a low concentration of SA (Dempsey and Klessig, 2017). SA is synthesized from chorismate through two distinct pathways in plants, the isochorismate (IC) and the phenylalanine ammonia-lyase (PAL) pathways (Zhang and Li, 2019). Li et al. (2022) suggested that NPRsor other SABPsbinds to SA to modulate transcription of important genes to influence plant growth. The studies conducted by Ari et al. (2020), Mazzoni-Putman et al. (2021) and Pokotylo et al. (2021) indicated SA interaction with other hormones (which includes auxin, gibberellic acid, and ethylene) either in a positive or negative way, regulates cell division and expansion to influence plant and organ growth.

MeJA (volatile methyl ester of jasmonic acid) is a key signalling molecule in abiotic and biotic stress (Wang et al., 2021). It affects seed germination, root growth, trichome development, phenols production, pollen viability, organ growth, defence responses, fruit maturation, and initiation of mechanisms to cold resistance (Meyer et al., 1984; Abdala et al., 1996; Reyes-Diaz et al., 2016; Boonyaritthongchai and Supapvanich, 2017; Asghari, 2019). Plants exposed to BABA enter primed state (Conrath, 2006) and produces reactive oxygen species and induces physical barriers by callose deposition and lignin accumulation in the cell walls. BABA induced stress triggers biochemical response, such as synthesis of secondary metabolites (e.g. phenols, phytoalexins, and anthocyanins) and activation of enzymes linked to ROS, lignifications, and secondary metabolism in plants. BABA promotes the buildup of PR proteins implicated in antimicrobial activity. After inoculation, these proteins were also found to accumulate in tomato (Cohen, 1994b), pepper (Hwang et al., 1997), potato (Altamiranda et al., 2008), and rape (Sasek et al., 2011). Potassium (K) an inorganic cation which is essential for plant growth (White and Karley, 2010) activates essential enzymes involved in protein synthesis, sugar transport, N and C metabolism, and photosynthesis. It improves yield and quality of produce (Marschner, 2012; Oosterhuis et al., 2014). K is also essential for cell growth, which is essential for plant function and development (Hepler et al., 2001). K is known to stimulates and controls ATPase in plasma membrane to generate acid stimulation, which causes cell wall loosening and hydrolase activation, hence increasing cell growth (Oosterhuis et al., 2014). K has high mobility and is vital for regulating cell osmotic pressure and balancing cations and anions in cytoplasm (Kaiser, 1982; Hu et al., 2016a). The study was formulated to test efficacy of these elicitors on radish seed crop against alternaria blight as an ecologically safe and non-toxic disease management strategy.

2. MATERIALS AND METHODS

The experiment was conducted in the field and laboratory of Department of Seed Science and Technology, Dr Y. S. Parmar University of Horticulture and Forestry from 2017–2019 during the months of November to June, at an altitude of 1150 m amsl. The seeds of Radish (cv. Japanese white), were procured from the Department of Seed Science and Technology, Dr YSP UHF, Nauni, Solan (HP). Surface sterilization of seeds were done using sodium hypochlorite (1%) and roots of radish were raised and were used as stecklings for planting in the field during mid-December on flat beds at a spacing of (60×30) cm. There were thirteen treatments viz.:

T_1: Foliar application of SA @ 50 ppm, T_2: Foliar application of SA @ 75 ppm, T_3: Foliar application of SA @ 100 ppm, T_4: Foliar application of MeJA @ 55 ppm, T_5: Foliar application of MeJA@110 ppm, T_6: Foliar application of MeJA @ 165 ppm, T_7: Foliar application of BABA @ 250 ppm, T_8: Foliar application of BABA @ 500 ppm, T_9: Foliar application of BABA @ 750 ppm, T_{10}: Foliar application of KNO_3 @ 1%, T_{11}: Foliar application of KNO_3 @ 1.5%, T_{12}: Foliar application of KNO_3 @ 2% and T_{13}: Control (No application).

The foliar applications of different plant defence activators were applied at three crop stages viz. initiation of flowering stalk, flowering and pod development stage. The experiment was laid out in randomized complete block design (RBD) with three replications of each treatment. The plot size was 2.4×1.2 m^2.

Rating scale used for recording the disease severity of Alternaria blight:

Rating	Description
0	No symptoms on the leaf.
1	Small, irregular brown spots covering 1% or less of the leaf area
3	Small, irregular, brown spots with concentric rings covering 1-10% of the leaf area
5	Lesions enlarging, irregular, brown with concentric rings covering 11-25% of the leaf area
7	Lesions coalescing to form irregular brown patches with concentric rings. Covering 26-50% of the leaf area. Lesions also on stem and petioles
9	Lesions coalescing to form irregular, dark brown patches with concentric rings covering 51% or more of the leaf area. Lesions on stem, petioles and silique

The seed yield parameters viz. no. of siliqua, length of siliqua (cm), no. of seeds silique^{-1}, seed yield (g plot^{-1}) and 1000 seed wt. (g) were observed on five plants of each replicated plot as per the standard procedures after harvesting. The seed quality parameters were recorded as per guidelines given by ISTA following paper towel and standard blotter methods. For calculating seed vigour, the formula given by Abdul-Baki and Anderson (1973) was used i.e. Seed vigour Index-I=Germination (%)×Seedling length (cm) and Seed vigour index-II=Germination (%)×Seedling dry weight (mg).

2.1. Statistical analysis

Data observed from the study were pooled for two years to obtain more precise estimates and to meet the more general and broader objective of common interpretation. Study of the treatment×year interaction was carried out as per bartlett's test and the interaction was found to be non-significant. Statistical analysis of data was done by using SPSS version 16 (SPSS Inc., Chicago, IL, USA) and Microsoft Excel (Microsoft, Redmond, WA, USA) at p=0.05 level of significance.

3. RESULTS AND DISCUSSION

3.1. Effect on disease severity of alternaria blight

Foliar application of plant defence activators viz. SA, MeJA, BABA and KNO_3 at various concentrations on radish seed crop reduced the severity of alternaria blight when recorded at different time intervals (Table 1). Lowest disease severity (9.44%) was observed in the plots sprayed with 750 ppm BABA followed by 100 ppm SA and 500 ppm BABA with 11.31 and 11.48% disease severity, respectively. These treatments were followed by foliar application of 2% KNO_3 which resulted into 12.86% severity of alternaria blight which was significantly lesser than that of other treatments including control while maximum disease severity of 21.15% was observed in the control.

It can also be observed from the table that the severity of Alternaria blight significantly increased with increase in time interval (weeks after last spray). The disease started appearing between second and third week of last spray of plant defence activators under different treatments. The disease severity significantly increased when observed at different time intervals from third week (5.04%) to sixth week (22.61%) after last application of defence elicitors.

BABA is a non-protein amino acid which has the ability to induce acquired resistance in plants for a wide range of disease-causing organisms which includes various fungi, bacteria and viruses on a variety of crop plants. The movement of BABA in plant is systemic and it increase the salicylic acid content in the leaf and induces different pathogenesis related (PR) proteins and also stimulates callose deposition around hypersensitive lesion and lignifications on plant tissues (Walters et al., 2005). It has been reported that BABA treated plant results in early and more pronounced callose accumulation when infected by pathogens like *Alternaria brassicicola* and callose acts as physical barrier against the colonization of intercellular spaces of the tissues (Ton and Mauch Mani, 2004). The activity of various phenolic enzymes like peroxidase (POD), polyphenol oxidase (PPO) and phenylalanine ammonia lyase (PAL) have been reported to increase in leaves after SA spray and these peroxidases are known to help in H_2O_2 supported lignification of cell wall, thereby, restrict the invasion of pathogen in the host tissues and reduce the progress of disease (Sreedhara et al., 1995). KNO_3 is a soluble source of potassium and nitrogen which plays a key role in helping the cells to adapt to abiotic stresses by affecting uptake of water, root growth, maintaining the turgour pressure and thus helps the plant to function normally during pathogen attacks (Bardhan et al., 2007).

Potassium also plays a role in synthesis of protein, enzyme activation, and carbohydrate metabolism. It also plays a role in mitigating various abiotic stresses such as metal toxicity, salinity, drought, high or chilling temperatures etc. (Wang et al., 2013). All these mechanisms might have acted in reducing the disease severity of alternaria blight in radish seed crop after foliar application of plant defence activators like BABA and SA and KNO_3 under the present study.

3.2. Seed yield parameters

SA, MeJA, BABA and KNO_3 at various concentrations increased yield parameters viz. no. of silique plant^{-1}, siliqua length, no. of seeds silique^{-1}, 1000 seed weight and seed yield plot^{-1} in radish seed crop (Table 2).

Table 1: Effect of foliar applied plant defence activators on severity of Alternaria blight in radish seed crop

Treatment	Disease severity (%) after weeks of last spray**					
	3rd*	4th*	5th*	6th*	Mean	Disease control (%)
SA @ 50 ppm (T_1)	5.39 (13.36)	13.24 (21.18)	18.75 (25.62)	23.38 (28.87)	15.19 (22.26)	28.18
SA @ 75 ppm (T_2)	4.34 (11.97)	11.27 (19.50)	17.62 (24.75)	21.08 (27.24)	13.58 (20.86)	35.79
SA @ 100 ppm (T_3)	3.34 (10.35)	9.15 (17.43)	15.75 (23.20)	17.01 (24.14)	11.31 (18.78)	46.52
JA @ 55 ppm (T_4)	6.76 (16.13)	15.41 (21.94)	22.88 (29.79)	25.65 (29.12)	17.67 (24.25)	16.45
JA @ 110 ppm (T_5)	6.72 (14.95)	13.59 (21.60)	21.67 (27.65)	24.62 (29.71)	16.65 (23.48)	21.28
JA @ 165 ppm (T_6)	5.35 (13.33)	11.85 (20.08)	21.50 (27.58)	23.20 (28.70)	15.47 (22.43)	26.86
BABA @ 250 ppm (T_7)	4.22 (11.81)	11.40 (19.66)	18.39 (25.26)	22.40 (28.18)	14.10 (21.23)	33.33
BABA @ 500 ppm (T_8)	3.13 (10.10)	8.92 (17.27)	15.37 (22.92)	18.49 (25.33)	11.48 (18.90)	45.72
BABA @ 750 ppm (T_9)	1.92 (7.94)	6.72 (14.83)	12.72 (20.72)	16.41 (23.70)	9.44 (16.80)	55.37
KNO_3 @ 1% (T_{10})	6.66 (14.92)	13.99 (21.90)	21.93 (27.87)	25.20 (30.10)	16.94 (23.69)	19.91
KNO_3 @ 1.5% (T_{11})	5.19 (13.10)	11.12 (19.44)	18.94 (25.71)	21.90 (27.83)	14.29 (21.52)	32.43
KNO_3 @ 2% (T_{12})	4.27 (11.87)	9.98 (18.37)	16.39 (23.78)	20.78 (27.04)	12.86 (20.27)	39.20
Untreated control (T_{13})	8.25 (16.66)	16.60 (24.01)	25.94 (30.53)	33.81 (35.39)	21.15 (26.65)	-
Mean B	5.04 (12.81)	11.79 (19.79)	19.06 (25.80)	22.61 (28.10)		
Factors		CD* p<0.05	SEd±	SEm±		
Treatment		0.80	0.40	0.28		
Date of observation		0.44	0.22	0.15		
Treatment×Date of observation		1.60	0.81	0.57		

**Pooled data (2018 and 2019) of the same experiment conducted in two different seasons; *Figures in parentheses are angular transformed value

The highest number of siliquae plant^{-1} (311.18), maximum siliqua length (7.28 cm), highest number of seeds siliquae^{-1} (6.34), highest 1000 seed weight (17.19 g), highest seed yield g plot^{-1} (379.17 g) were recorded in the plots sprayed with 100 ppm SA followed by the plots sprayed with 2% KNO_3 and 1.5% KNO_3 respectively. The lowest number of siliquae plant^{-1} (272.94), minimum length of siliqua (6.26 cm), number of seeds siliquae^{-1} (5.30), lowest 1000 seed weight (16.70 g), and lowest seed yield (297.71 g) was observed in control.

The results of present investigation are supported by earlier workers in case of rapeseed (Yazdanpanah et al., 2015), Indian mustard (Sharma et al., 2013), soybean (Sharma and Kaur, 2003), bean (Amal and Amira, 2009), clover (Kumar et al., 2013) and grass pea (Sarkar and Malik, 2001) after foliar application of SA. All of them have observed a significant increase in number of pods, number of seeds pod^{-1}, seed weight upon foliar application of SA in their test crops.

They indicated that SA helped the plants to tolerate higher temperature, reduced physiological losses of pollinated flowers and increased photosynthetic efficiency of plants. Kumar et al. (2013) and Mohammed and Tarpley (2011) were of the opinion that the increase in translocation of photosynthates to the seeds after application of SA might have increased the 1000 seed weight as well as seed yield. Application of acetyl SA increased the chlorophyll contents in plants (Amal and Amira, 2009) which might have increased photosynthetic productivity resulting in increased length of siliquae.

The application of KNO_3 during flowering supplies N and K to the plants and this delays the synthesis of abscisic acid and promotes cytokinin activity which caused higher retention of chlorophyll (Brevadan and Hodges, 1973). The process may secure higher photosynthetic activity in effective leaves and supply developing pods with current photosynthates for proper filling, resulting in higher yield and number of siliqua. The prevalence of K^+ in KNO_3also improve phytomass production, due to increase in photosynthetic activity and effective translocation of assimilates to reproductive parts resulting in higher yield (Mengal, 1976). These mechanisms might be responsible formore number of siliquae plant^{-1}, siliqua length, number of seeds siliqua^{-1}, 1000 seed weight and seed yield in this study.

Table 2: Effect of foliar application of plant defence activators on seed yield parameters in radish cv. Japanese white

Treatment	No. of siliqua plant^{-1}	Siliqua length (cm)	No. of seeds siliqua^{-1}	1000 seed weight (g)	Seed yield plot^{-1} (g)
SA @ 50 ppm (T_1)	290.80	6.51	5.57	16.72	314.43
SA @ 75 ppm (T_2)	293.95	6.74	6.05	17.08	350.77
SA @100 ppm (T_3)	311.18	7.28	6.34	17.19	379.17
JA @ 55 ppm (T_4)	282.78	6.45	5.42	16.74	312.29
JA @ 110 ppm (T_5)	289.85	6.55	5.57	16.79	315.52
JA @ 165 ppm (T_6)	294.15	6.65	5.75	16.84	315.04
BABA @ 250 ppm (T_7)	284.63	6.68	5.73	16.85	334.29
BABA @ 500 ppm (T_8)	280.77	6.69	5.67	16.81	319.60
BABA @ 750 ppm (T_9)	279.36	6.52	5.63	16.77	304.21
KNO_3 @ 1% (T_{10})	290.33	6.68	5.70	16.87	308.51
KNO_3 @ 1.5% (T_{11})	294.95	6.71	5.94	16.91	331.41
KNO_3 @ 2% (T_{12})	304.78	7.15	6.23	17.13	352.72
Untreated control (T_{13})	272.94	6.26	5.30	16.70	297.71
SEm±					
CD (p<0.05)	2.74	0.13	0.07	0.14	8.97

*Pooled data (2018 and 2019) of the same experiment conducted in two different seasons

3.3. *Seed quality parameters*

The foliar application of plant defence activators not only reduced the alternaria blight and enhanced the seed yield but also improved the quality of seeds which resulted in higher germination %age, speed of germination, seed vigour index-mass and seed vigour index-length of harvested seed of radish seed crop as evident from the data presented in Table 3.

It is evident from the data in Table 3 that amongst different treatments, the values related to various seed quality parameters viz., seed germination (93.67%), speed of germination (91.91), seed vigour index-I (2252.83) and seed vigour index-II (1259.90) were observed highest in the seeds harvested from plots sprayed with 100 ppm SA. The values of seed quality parameters under these treatments were followed by that of 2% KNO_3 and 75 ppm SA with 92.78 and 91.53% seed germination, 90.92 and 87.54 speed of germination, 2197.11 and 2099.14 SVI-I and 1223.36 and 1138.60 SVI-II, respectively. The values regarding all the seed quality parameters were found lowest in the seed harvested from control plots.

Table 3: Effect of foliar application of plant defence activators on seed quality and vigour parameters in radish cv. Japanese White

Treatment	Seed germination (%)**	Speed of germination	Seed vigour index	
			SVI-1	SVI-2
SA @ 50 ppm (T_1)	89.91(9.51)	83.61	1,956.01	1,075.98
SA @ 75 ppm (T_2)	91.53(9.63)	87.54	2,099.14	1,138.60
SA @ 100 ppm (T_3)	93.67(9.74)	91.91	2,252.83	1,259.90
JA @ 55 ppm (T_4)	90.04(9.55)	81.60	1,835.68	1,054.79
JA @ 110 ppm (T_5)	89.91(9.54)	82.47	1,846.54	1,063.06
JA @ 165 ppm (T_6)	90.11(9.56)	84.41	1,954.04	1,095.90
BABA @ 250 ppm (T_7)	91.27(9.62)	85.57	2,026.97	1,163.98
BABA @ 500 ppm (T_8)	90.78(9.59)	84.68	2,017.86	1,137.88
BABA @ 750 ppm (T_9)	90.53(9.58)	82.80	1,921.20	1,094.61
KNO_3 @ 1% (T_{10})	90.41(9.57)	85.65	1,995.86	1,138.02

Table 3: Continue...

Treatment	Seed germination (%)**	Speed of germination	Seed vigour index	
			SVI-1	SVI-2
KNO_3 @ 1.5% (T_{11})	91.28(9.62)	86.69	2,075.97	1,167.18
KNO_3 @ 2% (T_{12})	92.78(9.69)	90.92	2,197.11	1,223.36
Untreated control (T_{13})	89.53(9.53)	80.25	1,773.37	997.06
SEm±				
CD (p<0.05)	0.05	2.83	65.92	56.62

*Pooled data (2018 and 2019) of the same experiment conducted in two different seasons; **Figures in parentheses are square root transformed values

SA application promote seed quality and vigour by activating the biosynthesis of various enzymes involved in the metabolic pathways of glycolysis, the glyoxylate cycle, the pentose phosphate pathway, and gluconeogenesis which suggests that SA promote the establishment of vigorous seedling from quiescence state of seed (Rajjou et al., 2006).

Kuchlan et al. (2017) has already reported that application of SA significantly increased seed quality parameters in soybean. Application of KNO_3 @ 2% also improved seed germination, speed of germination and seed vigour indices. As mentioned earlier, the prevalence of K^+ in KNO_3, improved phytomass production by increasing the physiological activities and effective assimilate transportation to reproductive parts and thereby improving the quality of seed (Mengel, 1976). KNO_3 application also resulted in increased 1000 seed weight as discussed earlier and this increase in seed weight also increased seed quality and vigour (Cordazzo, 2002). More the seed weight higher is seedling length, seedling dry weight (Moshatati and Gharineh, 2012). The higher accumulation of photosynthates and effective absorption of N and K as anion and cation in treated plants resulted in delayed abscisic acid synthesis and promoted activity of cytokine in leading to higher retention of chlorophyll (Brevadan and Hodges, 1973). This might have increased photosynthetic activity in effective leaves and supplied developing pods with current photosynthates for proper filling; resulting in more assimilates in seeds.

4. CONCLUSION

Foliar application of defencesalicylic acid @ 100 ppm or potassium nitrate @ 2% at three stages i.e. seed stalk initiation, 50% flowering and pod development were found effective in reducing the severity of alternaria blight (up to 46% and 39%, respectively) and increasing the seed yield (up to 27% and 18%, respectively) and various seed quality parameters in radish seed crop cv. Japanese white.

5. REFERENCES

Abdala, G., Castro, G., Guinazu, M., Tizio, R., Miersch, O., 1996. Occurrence of jasmonic acid in organs of *Solanum tuberosum* L. and its effect on tuberization. Plant Growth Regulation 19, 139–143.

Abdul-Baki, A.A., Anderson, J.D., 1973. Vigor determination in soybean seed by multiple criteria. Crop Science 13(6), 630–633.

Altamiranda, E.A.G., Andreu, A.B., Daleo, G.R., Olivieri, F.P., 2008. Effect of b-aminobutyric acid (BABA) on protection against *Phytophthora infestans* throughout the potato crop cycle. Australasian Plant Pathology 37, 421–427.

Ari, Y., Sam, F., Siddiqui, H., Bajguz, A., Hayat, S., 2020. Salicylic acid in relation to other phytohormones in plant: A study towards physiology and signal transduction under challenging environment. Environmental and Experimental Botany 175, 104040. DOI: 10.1016/j.envexpbot.2020.104040.

El-Shraiy, A., Hegazi, A., 2009. Effect of acetylsalicylic acid, indole-3- bytric acid and gibberellic acid on plant growth and yield of pea (*Pisum sativum* L.). Australian Journal of Basic and Applied Sciences 3(4), 3514–3523.

Anonymous, 2017. Annual Report of National Horticulture Board (2016-17), Gurgaon, Haryana. Available from: https://www.nhb.gov.in on 29.03.2024. Accessed on May 2021.

Asghari, M., 2019. Impact of jasmonates on safety, productivity and physiology of food crops. Trends in Food Science & Technology 91, 169–183. DOI: https://doi.org/10.1016/j.tifs.2019.07.005.

Bardhan, K., Kumar, V., Dhimmsar, S.K., 2007. An evaluation of the potentiality of exogenous osmoprotectants mitigating water stress on chickpea. Journal of Agricultural Sciences 3(2), 67–74.

Boonyaritthongchai, P., Supapvanich, S., 2017. Effects of methyl jasmonate on physicochemical qualities and internal browning of 'Queen' pineapple fruit during cold storage. Horticultural and Environmental Biotechnology 58, 479–487. DOI: https://DOI.org/10.1007/s1358 0-017-0362-3.

Brevadan, E.R., Hodges, M.F., 1973. Effect of moisture deficit on 14C translocation in corn (*Zea mays* L.). Plant Physiology 52(5), 436–439.

Cohen, Y., 1994b. 3-Aminobutyric acid induces systemic resistance against *Peronospora tabacina*. Physiology and Molecular Plant Pathology 44(4), 273–288.

Conrath, U., 2006. Priming: getting ready for battle. Molecular Plant-Microbe Interaction 19(10), 1062–1071.

Cordazzo, C.V., 2002. Effect of seed mass on germination and growth three dominant species in Southern Brazilian coastal dunes. Brazilian Journal of Biology 62(3), 427–435.

Dempsey, D.A., Klessig, F., 2017. How does the multifaceted plant hormone salicylic acid combat disease in plants and are similar mechanisms utilized in humans? BMC Biology 15(23), 1–11.

Gupta, S.K., Thind, T.S., 2006. Disease problems in vegetable production (2nd Edn.). Scientific Publication (India), Jodhpur. 576p.

Hashempour, A., Ghasemzhad, M., Fotouhi, G., Sohani, M.M., 2014. The physiological and biochemical response to freezing stress olive plants treated with salicylic acid. Russian Journal of Plant Physiology 61(4), 443–450.

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

Hepler, P.K., Vidali, L., Cheung, A.Y., 2001. Polarized cell growth in higher plants. Annual Reviews of Cell and Developmental Biology 17, 159–187.

Hu, W., Nan, J., Yang, J., Meng, Y., Wang, Y., Chen, B., Wenqing, Z., Oosterhuis, D.M., Zhao, Z., 2016. Potassium (K) supply affects K accumulation and photosynthetic physiology in two cotton (*Gossypium hirsutum* L.) cultivars with different K sensitivities. Field Crop Research 196, 51–63.

Hwang, B.K., Sunwoo, J.Y., Kim, Y.J., Kim, B.S., 1997. Accumulation of b-1,3-glucanase and chitinase isoforms, and salicylic acid in the DL-bamino-n-butyric acid-induced resistance response of pepper stems to *Phytophthora capsici*. Physiology and Molecular Plant Pathology 51, 305–322.

Jones, J.D., Dangl, J.L., 2016. The plant immune system. Nature 444(7117), 323–329.

Kaiser, W.M., 1982. Correlation between changes in photosynthetic activity and changes in total protoplast volume in leaf tissue from hygro-meso-and xerophytes under osmotic stress. Planta 154(6), 538–545.

Kuchlan, P., Kuchlan, M.K., Husain, S.M., 2017. Effect of foliar application of growth activator, promoter and antioxidant on seed quality of soybean. Legume Research 40(2), 313–318.

Kumar, B., Singh, Y., Ram, H., Sarlach, R.S., 2013. Enhancing seed yield and quality of Egyptian clover (*Trifolium alexandrinum* L.) with foliar application of bio-regulators. Field Crops Research 146, 25–30.

Li, A., Sun, X., Liu L., 2022. Action of salicylic acid on plant growth. Frontiers in Plant Sciences 13, 1–7. DOI: 10.3389/fpls.2022.878076.

Marschner, P., 2012. Marschner's mineral nutrition of higher plants (3rd Edn.). Academic Press: London, UK, pp. 178–189.

Mazzoni-Putman, S.M., Brumos, J., Zhao, C., Alonso, J.M., Stepanova, N.A., 2021. Auxin interactions with other hormones in plant development. Cold Spring Harbor Perspectives in Biology 13, a039990. DOI: 10.1101/cshperspect.a039990.

Mengal, K., 1976. Potassium in plant physiology and yield formation. Indian Society of Soil Science Bulletin 10, 23–40.

Meyer, A., Miersch, O., Biittner, C., Dathe, W., Sembdner, G., 1984. Occurrence of the plant growth regulator jasmonic acid in plants. Journal of Plant Growth Regulation 3, 1–8.

Miura, K., Tada, Y., 2014. Regulation of water, salinity, and cold stress responses by salicylic acid. Journal of Plant Science 5, 410.

Mohammed, A.R., Tarpley, L., 2011. Characterization of rice (*Oryza sativa* L.) physiological responses to α-Tocopherol, glycine betaine or salicylic acid application. Journal of Agriculture Science 3(1), 3–13.

Moshatati, A., Gharineh, M.H., 2012. Effect of grain weight on germination and seed vigour of wheat. International Journal of Agriculture and Crop Sciences 4(8), 458–460.

Oosterhuis, D., Loka, D., Kawakami, E., Pettigrew, W., 2014. The physiology of potassium in crop production. Advances in Agronomy 126, 203–234.

Pokotylo, I., Hodges, M., Kravets, V., Ruelland, E., 2021. A ménage à trois: salicylic acid, growth inhibition, and immunity. Trends in Plant Sciences 27(5), 460–471. DOI: 10.1016/j.tplants.2021.11.008.

Rajjou, L., Belghazi, M., Huguet, R., Robin, C., Moreau, A., Job, C., Job, D., 2006. Proteomic investigation of the effect of salicylic acid on Arabidopsis seed germination and establishment of early defence mechanisms. Plant Physiology 141(3), 910–923.

Reyes-Diaz, M., Lobos, T., Cardemil, L., Nunes-Nesi, A., Retamales, J., Jaakola, L., Albedri, M., Ribera-Fonseca, A., 2016. Methyl jasmonate: an alternative for improving the quality and health properties of fresh fruits. Molecules 21(6), 567. DOI: 10.3390/molecules21060567.

Sarkar, R.K., Malik, G.C., 2001. Effect of foliar spray of potassium nitrate and calcium nitrate on grasspea (*Lathyrus sativus* L.) grown in rice fallows. Lathyrus Lathyrism Newsletter 2, 47–48.

Sasek, V., Novakova, M., Dobrev, P.I., Valentova, O., Burketova, L., 2011. b-Aminobutyric acid protects Brassica napus plants from infection by *Leptosphaeria maculans*. Resistance induction or a direct antifungal effect? European Journal of Plant Pathology 133, 279–289. DOI:10.1007/s10658-011-9897-9.

Sharma, K., Kaur, S., 2003. Effect of salicylic acid, caffeic acid and light intensity on yield and yield contributing parameters in soybean. Journal of Ecology and Environment 21(2), 332–335.

Sharma, P., Sardana, V., Banga, S.S., 2013. Effect of salicylic acid on growth and seed filling in indian mustard (*Brassica juncea* L.) under high temperature stress. Vegetos 26(1), 243–248.

Sreedhara, H.S., Nandini, B.A., Shetty, S.A., Shetty, H.S., 1995. Peroxidase activities in the pathogenesis of *Sclerospora graminicola* in pearl millet seedlings. International Journal of Tropical Plant Disease 13, 19–32.

Ton, J., Mauch-Mani, B., 2004. Beta-amino-butyric acid-induced resistance against necrotrophic pathogens is based on ABA-dependent priming for callose. The Plant Journal 38(1), 119–130.

Walters, D., Walsh, D., Newton, A., Lyon, G., 2005. Induced resistance for plant disease control: maximizing the efficacy of resistance elicitors. Phytopathology 95(12), 1368–1373.

Wang, M., Zheng, Q., Shen, Q., Guo, S., 2013. The critical role of potassium in plant stress response. International Journal of Molecular Science 14(4), 7370–7390.

Wang, Y., Mostafa, S., Zeng, W., Jin, B., 2021. Function and mechanism of jasmonic acid in plant responses to abiotic and biotic stresses. International Journal of Molecular Sciences 22(16), 8568. DOI: 10.3390/ijms22168568.

White, P.J., Karley, A.J., 2010. Potassium cell biology of metals and nutrients. Berlin: Springer, 199–224.

Yazdanpanah, M., Maki, H., Bakhtiari, I., Goorkhorram, H., Samadi, A., 2015. Effect of salicylic acid, nano-iron chelate and pseudomonas on quality and quantity of rapeseed yield. Journal of Biodiversity and Environmental Sciences 6(1), 310–317.

Zhang, Y.L., Li, X., 2019. Salicylic acid: biosynthesis, perception, and contributions to plant immunity. Current Opinion in Plant Biology 50, 29–36. DOI: 10.1016/j.pbi.2019.02.004.

Zhang, Y., Zhao, L., Zhao, J., Li, Y., Wang, J., Guo, R., Gan, S., Liu, C.J., Zhang, K., 2017. S5H/DMR6 encodes a salicylic acid 5-hydroxylase that fine tunes salicylic acid homeostasis. Plant Physiology 175(3), 1082–1093.