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EFFICACY OF MULTIPLE SILICON ROOT APPLICATIONS ON WHEAT RESISTANCE TO FUSARIUM HEAD BLIGHT

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A B S T R A C T

Fusarium head blight (FHB), provoked by various Fusarium organisms, is among the main damages presenting in all Triticum spp.-cultivation regions. Silicon (Si) application of Triticum host as sustainable disease management has been shown to increase host resistance to FHB. It has been approved that Si rate does not reach 1.67 mM for the prohibition of host diseases. To test the effect of multiple Si root applications on enhancing wheat resistance in controlled environments, six *Triticum* lines with different resistances to head blight and inoculated with various *Fusarium* pathogens with varied aggressiveness were grown in growth chamber amended with 1.7 mM Si. The reduction in disease symptoms due to the effect of Si was expressed as FHB incidence (DI, Type I resistance), FHB severity (DS, Type II) and Area Under Disease Progressive Curve (AUDPC) evaluated on the basis of DI and DS. Overall, DI, DS and AUDPC calculated on the basis of DI and DS were reduced by 21.2%, 21.3%, 20.2% and 20.3% in Si treatments in comparing with –Si wheat plants. In comparing with non-Si applied hosts, Si application strongly enhanced all tested components of the wheat resistance, reinforcing the theory that the tested Si concentration is needed for the effective resistance to be manifested to FHB. Sensitive to moderately sensitive and sensitive lines could reduce FHB damage assessed by DI, DS and AUDPC calculated on the basis of DI and DS to a line exhibited a resistance with moderate level that were not applied with Si. Thus, our results showed that Si increased resistance measured by FHB incidence, FHB severity, AUDPC DI, and AUDPC DS on less resistant wheat lines to levels equivalent to those of lines exhibited a resistance with moderate level to FHB and not applied with Si, postulating theoretically that Si absorption by the roots is necessary to avoid negative impact of *Fusarium* infection. To our best knowledge, this study involved controlled-environmental tests presented the primary pathogenic evidence linked with the feeding of multiple Si applications in wheat hosts infected by Fusarium. Overall, our results lead to the conclusion that, when commercial wheat lines with elevated levels of resistance are not accessible to farmers in areas where soil is Si deficient, multiple Si fertilization through the root system is a promising component in the integrated host management to increase wheat resistance to FHB.

Keywords: *Fusarium* pathogens, head blight, soluble Si, *Triticum* spp., wheat resistance.

INTRODUCTION

Wheat (*Triticum* spp.), being an essential nutrition for about 40% of the globe's people, plays a major role in global food security (FAOSTAT, 2021). Unfortunately, wheat is infected by many destructive diseases that reduce the harvest quality and quantity (Naseri and Jalilian, 2021; Naseri and Sabeti, 2021). Across the world, Fusarium head blight (FHB) is a widely known destructive fungal damage influencing the *Triticum* productivity (Bentivenga *et al.,* 2021). FHB disease complex is linked to a set of pathogen organisms; *F. culmorum* and *F. graminearum* are established to be the primary etiological causative Fusarium pathogens in Triticum wheat across the globe (Covarelli *et al.,* 2015). In more severe infections, harvest can be reduced by up to 50-60% due to blighting of considerable rations of the head resulting in chalk-similar tombstone grains which are low in size and weight (Beccari *et al.,* 2020).

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Production of mycotoxins deoxynivalenol (DON) may produce grave difficulties and is a menace to humans and animals (Fernando *et al.,* 2021). DON occurs abundance in FHB-inoculated *Triticum*. It is considered a pathogenicity component which permits *Fusarium* pathogens to defeat plant protections and develop from inoculated to non-inoculated tissues (Dweba *et al.,* 2017). Strategies for FHB management are limited (Beccari*et al.,* 2020). To date, breeding for defeating head blight susceptibility is the elevated cost-efficient way to manage this *Fusarium* damage (Fernando *et al.,* 2021). However, the different quantitative, in nature, resistance mechanisms in wheat to FHB are and extremely infected by the climate (Buerstmayr *et al.,* 2020). FHB resistance is highly complex and divided into several resistance types (Covarelli *et al.,* 2015). Two major models to defeat head blight susceptibility have been more extensively evaluated (Bentivenga *et al.,* 2021): model I, defeating head blight invasion susceptibility (primary inoculation) and model II, defeating head blight susceptibility to *Fusarium* movement in invaded zone. Unfortunately, this strategy does not guarantee high resistance to FHB infection since resistance will break down due to pathogenicity shifts of *Fusarium* species (Dweba *et al.,* 2017). Also, because of deficient knowledge of agents that influence the complex interactions between wheat quantitative resistance and FHB development, commercial wheat genotypes with elevated scales of defeating head blight susceptibility are not obtainable to farmers (Buerstmayr *et al.,* 2020). So, defeating varietal susceptibility in the structure of a united way will be the elevated promising and effective management strategy to eradicate the disease. Silicon (Si) becomes as an attractive alternative to be encompassed in the control of FHB on *Triticum* host in this scenario (Dallagnol *et al.,* 2020).

The success stories of application of Si against various host pathogen interactions is well documented, i.e., blast (*Pyricularia oryzae* on rice), powdery mildew (*Erysiphe cichoracearum on* zucchini squash; *Sphaerotheca fuliginea on* muskmelon and cucumber), brown rot decay (*Monilinia fructicola* on sweet cherry), and angular leaf spot (*Pseudocercospora griseola* on bean) (presented by Wang *et al.* (2017), the correct description of the association between Si and pathways resulting to defeated susceptibility to plant pathogens remains unobvious (Debona *et al.,* 2017). In general, Si analysis has been largely carried out in monocots, and especially in grasses. This is clearly linked to the evidence that grasses accumulate high Si quantities (more than 5% Si on dry weight base) (Guo-chao *et al.,* 2018). Actually, the advantageous impacts of Si are extremely impeded by the absorption capacity of plants (Kaur and Greger, 2019). For instance, *Triticum* host, which is monocot, absorbs higher amounts of Si in their shoots (Deshmukh and Belanger, 2016). Several studies performed with wheat infected with destructive fungal species, i.e., *Magnaporthe oryzae*/blast, *Oculimaculay allundae*/eyespot, *Parastagnospora nodorum*/leaf blotch, *Blumeria graminis f. sp. tritici*/ powdery mildew, *Pyrenophora tritici-repentis*/tan spot, *Bipolaris sorokiniana*/ spot blotch and *Zymoseptoria tritici*/ septoria leaf blotch, have been demonstrated appropriate advantages of Si input, especially in promoting host resistance and avoiding the negative impact of fungal pathogen infection (Dallagnol *et al.,* 2020). In wheat, the accumulation and polymerization of Si under the cuticle forming a cuticle-silica layer prevented or retarded pathogen invasion by specified control responses encompassing fabrication of callose, papilla creation, Si accumulation at the position of invasion and pathogen toxic phenolic compounds (Guevel *et al.,* 2007). Similarly, Kim *et al.* (2002) observed that silicified epidermal cell walls were widely linked with the decreased intensity of the blast symptoms (*Magnaporthe grisea*) in sensitive and quantitatively resistant rice genotypes, in spite of the density of the epidermal cell wall was not remarkably influenced by the existence of Si. Furthermore, the stimulation of plant defense reactions by Si is one of the most important impacts of this element; defeating susceptibility of wheat host applied with Si to several diseases is related with their large ability to fabricate elevated levels of lignin and phenolics as well as to enhance the activities of defense-related enzymes (e.g., phenylalanine ammonia-lyase, polyphenoloxidase, β-1,3-glucanase and chitinase) (Dorneles *et al.,* 2017).

Root and foliar Si applications enhanced wheat resistance to *Fusarium* infection under *in vitro*, controlled and field conditions (Sakr, 2021b,c, 2022; Pazdiora *et al.,* 2021). Recently, the effect of multiple Si treatments via roots applied constantly into *Triticum* host has been investigated so far in the field (Sakr and Kurdali, 2022), although not in details. While expression of *Fusarium* damages in plants treated with Si is highly affected by climate factors (Buerstmayr *et al.,* 2020), the testing of multiple Si root applications on enhancing wheat resistance in environments controlling strictly all biotic and abiotic factors would be of great importance. Taking into account that growth chamber conditions are logistically more convenient to explore the impact of Si on wheat infected with FHB pathogens, the objective of this report was to characterize precisely and correctly which components of the wheat resistance, FHB incidence (DI, Type I resistance), FHB severity (DS, Type II) as well as area under disease progressive curve calculated on the basis of DI and DS, are involved in FHB resistance expression in wheat. We also tried to analyze theoretically the impact of Si absorption by the root system to decrease the development of head blight symptomsin wheat heads. Also, we tried to explore whether supply with Si could defeat host susceptibility of less resistant wheat genotypes to scales identical to those of genotypes extremely resistant to FHB and not supplied with this element.

MATERIALS AND METHODS

Plant materials and cultivation conditions: The six *T. aestivum* and *T. durum* cultivars widely cultivated in Syrian field with agreeable quality and agronomic traitsand identical maturity and flowering dates used were Acsad65 (*T. durum*, sensitive),Cham9 and Cham7 (*T. durum*, sensitive to moderately sensitive), Douma4 and Cham4 (*T. aestivum*, moderately sensitive), and Bohoth10 (*T. aestivum*, showing a resistance with moderate level) classified according to earlier laboratory, controlled and field conditions to display a progressive scale of *Fusarium* susceptibility (Sakr, 2021c). Three kg plastic pots (20 × 15 cm) size were filed with 2 kg of air dehydrated soil, screened to exceed into a sieve with a 3 mm. Eight surface-disinfected wheat seeds with 5% sodium hypochlorite solution were placed in the pot. After the emergence of seedlings, thinning to five seedlings was applied and N fertilization was conducted to prevent any nitrogen deficiency: plant tillering and appearance. Plants were kept during the experiment under controlled conditions (16 h of per day and temperature at 20°C in day and night) and irrigated as requested to harvest.

Soil traits and treatments: The pot/soil encompassed of ~ 40% loam and 60% clay and less than 2% sand, gathered from the Sojji Agricultural Experimentation Station (36°07′ E, 33°30′ N, over sea level by 700 m altitude), set east in the countryside of Damascus, Syria with organic matter = 1.25%; Mg, Ca, K, Na = 14, 33.1, 1.81, 2.99 mg/100 g soil respectively; P = 13.4 mM and pH =7.8 was sterilized in the gamma irradiator (ROBO, Russia) at 5 k Gy of Gamma Ray with Co^{60} material.

A SiO_2 powder (Kieselsaure, Carl Roth GmbH + Co. KG) was the source of Si, which is composed of 99% Si at a minimum content. Si (1.7 mM) was supplied to plants in the format of silicic acid [H_4SiO_4], which was obtained by dissolving SiO_2 powder in demineralized water. The watering solution amended with silicic acid (300 ml/pot) was supplied weekly for plants from the sowing till the fungal inoculation time. Non-Si-applied plants (–Si) were irrigated with a demineralized water without Si and divided from Si-applied plants (+Si).

***Fusarium* strains and inoculum preparation:** Sixteen strains of four head blight pathogens, i.e. (*F. equiseti* (one strain), *F. verticillioides* (4 strains), *F. culmorum* (5 strains), and *F. solani* (6 strains)) were used due to their different pathogenic behavior levels (built on earlier several experimental findings (Sakr, 2021c) were used. At the 2015 growth season, strains were sampled from field infected *Triticum* heads over 9 locations in Ghab Plain with a FHB history, one of the major *Triticum* producing zones in Syria. On Petri-plates with potato dextrose agar (PDA) with 13 mg/l kanamycin sulphate added after autoclaving, strains were classified morphologically to species level by utilizing the methods of Leslie and Summerell (2006). By using random amplified polymorphic DNA markers, the 16 strains were tested. Fungal strains were preserved at-16°Cby freezing or at 4°Cin sterile distilled water (SDW) till use.

Head blight substance used for inoculation was arranged as following: preserved strains were installed at the surface of PDA plates and put in the incubator for 10 days at 22ºC in the dark climate to permit sporulation and fungal development. After fungal growth, isolates were dealt with 10 ml of SDW and conidia were taken. By passage via 2 layers of sterilized cheesecloth, fungal suspensions were purified to take out mycelium portions and agar and instantly measured with a Neubauer chamber under an optical binocular and adjusted to 5×10^4spores/ml.

Head blight evaluation: When each head reached 50% anthesis at the full maturity stage, wheat cultivars were separately inoculated by spraying for blighting of heads (FHB incidence, DI) and injecting into two neighboring spikelets (10 µL per spikelet) at the center of each head (without wounding) for blighting of spikelets (FHB severity, DS) evaluations with a conidial suspension for the 16 *Fusarium* isolates. Non-infected *Triticum* hosts were treated with SDW and kept under the similar conditions as the infected *Triticum* hosts. Inoculated heads were then kept with clear plastic bags for two days to create an elevated level of moisture to stimulate initial head blight invasion.

Resistance components evaluated at the soft dough stage on visual assessment of blighting of spikelets and heads of each *Triticum* host included: FHB incidence (DI, Type I resistance), FHB severity (DS, Type II) and Area Under Disease Progressive Curve (AUDPC) evaluated on the basis of DI and DS. Briefly, DI (% symptomatic spikes) was rated as the % of heads exhibiting head blight damages. DS (% symptomatic florets/head) was rated as the % of florets on the infected heads with obvious and visually head blight damages on a 9 scale (Xu e *et al.,* 2019), where 9 showed severely damaged or dead and 0 showed no damage. In each treatment and experiment, AUDPC for each *Triticum* host was evaluated on the rates of DI and DS utilizing the disease progress curve including a trapezoid integration (Jeger *and* Viljanen-Rollinson*,* 2001) over the continuous damage of spikes rated at 1, 2, 3 and 4 weeks after inoculation (wai). AUDPC was carried out with the starting of spikes with damaged florets that are representative of head blight about 1 wai.

Experimental design: The trails were carried out to quantify precisely and correctly the impact of multiple Si root treatments applied continuously into *Triticum* hosts on *Fusarium* DS, DI as well as AUDPC. The test was randomized in a complete level with 192 applications arranged in a 2 × 6 × 16 factorial model in which the factors included Si application (with or without treatment), cultivars (six wheat bread and durum cultivars), and plant inoculation (inoculated with 16 *Fusarium* isolates causing FHB or treated with SDW). The test consisted of 192 treatments was repeated twice.

The reduction of FHB symptoms measured by the four analyzed components, i.e., DI, DS and AUDPC calculated on the basis of DI and DS, of cultivars treated with Si was measured by comparing a given component of the cultivar infected with fungus and treated with Si to the cultivar infected with fungus and no Si application.

Result analysis: Findings were analyzed utilizing the statistical analysis model (DSAASTAT add-in version 2011) for analysis of variances (ANOVA) followed by averages separation at P<0.05 (Fisher test). Data were log-transformed. To make comparisons between specific cultivar groups, non-applied and applied with Si, single degree-of-freedom contrasts were utilized.

RESULTS

Regardless of botanical and pathogenic source for the *Triticum* and fungal materials in our research, *Fusarium* symptoms DI, DS and AUDPC calculated on the basis of DI and DS (Tables 1, 2, 3 and 4) were significantly reduced in +Si plants of all tested bread and durum wheat cultivars infected with all analyzed fungal isolates compared to –Si plants, suggesting that multiple Si (1.7 mM) root application protects any durum or bread Triticum genotype whatever its quantitative susceptibility from inoculation with any *Fusarium* pathogen whatever its aggressive level. No diseased damages were observed in –Si *Triticum* hosts amended with SDW. Overall, DI, DS and AUDPC calculated on the basis of DI and DS were reduced by 21.2%, 21.3%, 20.2% and 20.3% in Si treatments in comparing with –Si wheat plants.

Si (1.7 mM)-supplied cultivars, Bohoth10 exhibited a resistance with moderate level; Douma4 and Cham4 which are moderately sensitive; Cham9 and Cham7 which are sensitive to moderately sensitive; and Acsad65 which is sensitive cultivar, had a DI that was lower by 25, 20, 19 and 23% respectively in replicate 1; 26, 20, 20 and 22% in replicate 2, and 27, 20, 20 and 22% respectively in replicate 3 than plants without Si (Table 1).

Table 1. Effect of silicon amendment on wheat resistance of Type assessed by FHB incidence (DI)

Genotypes	Replicate 1		Replicate 2		Replicate 3	
	Without Si	With silicon	Without Si	With silicon	Without Si	With silicon
Bohoth10	40a	30b	39a	29b	41a	30b
Cham4	44a	37b	43a	35b	43a	35b
Douma4	46a	36b	45a	36b	45a	36b
Cham7	54a	43b	53a	42b	54a	42b
Cham9	51a	42b	52a	42b	51a	43b
Acsad65	56a	43b	54a	43b	55a	43b

Regarding the Fisher's LSD analysis at P<0.05, averages followed by the similar letter in a line are not significantly distinguished. In the present research, the damage reaction of all lines inoculated with *Fusarium* without Si was retested for DI, nevertheless; DI of all lines inoculated with *Fusarium* was tested earlier and presented by Sakr (2021c).

DS was lower by 25, 20, 20 and 21% respectively in replicate 1; 26, 19, 21 and 22% in replicate 2, and 24, 19, 21 and 25% respectively in replicate 3 in a resistance with moderate level, moderately sensitive, sensitive to moderately sensitive, sensitive +Si genotypes than wheat plants amended with SDW (Table 2).

Table 2. Effect of silicon amendment on wheat resistance of Type II assessed by FHB severity (DS)

Genotypes	Replicate 1		Replicate 2		Replicate 3	
	Without Si	With silicon	Without Si	With silicon	Without Si	With silicon
Bohoth10	40a	30b	39a	29b	41a	31b
Cham4	42a	34b	43a	35b	43a	35b
Douma4	44a	36b	44a	36b	45a	37b
Cham7	46a	37b	46a	36b	46a	37b
Cham9	48a	38b	49a	39b	48a	39b
Acsad65	50a	38b	51a	39b	52a	39b

Regarding the Fisher's LSD analysis at P<0.05, averages followed by the similar letter in a line are not significantly distinguished. In the present research, the damage reaction of all lines inoculated with *Fusarium* without Si was retested for DS, nevertheless; DS of all lines inoculated with *Fusarium* was tested earlier and presented by Sakr (2021c).

Si treatment reduced AUDPC calculated on the basis of DI by 20, 19, 19 and 24% respectively in replicate 1; 22, 19, 19 and 26% in replicate 2, and 21, 19, 21 and 25% respectively in replicate 3 inAcsad65, Cham9 and Cham7, Douma4 and Cham4 and Bohoth10 as compared with –Si plants (Table 3).

Table 3. Effect of silicon amendment on wheat resistance measured by area under disease progressive curve (%) calculated on the basis of disease incidence, Type I

Genotypes	Replicate 1		Replicate 2		Replicate 3	
	Without Si	With silicon	Without Si	With silicon	Without Si	With silicon
Bohoth10	33a	25b	34a	25b	35a	26b
Cham4	35a	29b	34a	28b	35a	29b
Douma4	37a	30b	36a	29b	37a	30b
Cham7	42a	34b	41a	34b	42a	34b
Cham9	40a	33b	40a	33b	40a	33b
Acsad65	45a	35b	45a	35b	45a	36b

Regarding the Fisher's LSD analysis at P<0.05, averages followed by the similar letter in a line are not significantly distinguished.

AUDPC calculated on the basis of DS was reduced by Si treatments in Acsad65, Cham9 and Cham7, Douma4 and Cham4 and Bohoth10 by 21, 23, 19 and 24% respectively in replicate 1; 20, 21, 18 and 23% in experiment 2, and 20, 21, 17 and 23% respectively in replicate 3 than wheat plants amended with SDW (Table 4).

Table 4.Effect of silicon amendment on wheat resistance measured by area under disease progressive curve (%) calculated on the basis of disease severity, Type II

Genotypes	Replicate 1		Replicate 2		Replicate 3	
	Without Si	With silicon	Without Si	With silicon	Without Si	With silicon
Bohoth10	29a	22b	30a	23b	30a	23b
Cham4	32a	26b	32a	27b	32a	27b
Douma4	33a	27b	34a	28b	34a	28b
Cham7	36a	28b	36a	29b	36a	29b
Cham9	35a	27b	37a	29b	36a	28b
Acsad65	38a	31b	36a	28b	37a	29b

According to the Fisher's LSD test, means followed by the same letter within a linage are not significantly different at P<0.05.

To detect whether the Si fertilization to moderately sensitive, sensitive to moderately sensitive and sensitive cultivars could reduces FHB damage assessed by DI, DS and AUDPC calculated on the basis of DS and DIto a genotype exhibited resistance with a moderate level that was not applied with Si, single degree of freedom contrasts compared selected cultivar-Si combinations (Table 5). In all trails, the combination of Douma4 and Cham4 and Cham9 and Cham7 or these genotypes tested individually encompassing Acsad65, plus silicon decreased FHB damage quantified by DI, DS AUDPC calculated on the basis of DS and DIto the identical statistical scale as that for the genotype Bohoth10 exhibited resistance with a moderate level without Si.

Table 5. Single degree of freedom contrasts for comparisons between specified groups of genotypes non-applied and applied with Si on damage of *Fusarium* assessed by disease incidence (DI), disease severity (DS), area under disease progressive curve (AUDPC) calculated on the basis of DI, and AUDPC calculated on the basis of DS

Cultivar groups												
	DI			DS			AUDPC DI			AUDPC DS		
- Si- + Si	Rep. 1	Rep. 2	Rep. 3	Rep. 1	Rep. 2	Rep. 3	Rep. 1	Rep. 2	Rep. 3	Rep. 1	Rep. 2	Rep. 3
Cham4 and Douma4 vs. Bohoth10												
Cham4 vs. Bohoth10												
Douma4 vs. Bohoth10	not significant											
Cham9 and Cham7 vs. Bohoth10												
Cham7 vs. Bohoth10												
Cham9 vs. Bohoth10												
Acsad65 vs. Bohoth10												

Rep. = replicate, significance at P<0.05.

DISCUSSION

While head blight is common in most wheat-producing regions worldwide (Bentivenga *et al.,* 2021), it has proven to be considerably challenging to manage (Fernando *et al.,* 2021). Because of the loss of commercial wheat genotypes with favorable genetic resistance to head blight (Buerstmayr *et al.,* 2020), a practical alternative was effectively undertaken to manage mineral nutrition by Si feeding through root systems in order to enhance *Fusarium* resistance in *Triticum* (Dallagnol *et al.,* 2020). Recently, multiple Si treatments via roots applied constantly into *Triticum* host was found to enhance wheat resistance to FHB infection under filed conditions (Sakr and Kurdali, 2022). However, uncontrollable climate factors such as humidity, temperature, and the parallel existence of other organisms in the field greatly influenced FHB development in wheat supplied with Si (Sakr and Kurdali, 2022), resulting in difficulties to distinguish precisely and correctly resistance components involved in the expression of +Si wheat to *Fusarium* infection (Pazdiora *et al.,* 2021). To defeat these limitations, we analyzed for the first time the effect of multiple Si fertilization through root system under controlled environmental conditions where the inoculum load, temperature, light and moisture conditions were monitored and regulated (Sakr, 2021c).

In spite of partial *Triticum* resistance criteria to *Fusarium* are most generally found under field factors (Covarelli *et al.,* 2015; Dweba *et al.,* 2017; Fernando *et al.,* 2021), they are precisely and correctly distinguished under controlled conditions controlling all abiotic and biotic experimental conditions (Sakr, 2021c). In respect to multiple Si treatments in six *T. durum* and *T. aestivum* cultivars, the average scores of the reduction of *Fusarium* incidence, for model I, and *Fusarium* severity, for type II, in wheat kept in the growth chamber and field (Sakr and Kurdali, 2022) conditions ranged from (18.3% and 18.7%) and (21.2% and 21.3%), respectively. This result indicates the significance of environmental conditions on wheat defense responses against infection by FHB pathogens. *Fusarium* intensity in wheat heads is strongly influenced by environmental conditions (Buerstmayr *et al.,* 2020).

The four criteria assessed in this report were negatively influenced by silicon. The data that there was a reduction of blighting of heads and florets is of large pathogenic estimate (Sakr, 2021b,c). Resistance to *Fusarium* invasion, Type I and resistance to *Fusarium* movement in invested area, Type II, were enhanced following multiple Si root applications; wheat plants with contrasting susceptibility to disease showed less damage caused by several *Fusarium* species with diverse pathogenicity, as indicated by the smallest DI, DS as well as AUDPC calculated on the basis of DI and DS. These smallest values indicate that the progress of *Fusarium* symptoms in host tissues was later, an evidence that permitted the host to keep a non-diseased head zone for a prolonged duration. A similar finding was also observed in +Si wheat defeated several destructive fungal pathogens (Dallagnol *et al.,* 2020) via modification of their monocyclic criteria such as and number of lesion expansion rate, lesions per unit leaf area, infection efficiency, incubation period and lesion size (Dorneles *et al.,* 2017).

In spite of the invasion pathway of *Fusarium* speciesin *Triticum* spp. heads has been well clarified (Fernando *et al.,* 2021), the development of *Fusarium* pathogens in wheat supplied with Si as well as the interactions between Si, the plant and the pathogen has not been investigated. In this work, a theoretical description is proposed to analyze the impact of Si absorption by the root system to decrease the development of head blight symptoms in wheat heads. *Fusarium* species entering wheat floret initiate infection at anthesis by forming invasive mycelia over the glumes that extend to stomata, anthers and the crevices between the palea and lemma (Bentivenga *et al.,* 2021). This is followed by the invasion of the rachis, and spared between the spikelets of the *Triticum* spp. head occurs via the vascular bundles until FHB symptoms, involving necrosis and bleaching of head resulting in shriveled kernels, are clear (Dweba *et al.,* 2017). FHB pathogens also produce high concentrations of DON during infection of the epicarp (Beccari *et al.,* 2020); DON is considered a pathogenicty factor that enable *Fusarium* pathogens to spread from infected to uninfected tissues and then overcome plant defenses which are inefficient against the pathogen (Buerstmayr *et al.,* 2020). Pathogenicity of *Fusarium* species is likely the outcome of appropriate manifestation of several genes, governing manipulation of DON that modify the wheat's resistance response (Covarelli *et al.,* 2015), indicating that the suppression of DON biosynthesis would be an effective management policy of head blight (Fernando *et al.,* 2021).

From the beginning, taking of Si by the root system in wheat is a prerequisite for decreasing symptom development in the heads. In a higher Si absorber and accumulator moncot, i.e., wheat (Deshmukh *et al.,* 2016), Si uptake has been reported to be mediated by two diverse types of transporters, *Lsi1* and *Lsi2* (Guo-chao *et al.,* 2018). *Lsi1*, influx transporter absorbs monosilicic acid, H_4SiO_4, from external solution to the root cells, followed by *Lsi2*, efflux transporter, which moves it further through the branches. Another Si transporter *Lsi6*, which moves H_4SiO_4 across the vascular bundle, is expressed in the parenchyma cells of the leaves (Kaur and Greger, 2019). Since the expressing of *TaLsi1* (Montpetit *et al.,* 2012) in wheat challenged with *Fusarium* species causing head blight has not been analyzed, it can be concluded that differences in Si concentrations in Si-applied hosts versus non-Si-applied hosts did account for positive effects of Si feeding to decrease FHB infection on wheat heads (Dallagnol *et al.,* 2020). Taking into account that Si did not affect directly on the pathogen (Sakr, 2021a) and the silicified cells were existing in stem, rachilla, lemma, leaf sheath, awn, and leaf blade; the later organ contains the elevated Si rate (Dallagnol *et al.,* 2020); we theoretically propose that Si inhibits DON biosynthesis by enhancing plant defense mechanisms to head blight pathogenesis which involve enhancing activity of peroxidase, superoxide dismutase phenylalanine ammonia-lyase and chitinase, the accumulation of derivatives of the hydrogen peroxide and phenylpropanoid pathway as well as enhancing the level of inhibitory phenolic compounds (Dallagnol *et al.,* 2020).

In comparing to non-Si applied hosts, multiple Si root application strongly enhanced all tested components of the wheat resistance, reinforcing the theory that the tested Si concentration is needed for the effective resistance to be manifested to FHB. For Si to begin this influence on wheat protection in the current work, a minimum rate of the element in the host tissue is required for effective resistance to FHB disease (Wang *et al.,* 2017). The concentration of Si in the Triticum spp. heads was accurately equilibrated in all applications to stimulate its potential capacity in the elimination of FHB. Reports under filed conditions to detect the effectiveness of Si for the management of host damages, Si value does not reach 1.67 mM (Deshmukh *et al.,* 2016). Such Si concentration reduced FHB symptoms following several applications thought root and foliar systems in wheat and barley under *in vitro*, growth chamber and filed conditions (Sakr, 2021b,c, 2022; Sakr and Kurdali, 2022). Si treatment via root at a value of 1.7 mM gave the best results in terms of Si accumulation in wheat and management of *Blumeria gramini s*f. sp. *tritici*/powdery mildew (Guevel *et al.,* 2007), in banana and control of *Mycosphaerella fijiensis*/ black sigatoka (Kablan *et al.,* 2012), and in soybeanand suppression of *Phakopsora pachyrhizi*/Asian rust (Arsenault-Labrecque *et al.,* 2012). Also, it is clear that soybean host inoculated with *P. pachyrhizi* accumulated more Si when absorbed 1.7 mM, showing that this rate is sufficient to detect notable variations among *Glycine max* genotypes (Arsenault-Labrecque *et al.,* 2012).

More importantly, Si increased resistance measured by DI, DS, AUDPC disease incidence and AUDPC disease severity on less resistant wheat genotypes to levels similar to those of genotypes extremely resistant to FHB and not applied with Si, suggesting that Si absorption by the roots is necessary to avoid negative impact of *Fusarium* infection. Our results are comparable with those obtained under field conditions (Sakr and Kurdali, 2022); this result indicates (1) the significance of Si feeding on enhancing wheat defense responses against infection by FHB pathogens under several growth habitats, i.e. in vitro, controlled and field conditions, and (2) Si absorption and accumulation manifest in different *T. durum* and *T. aestivum* genotypes inoculated with diverse head blight pathogens under several experimental factors. The elevated protection of haed blight was generated with a cultivar showing a moderate level, i.e., Bohoth10, bread, planted in soil applied with multiple Si applications under controlled and field conditions. Taking into consideration that the scale of susceptibility to head blight invasion decreases from *T. durum* to *T. aestivum* and the moderate resistance observed is associated with stronger plant defense through increased biochemical defense mechanisms (Buerstmayr *et al.,* 2020), it seems that the effect of Si in Bohoth10 may be linked with higher expression of the host's ability to protect itself against *Fusarium* invasion compared to other tested durum and bread cultivars. Nevertheless, in the present study, we showed that Si decreased *Fusarium* invasion in durum wheat, i.e., Acsad65, showing a susceptibility to FHB. This indicates that increased *Fusarium* resistance by Si is not restricted to bread wheat. In line with our data, Si decreased sheath blight progress of sensitive and moderately sensitive US *Oryza sativa* genotypes to levels similar to those found in genotypes high in quantitative resistance to *Rhizoctonia solani* but, not supplied with Si (Rodrigues *et al.,* 2001).

CONCLUSION

This study involved controlled-environmental tests presented the primary pathogenic confirmation linked with the input of multiple Si applications in wheat host invaded by *Fusarium*. Pathogenic pieces of confirmation were exhibited regarding the positive influence of Si on enhancing wheat resistance against FHB, showing that the four components evaluated in this study, DI, DS, AUDPC DI and AUDPC DS, were negatively impacted by Si. Most Si treatment was carried out as a component of input because it can be taken by the influx transporter located on roots. Overall, our results lead to the conclusion that, when commercial wheat genotypes with elevated levels of resistance are not accessible to farmers in areas where soil is Si deficient, multiple Si fertilization thought the root system is a promising component in the integrated host management to increase wheat resistance to FHB. Further biochemical and genetic studies are required to test the Si transporters in wheat plants challenged with *Fusarium* species causing head blight upon Si fertilization.

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