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Harnessing Organic Defence Inducers (SA, BTH, CHITOSAN) for Effective Management of *Fusarium* Wilt in Lentil

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ABSTRACT

Background: Lentil (*Lens culinaris* Medik.) is a crucial pulse crop globally, valued for its nutritious seeds but significantly affected by Fusarium wilt caused by *Fusarium oxysporum f.sp. lentis*. Traditional management often relies on synthetic fungicides, which can harm the environment. This study explores the potential of organic defense inducers *viz;* salicylic acid (SA), benzothiadiazole (BTH) and chitosan (Cs) in managing Fusarium wilt sustainably.

Methods: The effects of these inducers were tested at concentrations of 100 ppm, 500 ppm and 1000 ppm on lentil plants, focusing on defense enzyme activity, disease incidence and yield.

Result: Results showed that the application of these inducers significantly reduced disease incidence and increased yield under field conditions. Notably, enzyme activities of phenylalanine ammonia-lyase (PAL), polyphenol oxidase (PPO), peroxidase (PO) and catalase increased substantially. PAL, PPO and PO showing a 10 to 12-fold increase 24 hours post-inoculation and Catalase, 48 hours after inoculation. The most effective inducer found was SA at a concentration of 1000ppm followed by BTH and Chitosan. These findings suggested that organic defense inducers effectively enhance the resistance of lentil plants to Fusarium wilt by promoting systemic acquired resistance (SAR), offering a sustainable approach to crop protection and improved yields.

Key words: Benzothiadiazole (BTH), Chitosan (Cs), Lentil, Salicylic acid (SA), SAR, Wilt.

INTRODUCTION

Fusarium oxysporum f.sp. *lentis* is one of the fungal and bacterial pathogens those affect lentil (Arya *et al*., 2021; Arya *et al*., 2022). Plants possess the capacity to elicit systemic defence responses, including induced systemic resistance (ISR) (Yadav *et al.,* 2023a and b; Arya and Yadav, 2025) and systemic acquired resistance (SAR), in addition to local defence responses. Induced systemic resistance (ISR) is commonly triggered by the colonization of beneficial bacteria on the roots, as discussed by Van Wees *et al.,* (2008). On the other hand, systemic acquired resistance (SAR) is induced as a response to pathogen infection, as explained by Kachroo and Robin (2013). Systemic tissues of the plant develop a broad and enduring resistance to secondary pathogens through SAR, which is triggered by localized infection from the primary pathogen. Furthermore, the transmission of SAR to future generations can occur through alterations in the chromatin structure, as demonstrated by Luna *et al.* (2012) and Slaughter *et al.* (2012). The unique advantages of SAR make it highly desirable in agricultural production. According to Chaturvedi *et al.* (2012), SAR initiates within 4-6 hours of primary infection through the generation of mobile signals at the site of local infection. The signals are then transported to the systemic tissues, most likely through the phloem, where they initiate the defense response. Several chemical substances, such as salicylic acid (SA) and its methylated derivative MeSA (Gao *et al.,* 2014), as well as Chitosan (Kim *et al.,* 2005), have the ability to generate SAR.

Salicylic acid is a well-known organic compound that has been found to induce resistance in various plants against fungal, bacterial and viral pathogens. SA is not only essential for pathogen-induced SAR, but it is also necessary for the activation of SAR by chemical inducers in backgrounds without SA (Kuchlan and Kuchlan, 2023). Chitosan is a linear polymer composed of β-(1,4)-glucosamine. It is formed by deacetylating chitin and serves as a vital structural component in plant and fungal cell walls. Chitosan is widely recognized as an elicitor (Radman *et al.,* 2003). According to Vander *et al.* (1998), chitosan has been found to effectively stimulate various plant defence mechanisms, such as the synthesis of phytoalexins, PIs, lignin deposition, phenylalanine ammonia lyase (PAL) and peroxidase (POD) (Laxman *et al.,*

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2022). External treatments using salicylic acid (SA) or its chemical analogue benzothiadiazole (BTH) have been found to induce systemic acquired resistance (SAR) (Fu and Dong, 2013). In a recent study by Friedrich *et al.* (1996), CGA 245704, also referred to as benzothiadiazole (BTH), was found to effectively induce systemic acquired resistance (SAR). This induction of SAR by BTH offers protection against a broad range of plant pathogens. In their initial research, Benhamou and Belange (1998) conducted histological studies on the pathogen *F. oxysporum* f.sp. *radicis-lycopersici* after applying BTH, they observed that it sensitized the plant to the pathogen. This led to the deposition of callose, which inhibited the invasion of the pathogen in the roots of tomato plants. In a study conducted by El-Hassni *et al.* (2004), chitosan was found to be an effective inducer of PPO and PAL, which are defense-related enzymes (Pandey *et al.,* 2024). The researchers observed this effect in the roots of date palm trees when they were exposed to *Fusarium oxysporum*. The results showed a noteworthy reduction in disease incidence when the seed treatment with elicitors was done. The study concluded that salicylic acid demonstrated superiority over other treatment. The objective of this study was to investigate the impact of SA, BTH and chitosan on lentil defense mechanism against *Fusarium oxypsorum* f.sp. *lentis*.

MATERIALS AND METHODS

The study was conducted at Govind Ballabh Pant University of Agriculture and Technology in Pantnagar, Udham Singh Nagar, Uttarakhand, over a two-year period from 2017 to 2019 under in vitro and in vivo conditions (29°0′43″N, 79°28′58″E, 243.8 M a.s.l). Three novel products, namely Salicylic Acid (SA), BTH and Chitosan (CS), were tested at different concentrations to assess their defense-inducing properties against the pathogen along with the mock control (MC) (where after spray of the inducer inoculation with distil water was done) and Control (Co) (where no treatment was done except pathogen inoculation). The concentrations used included 100 ppm, 500 ppm and 1000 ppm. The *in vivo* study included the impact of products on the disease incidence and yield of the crop, besides the study under *in vitro* conditions involved the exploration of the enzymatic activity (PAL, PO, PPO, Catalase) for induction of defense mechanism in plants against the pathogen.

Study under the polyhouse

Under the *in vitro* conditions the susceptible lentil variety - L-9-12 were sown in the pots maintaining the 30 plants in each pot contained sterilized soil. At 25 days after sowing (DAS), the plants underwent sprays with the inducers at different concentration (100, 500 and 1000 ppm) while maintain the three replications for each treatment with a different concentration. After a 24-hour period, they were subjected to a test involving the inoculation of the pathogens in the pot soil with a maize sand medium (up to 10^7 microconidia per gram of soil). The root samples were taken before the pathogen inoculation selecting 5 plants and at 24 hours intervals (24, 36, 72 and 96 hour) after the pathogen inoculation to test the activity of enzymes, including PAL, PO, PPO and catalase using the methods described below and the statistical analysis was conducted using the R software to assess the significance of effect differences between the treatments and their controls. The pair wise comparison Duncan test was performed, with a significance level set at $p<0.05$.

Preparation for extraction

The root samples, which had been treated and challenge inoculated with a pathogen, were collected separately (5 plants from each pot and from each replication) and promptly homogenized in a pestle and mortar using extraction buffers (Sodium phosphate, Potassium phosphate and methanol) at 4°C, in line with the enzyme being assessed. Performing centrifugation on the extracted material for a duration of 20 minutes at a speed of 10,000 revolutions per minute. The liquid is transferred to a new tube for the purpose of analyzing different enzymes.

Phenylalanine ammonia lyase activity (PAL activity) assay

The enzyme extract was prepared by homogenizing 1 g of root samples in 2 ml of 0.1 M Sodium Phosphate buffer (pH 7.0) at 4°C, following the procedure outlined by Whetten and Sederoff (1992). Following this step, the extract was placed into a centrifuge tube and spun at a speed of 10,000 rpm for a duration of 20 minutes. To prepare the test mixture, the following components were used: 500 ml of Tris HCl (pH 8.8) at a concentration of 50 mM, 600 µl of L-phenylalanine at a concentration of 1 mM and 100 µl of the separated supernatant as enzyme extracts. The assay mixture was incubated at a temperature of 30°C for a duration of 1 hour. The process was halted by adding 0.5 ml of 2N HCl. The PAL activity, expressed as ΔO.D./min/g of fresh tissue, was determined by measuring the rate of L-phenylalanine conversion to transcinnamic acid using a spectrophotometer.

An analysis of catalase activity

The catalase activity was measured spectrophotometrically using the method described by Dhindsa *et al.,* (1981). The root sample, weighing one gram, was mixed with a standard extraction buffer and then subjected to centrifugation at 10,000 rpm for 20 minutes to produce the crude extract. To create the reaction mixture, 100 µl of enzyme extract, 50 mM phosphate buffer (pH 7.0) and 15 mM hydrogen peroxide were combined, resulting in a final volume of 2 ml. The measurement of catalase activity was conducted by determining the rate of decrease in absorbance at 415 nm as hydrogen peroxide decomposed, expressed as A415/min/g of fresh tissue.

Peroxidase activity assay

The assessment of PO activity was conducted following the method described by Hammerschmidt *et al.* (1982).

The enzyme extract was prepared by homogenizing 1 g of root sample in 1ml of 0.1M sodium phosphate buffer (pH 6.5) at 4°C. The resulting mixture was then subjected to centrifugation at 10,000 rpm for 20 minutes to obtain the crude extract. A 2ml enzyme assay was prepared using Guaiacol and 1 percent hydrogen peroxide, utilizing the supernatant. The results were subsequently expressed as the optical density per minute per gram of fresh tissue, following measurement of the absorbance at 420 nm.

An analysis to measure the activity of polyphenol oxidase (PPO)

The assessment of PPO activity was conducted using the method outlined by Mayer *et al.,* (1965). The crude extract was prepared by mixing 1 ml of 0.1 M sodium phosphate buffer (pH 6.8) at 4°C and then centrifuging it for 20 minutes at 10,000 rpm. The reaction was initiated by combining 1.5 ml of enzyme extract with 0.2 ml of 0.01 M Catechol in the reaction mixture. The findings are displayed as the alteration in O.D./min/g of fresh tissue at 495 nm.

Experimental study in the field

The randomized block design was used to sow and maintain the susceptible lentil variety (L-9-12 variety) in a pathogen sick plot (10^7 Microconidia/g of soil) of size 12 meter square. The study was consecutively conducted over two years. Three replications, along with the control and mock control were maintained in the field. To examine the impact of these inducers on disease and crop health, the data was collected on disease incidence and yield. The incidence of Wilt disease was also recorded using the following formula.

$$\text{Wilt incidence (\%)} = \frac{\text{Number of infected plants}}{\text{Total number of plant observed}} \times 100$$

Three sprays of the products were conducted at intervals of 30 days after sowing (DAS), 60 DAS and 90 DAS. Subsequently, data on disease incidence was gathered seven days following the final application. The details of the treatment are outlined below.

Treatment 1: Involved spray with SA at a concentration of 500 ppm at different intervals (30 DAS, 60 DAS, 90 DAS).

Treatment 2: Involved spray with SA at a concentration of 1000 ppm at different intervals (30 DAS, 60 DAS, 90 DAS).

Treatment 3: Involved spray with BTH at a concentration of 500 ppm at different intervals (30 DAS, 60 DAS, 90 DAS).

Treatment 4: Involved spray with BTH at a concentration of 1000 ppm at different intervals (30 DAS, 60 DAS, 90 DAS).

Treatment 5: Involved spray with chitosan at a concentration of 500 ppm at different intervals (30 DAS, 60 DAS, 90 DAS).

Treatment 6: Involved spray with chitosan at a concentration of 1000 ppm at different intervals (30 DAS, 60 DAS, 90 DAS).

Treatment 7: No spray was administered; Control.

Treatment 8: Spray with distilled water; Mock control at different intervals (30 DAS, 60 DAS, 90 DAS).

RESULTS AND DISCUSSION

Enzymatic activities

PAL (Phenylalanine Ammonia-Lyase) (Table 1), PO (Polyphenol Oxidase) (Table 2), PPO (Polyphenol Oxidase) (Table 3) and catalase (Table 4) activities were significantly influenced by various treatments, doses and time points. PAL activity was highest in plants treated with salicylic acid (SA) across all doses and time points, particularly at 1000 ppm concentration, followed by benzothiadiazole (BTH), Chitosan, Mock control and Control, which displayed consistently lower activities. PO activity also peaked with SA treatment, demonstrating a clear dose-dependent increase, while BTH and Chitosan exhibited moderate levels and Mock control and Conttrol showed minimal activity. For PPO, SA at 1000 ppm concentration yielded the highest activity at initial time points, while other showed moderate effectiveness. Lastly, catalase activity was maximized with SA at 1000 ppm, outperforming BTH and Chitosan. Overall, higher doses generally enhanced enzyme activities across treatments, with SA consistently leading in efficacy for all enzymatic activities. The results of this study demonstrated that the application of organic defense inducers, particularly salicylic acid (SA) and benzothiadiazole (BTH), significantly enhances the activity of defense enzymes such as phenylalanine ammonia-lyase (PAL), polyphenol oxidase (PO), peroxidase (PPO) and catalase in lentil plants. The observed increase in PAL activity across various treatments and doses aligns with previous findings that highlight the role of PAL in plant defense mechanisms against pathogens (Keinänen *et al.,* 2001). Specifically, SA treatment consistently yielded the highest PAL activity, indicating its effectiveness in promoting systemic acquired resistance (SAR) and enhancing the plant's ability to combat Fusarium wilt caused by *Fusarium oxysporum f.sp. lentis*. The results also indicate that higher doses of SA lead to increased enzyme activity, corroborating studies that demonstrate a positive correlation between SA concentration and PAL activity (Zhong *et al.,* 2024). This is particularly important as PAL is a key enzyme in the phenylpropanoid pathway, which produces various secondary metabolites that contribute to plant defense (Alon *et al.,* 2013). The significant increase in PO activity with SA treatment further supports the notion that SA not only activates PAL but also enhances other defense-related pathways, as noted in previous research highlighting the interconnectedness of these enzymatic activities in plant defense responses.

Disease incidence and yield under field conditions

The comparison of disease incidence and yield across various chemical treatments over the years 2017-18 and

Table 1: Effect of defence inducers on PAL, activity against wilt disease of lentil at different intervals after challenge inoculation.

Treatments	PAL (Δ O.D./min/g of fresh tissue)														
	Doses														
	100 ppm					500 ppm					1000 ppm				
	pre	24 h	48 h	72 h	96 h	pre	24 h	48 h	72 h	96 h	pre	24 h	48 h	72 h	96 h
SA	0.19z	3.85d	1.65l	1.10q	0.55v	0.31xy	4.27c	1.83k	1.22p	0.61uv	0.34xy	5.04a	2.16i	1.44m	0.72s
BTH	0.09AB	2.52g	1.08q	0.72s	0.36x	0.17z	3.08f	1.32no	0.88r	0.44w	0.27y	3.22e	1.38mn	0.92r	0.46w
CH	0.06B	1.05q	0.45w	0.30xy	0.15za	0.17z	2.45h	0.45w	0.70st	0.35x	0.29xy	4.48b	1.92j	1.28op	0.64tu
MC	0.05B	0.07B	0.07B	0.07B	0.07B	0.07B	0.07B	0.07B	0.07B	0.07B	0.07B	0.07B	0.07B	0.07B	0.07B
Co	0.02B	0.02B	0.02B	0.02B	0.02B	0.02B	0.02B	0.02B	0.02B	0.02B	0.02B	0.02B	0.02B	0.02B	0.02B
SEM	A: 0.008	B:0.005	C:0.006	AB: 0.014	AC:0.018	BC:0.011	ABC:0.045								
LSD (p≤0.05)	Factor A: <2.2e-16	Factor B: <2.2e-16	Factor C: <2.2e-16	Factor A×B: <2.2e-16	Factor B×C: <2.2e-16	Factor A×C: <2.2e-16	Factor A×B×C: <2.2e-16								

Different letters indicate significant differences at *P*<0.05 according to the Duncan's multiple range tests.

Table 2: Effect of defence inducers on PO activity against wilt disease of lentil at different intervals after challenge inoculation.

Treatments	PO activity (ΔO.D./min/g of fresh tissue)														
	Doses														
	100 ppm					500 ppm					1000 ppm				
	pre	24 h	48 h	72 h	9 6h	pre	24 h	48 h	72 h	96 h	pre	24 h	48 h	72 h	96 h
SA	0.21BC	2.94c	1.62j	0.95qr	0.63vw	0.23B	3.22b	1.84i	0.98pq	0.69v	0.31A	4.34a	2.48e	1.22m	0.93qrs
BTH	0.14DE	1.96h	1.12m	0.89rst	0.42z	0.17BCDE	2.38f	1.36l	0.94qrs	0.51xy	0.19BCD	2.66d	1.52k	1.09no	0.57wx
CH	0.10EF	1.47k	0.84t	0.77u	0.31A	0.13DE	1.82i	1.04op	0.88st	0.39z	0.15CDE	2.100g	1.20m	1.04op	0.45yz
MC	0.05FG	0.50FG	0.50FG	0.50FG	0.50FG	0.50FG	0.50FG	0.50FG	0.50FG	0.50FG	0.50FG	0.50FG	0.50FG	0.50FG	0.50FG
Co	0.02G	0.02G	0.02G	0.02G	0.02G	0.02G	0.02G	0.02G	0.02G	0.02G	0.02G	0.02G	0.02G	0.02G	0.02G
SEM	A: 0.007	B:0.004	C:0.006	AB: 0.012	AC:0.016	BC:0.01	ABC:0.028								
LSD (p≤0.05)	Factor A: <2.2e-16	Factor B: <2.2e-16	Factor C: <2.2e-16	Factor A×B: <2.2e-16	Factor B×C: <2.2e-16	Factor A×B×C: <2.2e-16									

Different letters indicate significant differences at *P*<0.05 according to the Duncan's multiple range tests.

Table 3: Effect of defence inducers on PPO activity against wilt disease of lentil at different intervals after challenge inoculation.

Treatments	PPO activity (ΔO.D./min/g of fresh tissue)														
	Doses														
	100 ppm					500 ppm					1000 ppm				
	pre	24 h	48 h	72h	96 h	pre	24 h	48 h	72 h	96 h	pre	24 h	48 h	72 h	96 h
SA	0.09ABC	1.35h	0.90k	0.36q	0.13wxz	0.19uv	2.85b	1.90e	0.76l	0.28s	0.22tu	0.60n	2.20d	0.88k	0.33qr
BTH	0.04DEF	3.30a	0.40p	0.16vwx	0.07BCD	0.11yzAB	1.65f	1.10i	0.42o	0.16vw	0.15wxyz	0.45o	1.50g	0.60n	0.22tu
CH	0.02EF	2.25c	0.30rs	0.12xyzA	0.045CDEF	0.06CDE	0.90k	0.60n	0.24t	0.08ABC	0.07BCD	1.05j	0.70m	0.28s	0.10zAB
MC	0.01EF	0.05CDEF	0.05CDEF	0.05CDEF	0.05CDEF	0.05CDEF	0.05CDEF	0.05CDEF	0.05CDEF	0.05CDEF	0.05CDEF	0.05CDEF	0.05CDEF	0.05CDEF	0.05CDEF
Co	0.011F	0.02EF	0.02EF	0.02EF	0.02EF	0.02EF	0.02EF	0.02EF	0.02EF	0.02EF	0.02EF	0.02EF	0.02EF	0.02EF	0.02EF
SEM	A: 0.004	B:0.003	C:0.003	AB: 0.008	AC:0.01	BC:0.006	ABC:0.017								
LSD	Factor A:	Factor B	Factor C:	Factor	Factor	Factor									
(p≤0.05)	<2.2e-16	<2.2e-16	<2.2e-16	A×B:	B×C:	A×C:									
				<2.2e-16	< 2.2e-16	<2.2e-16									

Different letters indicate significant differences at *P*<0.05 according to the Duncan's multiple range tests.

Table 4: Effect of defence inducers on Catalase activity against wilt disease of lentil at different intervals after challenge inoculation.

Treatments	Catalase activity (Δa415/min/g of fresh tissue)														
	Doses														
	100 ppm					500 ppm					1000 ppm				
	pre	24 h	48 h	72 h	96 h	pre	24 h	48 h	72 h	96 h	pre	24 h	48 h	72 h	96 h
SA	0.05y	0.98o	3.50f	1.65j	0.27rstu	0.09wxy	1.08n	5.40c	1.79i	0.035rst	0.12wxy	1.44k	7.20a	1.94h	0.36r
BTH	0.02y	0.36r	1.80i	1.19lm	0.18uvw	0.07y	0.84p	4.20e	1.23l	0.22tuv	0.09wxy	1.08n	5.40c	1.36k	0.23stuv
CH	0.03y	0.48q	2.40g	1.12mn	0.07y	0.08wxy	0.96o	4.80d	0.22tuv	0.17vwx	0.10wxy	1.20lm	6.00b	0.31rst	0.32rs
MC	0.02y	0.05y	0.05y	0.05y	0.05y	0.05y	0.05y	0.05y	0.05y	0.05y	0.05y	0.05y	0.05y	0.05y	0.05y
Co	0.01y	0.02y	0.02y	0.02y	0.02y	0.02y	0.02y	0.02y	0.02y	0.02y	0.02y	0.02y	0.02y	0.02y	0.02y
SEM	A: 0.01	B:0.006	C:0.008	AB: 0.018	AC:0.023	BC:0.014	ABC:0.04								
LSD	Factor A	Factor B	Factor C	Factor	Factor	Factor	Factor								
(p≤0.05)	<2.2e-16	<2.2e-16	<2.2e-16	A×B:	B×C:	A×C:	A×B×C:								
				<2.2e-16	<2.2e-16	< 2.2e-16	<2.2e-16								

Different letters indicate significant differences at *P*<0.05 according to the Duncan's multiple range tests.

Table 5: Evaluation of spray with defense inducers for the management of lentil wilt pathogen *Fusarium oxysporum* f.sp. *lentis* during 2017-18 and 2018-19 under field conditions and its impact on yield.

Treatments/ year	Disesae incidence				Yield			
	Doses						Doses	
	500 ppm		1000 ppm		500 ppm		1000 ppm	
	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19
SA	5.72g	6.92f	2.12k	4.37i	14.35b	6.15h	17.85a	10.56e
BTH	6.92f	7.22f	3.42j	5.08d	9.64f	7.48g	13.64c	5.56i
Cs	14.78d	17.13c	4.97h	8.72e	3.89jk	4.00jk	12.34d	4.23j
MC	21.36b	21.00b	22b	21.48b	6.00g	6.3g	3.00k	4.00k
Co	21.39b	21.99b	23.27a	23.00a	2.54jk	3.9jk	3.72k	3.99k
SEM	A:0.065	B:0.056			A: 0.076	B:0.046		
LSD	Factor A:	Factor B:	Factor C:	Factor A:	Factor B:	Factor C:		
($p \leq 0.05$)	<2.2e-16	2.2e-16	2.2e-16	<2.2e-16	<2.2e-16	<2.2e-16		

Different letters indicate significant differences at $P<0.05$ according to the Duncan's multiple range tests.
*Values for disease incidence are the transformed values.

2018-19 reveals significant insights into their effectiveness (Table 5). In comparing the treatments based on disease incidence and yield, Salicylic Acid (SA) and Benzothiadiazole (BTH) demonstrate a notable reduction in disease incidence at higher doses (1000 ppm), with SA showing a significant yield increase from 14.35 to 17.85, despite a decrease in disease incidence. Chitosan (Cs) also effectively reduces disease incidence at 1000 ppm, leading to a substantial yield increase from 3.89 to 12.3, although its initial yield was low. In contrast, Mock control (MC) and control (Co) maintain high disease incidences with minimal yield improvements across both doses. SA stands out as the most effective treatment in controlling disease while maintaining high yields followed by BTH, Chitosan, whereas MC and Co show less effectiveness in both disease control and yield enhancement across the doses tested.

The study conducted by Jabnoun-Khiareddine *et al.* (2016), demonstrated that both chitosan and salicylic acid exhibit significant antifungal activity against various tomato phytopathogenic fungi, including *Fusarium oxysporum*, *Verticillium dahliae*. In terms of disease management, the reduction in disease incidence observed with SA application is consistent with its role in activating defense responses. The lowest disease incidence was recorded at a 1000 ppm concentration of SA, which aligns with findings from other studies indicating that SAR activators can effectively reduce pathogen susceptibility. The yield improvements associated with higher doses of SA further emphasize its potential as a sustainable solution for enhancing lentil production while managing disease. This supports earlier findings that combinations of SAR activators can lead to enhanced resistance and improved crop performance. In conclusion, this study highlights the efficacy of organic defense inducers like salicylic acid and benzothiadiazole in enhancing enzyme activities and reducing disease incidence in lentil crops. The findings suggest that these treatments can be integrated into sustainable agricultural practices to improve lentil production while minimizing reliance on synthetic fungicides.

CONCLUSION

Ensuring food security in all nations necessitates the implementation and upkeep of sustainable agricultural practices. Only a limited amount of research has been conducted on the efficacy of these substances in combating soil-borne diseases. Studying the molecular basis of resistance induced by treatments such as SA, BTH and chitosan on a genome-wide scale can offer valuable insights into the defense mechanisms present in lentil. This knowledge can be utilized in breeding or biotechnology strategies to enhance resistance against *Fusarium oxysporum* f.sp. *lentis* in the future.

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Disclaimers

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Informed consent

All animal procedures for experiments were approved by the Committee of Experimental Animal care and handling techniques were approved by the University of Animal Care Committee.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data

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