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SUPPRESSIVE EFFECT OF SI ON THE DEVELOPMENT OF FUSARIUM HEAD BLIGHT IN YOUNG BARLEY ORGANS UNDER *IN VITRO* CONDITIONS

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A B S T R A C T

Although barley is a high silicon (Si) absorber and accumulator monocot; few reports have shown an enhanced adult host resistance to destructive fungal diseases including Fusarium head blight (FHB). However, no study has ever conducted to demonstrate Si ability to suppress FHB development in young barley organs under *in vitro* environment. To elucidate this, the effect of Si uptake at 1.7 mM on the susceptibility of two barley cultivars, Arabi Aswad (AS, moderately resistant) and Arabi Abiad (AB, moderately susceptible) to four *Fusarium* species with diverse aggressiveness was investigated in three *in vitro* experiments. Development of FHB pathogens was expressed by latent period (LP) of detached leaf inoculation, area under disease progress curve (AUDPC) of Petri-dish inoculation as well as coleoptile length reduction (CLR) of a coleoptile infection. At the early development stage, differences in LP, AUDPC and CLR were observed on barley detached leaves and seedlings of Si-*Fusarium*-inoculated treatments relative to fungal-inoculated-controls, showing the beneficial role played by this element in decreasing head blight disease symptoms on young plant parts under *in vitro* conditions. Si absorption at 1.7 mM did significantly result in significantly higher LP and lesser AUDPC and CLR compared with controls in AS and AB. Si increased resistance measured by LP, AUDPC and CLR on AB to level comparable to AS not amended with Si, suggesting that Si feeding increase host resistance to FHB development. To our best knowledge, this *in vitro* study presented the first pathogenic evidence associated with the positive effect of Si on enhancing barley resistance against *Fusarium* infection in the young host parts, showing that the three components evaluated in this study, i.e., LP, AUDPC and CLR, were negatively impacted by Si. Thus, Si supply at 1.7 mM could be a valuable tool in integrated pathogen management by suppressing pathogen development on barley.

Keywords: Barley resistance, *Fusarium* species, *in vitro* bio-experiment, soluble silicon, *Hordeum vulgare*.

INTRODUCTION

Barley (*Hordeum vulgare* L.) is one of the most highly adapted cereals to harsh climatic conditions and cultivates in climates ranging from sub-Arctic to sub-Tropical environments. The global production of barley reached to about 147.1 million metric tons in the 2021/2022 growing season; this production is commonly used as feed grain crops (70%) and for beer manufactory (27%). *H. vulgare*is susceptible to a wide range of serious fungal pathogens of great economical importance. to date, Fusarium head blight (FHB) is one of the most important diseases of barley and other small-grain cereals (i.e., wheat, oat, rye and triticale) worldwide (Parry *et al.,* 1995). More than 17 *Fusarium*species have been isolated from naturally diseased barley heads; however, *F. graminearum* and *F. culmorum* are the principal pathogens of FHB disease complex (Bai and Shaner, 2004). FHB can lead to severe yield and quality losses; it decreases grain weight as well as varies protein accumulation (Dahl and Wilson, 2018). In addition, FHB is able to biosynthesize and accumulate dangerous mycotoxins, secondary metabolites with toxic impacts on humans and animals, and it makes harvested grains unacceptable for malting and brewing industry (Janssen *et al.,* 2018).

Quantitative host resistance has the potential to provide

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economical and effective control of this disease (Fernando *et al.,* 2021). Two major Types of barley resistance to FHB infection are widely reported in the phytopathological literature: resistance to the initial pathogen infection (Type I), and resistance to the spread of pathogen infection in the head tissues (Type II), with Type I is the predominant Type (Dahl and Wilson, 2018). Currently, the *in vitro* criteria, i.e., latent period (LP) (time from inoculation to sporulation), area under disease progress curve (AUDPC) and coleoptile length reduction (CLR), have been shown to be the most reliable methods for evaluating barley resistance to *Fusarium* pathogens causing head blight at the early growth stages, indicating the predictive ability of these *in vitro* components as indicators of mechanisms of Type I and Type II occurring in barley heads during FHB development at the adult stage in the field (Browne, 2009; Purahong *et al.,* 2012; Soresi *et al.,* 2015; Sakr, 2020b; Sakr and Al-Attar, 2022). However, breeding for FHB resistance has proven to be complicated due to complex inheritance of resistance genes and strong genotype-by-environment interaction (Dahl and Wilson, 2018), resulting in the absence of commercial barley cultivars with satisfactory genetic resistance (Fernando *et al.,* 2021). Given this evidence, novel methods for inhibiting *Fusarium* species or promoting barley defense need to be investigated to avoid the negative impact of FHB on crop productivity (Janssen *et al.,* 2018).

Mineral nutrients, in addition to their substantial role in plant metabolism, have a long history in modulating the effects of plant pathogens on cultivated crops (Datnoff*et al.,* 2007). For instance, the supply of silicate fertilization to plants which confers increased host resistance to soil-borne and foliar fungal pathogens in a wide range of crops (Wang *et al.,* 2017), as a source of soluble silicon (Si), has been proposed as a viable alternative to conventional control techniques (Debona *et al.,* 2017). Till recently, the mechanism by which Si is beneficial for plants is not entirely understood (Guo-Chao *et al.,* 2018). In essence, the beneficial effects of Si are greatly hampered by the absorption ability of plants (Datnoff *et al.,* 2007; Wang *et al.,* 2017). New evidence confirmed that the Si absorption and accumulation in barley could be explained by the active transport mechanisms inherent to the roots (Kaur and Greger, 2019). Influx transporter (*Lsi1*) takes silicic acid, H_4SiO_4, from soil solution up to the exodermis, followed by the efflux transporter (*Lsi2*), which takes it further across the aerenchyma (Kaur and Greger, 2019). Both radial transport of H_4SiO_4 mediating by *Lsi1* and *Lsi2* in roots have also been identified in barley (*HvLsi1*, *HvLsi2*) (Chiba *et al.,* 2009; Mitani *et al.,* 2009). Although barley is a monocot, which absorbs Si at higher rates from soil solution and accumulates them in its shoots (Deshmukh *et al.,* 2016), Si reduced the severity of limited destructive fungal diseases inducing powdery mildew (*Blumeria graminis*f. sp. *hordei*) and spot blotch (*Bipolaris sorokiniana*) (Wiese *et al.,* 2005; Holz *et al.,* 2022). The reduction of disease intensity by Si results from the better performance of physical and biochemical features that act additively and/or synergistically; Si barrier enhances resistance to pathogens by preventing fungal penetration and Si acts a modulator of host resistance to pathogens (Datnoff *et al.,* 2007; Wang *et al.,* 2017).

Si treatment of barley plants has been shown to increase host resistance to FHB (Sakr, 2022). Root and foliar Si applications enhanced host resistance to *Fusarium* infection under controlled conditions (Sakr, 2021b). However, no study has ever conducted to demonstrate Si ability to suppress FHB development in young barley organs under *in vitro* environment. Thus, it is of great importance to examine the usefulness of three different *in vitro* bio-experiments (LP of detached leaf inoculation, AUDPC of Petri-dish inoculation and CLR of a coleoptile infection) to clarify the effect of Si in the barley-FHB pathosystem. Given the evidence of using of Si to enhance barley resistance in adult plants against head blight pathogens (Sakr, 2021b), this *in vitro* study aimed to evaluate the effect of Si to suppress the development of four *Fusarium* species with different pathogenicity on two barley cultivars with contrasting susceptibility to disease. The ability of Si to increase resistance measured by LP, AUDPC and CLR on moderately susceptible to level comparable to moderately resistant not amended with Si was also investigated.

MATERIALS AND METHODS

Plant materials, fungal isolates and inoculum preparation: The two morphologically, physiologically and genetically different barley cultivars (Ceccarelli *et al.,* 1987) of Syrian origin with favorable agronomic and quality characteristics used were Arabi Aswad (AS) and Arabi Abiad (AB) classified as moderately resistant and moderately susceptible to head blight, according to previous *in vitro*, growth chamber and field observations to display a progressive range of *Fusarium* susceptibility (Sakr, 2020a,b, Sakr and Al-Attar, 2022).

To date, the incidence of head blight pathogens on barley

has not reported in Syria. But, FHB species are frequently isolates form diseases wheat plants. A set of 16 single-spore derived cultures of four *Fusarium* species causing head blight, i.e. (*F. culmorum* (5 isolates), *F. solani* (6 isolates), *F. verticillioides* (synonym *F. moniliforme*) (4 isolates), and *F. equiseti* (one isolate)) chosen for their diverse pathogenicity levels (established on previous several experimental findings (Sakr, 2020a,b, Sakr and Al-Attar, 2022) were used. The isolates were collected through the 2015 growth season from naturally infected wheat heads over 9 locations in Ghab Plain with a FHB history, one of the principal Syrian wheat production areas. Sakr and Al-Attar (2022) observed a similar range of aggressiveness in these 16 FHB isolates recovered from diseased wheat heads on Arabi Aswad (AS) barley and durum wheat (*Triticum durum*) plants *in vitro*. By using the keys of Leslie and Summerell (2006), single spore cultures on Petri dishes with potato dextrose agar (PDA) with 13 mg/l kanamycin sulphate added after autoclaving, were classified morphologically to species level. By using random amplified polymorphic DNA markers, the 16 *Fusarium* species causing head blight isolates were recently analyzed. The 16 *Fusarium* isolates were preserved by freezing at-16°C or in sterile distilled water at 4°Ctill use.

Inoculum was obtained as follows: fungal isolates were grown PDA medium. After incubation for 10 days at 22ºC under continuous darkness to allow sporulation and fungal development, fungal suspensions were harvested from PDA dishes by flooding with sterile distilled water (SDW). Following dislodging of conidia, suspensions were filtered through 2 layers of sterile cheesecloth to remove the pieces of mycelia and agar and directly quantified with a Neubauer chamber under an optical microscope and diluted to 5×10^4conidia/mlas inoculum sources.

Silicon application: The source of Si was a SiO_2 powder (Kieselsaure, Carl Roth GmbH + Co. KG), which is composed of 99% Si at a minimum content. Liquid solution of Si (1.7 mM) was supplied to plants in the form of silicic acid [H_4SiO_4], which was prepared by dissolving a SiO_2 powder in demineralized water. Si at a concentration 1.7 mM reduced FHB symptoms following several applications via root and foliar systems in barley under growth chamber conditions (Sakr, 2021b).

Experimental design: The usefulness of three different *in vitro* bio-experiments, i.e., latent period (LP) of detached leaf inoculation, area under disease progress curve (AUDPC) of Petri-dish inoculation and coleoptile length reduction (CLR) of a coleoptile infection was investigated herein to analyze the effect of Si in the barley-FHB pathosystem with modification in respect to Si application. The experiments were laid out in a completely randomized design with three replications. The experiment was repeated three times.

Methods for LP assay were carried out as reported previously by Browne (2009) to assess *in vitro* quantitative resistance components and utilized cited by Sakr and Al-Attar (2022) to assess resistance and pathogenicity in the barley–FHB system. Seeds of two barley cultivars were disinfested with NaOCl for 8 minutes followed by 6 rinses in sterile distilled water (SDW). Then, barley seeds were grown into plastic 15-cm pots including sterilized soil in a growth chamber with 20°C at day/night temperature and 16 h of light per day. Liquid formulation of silicon was first applied prior to planting, so the seeds were irrigated. Separate drenches were applied as a 300 mL per pot once a week. SDW was used for controls. Two weeks after planting, seedlings were harvested and leaf segments 4 cm in length were collected from the midsection of the expanding seedling leaf and then placed adaxial surface up on the surface of 0.5% water agar (four leafs per plate). Si- and SDW-leaf segments were inoculated at the center of the adaxial surface with a 10 µL condial suspension at 1×10^6 conidia/ml of the 16 fungal isolates. The detached leaves were then incubated at 10°C with a 12-h photoperiod. Assessments of symptom manifestation and sporulation were tested daily under a light microscope (magnification X40), and the resistance of a cultivar measured by LP was evaluated as a period in days from inoculation to sporulation. Three replicates of each cultivar based on observations on 120 detached leaves were set up.

Methods for AUDPC assay were conducted as described previously by Purahong *et al.* (2012) to quantify *in vitro* aggressiveness components and cited recently by Sakr and Al-Attar (2022) to analyze both pathogenicity and resistance in the association of barley and FHB fungi. Prior to infection, the 16 *Fusarium* cultures were covered with 10 ml of a Si-solution or SDW for controls. The mixture was filtered through autoclaved cheesecloth. The spore concentration was adjusted to 1×10^6 conidia/ml. Then, the 15 surface-sterilized barley seeds were inoculated with 6 ml of a Si-suspension of each of 16 *Fusarium* isolates or SDW-suspension of each of 16 FHB isolates in the control treatment into a Petri-dish (9 cm in diameter) with sterile double-layer filter paper. The

seeds were submerged under the fungal inoculum with/or without Si in the slanting Petri-dish then immediately aligned on the filter with the embryo turned upwards. Petri-dishes were then hermetically closed and sealed with 2 cm Para Film strips to ensure high relative humidity and low air movement. Infected and control treatments were incubated in an incubator at 22°C in the dark. The resistance of a cultivar measured by AUDPC was measured as disease progress over 6 days post inoculation (dpi) and its value was ranged from 0 (very resistant) to 1 (not resistant) and calculated from the percentage of healthy coleoptiles as a function of time (from 2 to 6 dpi).

Methods for CLR assay were conducted as reported previously by Soresi *et al.* (2015) to evaluate *in vitro* resistance components and cited recently by Sakr (2020b) to analyze both pathogenicity and resistance in the association of barley and FHB fungi. Fungal suspensions with/or without Si were prepared as mentioned above with a spore concentration adjusted to 2 × 10^5conidia/ml. Surface- disinfested *barley seeds in Petri dishes* (10 seeds per Petri dish) were imbibed for 15 minutes in 4 ml of a Si-suspension of each of 16 *Fusarium* isolates or SDW-suspension of each of 16 FHB isolates in the control treatment. Later, the excess suspension was recovered and the inoculated barley seeds were seeded on a filter paper placed in Petri dishes with 0.5% agar, then they were kept under incubation conditions (15ºC with a photoperiod of 16 h light). Coleoptiles were taken from each seedling and their lengths were measured. Coleoptile estimations were recorded in each germinated individual and expressed as a portion of the SDW dish mean without fungi. The resistance of a cultivar measured by CLR component was quantified 6 dpi.

STATISTICAL ANALYSES

Experimental data were subjected to analysis of variances (ANOVA) using DSAASTAT, 2015, version *1.514*. Arcsine transformation was used in the analysis of the percentage of coleoptile length reduction. The differences were compared using Fisher's least significant difference test with a significant level of $P<0.05$.

RESULTS

Fusarium development in Si-*Fusarium*-inoculated treatments measured by LP (Table 1), AUDPC (Table 2) and CLR (Table 3) was significantly reduced in AS and AB supplied with Si infected with all analyzed fungal isolates compared to barley plants without Si, showing a suppressive effect of Si under *in vitro* conditions on the development of four *Fusarium* species. No diseased symptoms were observed in barley plants amended with SDW. Overall, Si absorption at 1.7 mM did significantly result in significantly higher LP and lesser AUDPC and CLR compared with controls in AS and AB.

LP was higher by 21 and 14% respectively in experiment 1; 20 and 15% in experiment 2, and 20 and 16% respectively in experiment 3 in moderately resistant and moderately susceptible cultivars supplied with Si than barley plants amended with SDW (Table 1).

Si treatment reduced AUDPC by 21 and 15% respectively in experiment 1; 19 and 14% in experiment 2, and 21 and 15% respectively in experiment 3 in AS and AB as compared to plants without Si (Table 2).

CLR was reduced by Si treatments in AS and AB by 21 and 17% respectively in experiment 1; 19 and 15% in experiment 2, and 20 and 14% respectively in experiment 3 than barley plants amended with SDW (Table 3). To determine whether the application of Si to moderately susceptible cultivar, AB, could decrease the intensity of head blight pathogens development measured by LP, AUDPC and CLR to a cultivar displayed a moderately resistant that had not been treated with Si, a cultivar-Si combination (AS versus AB) was compared by single degree of freedom contrasts. In all experiments (Table 4), Si applied to AB reduced the intensity of head blight pathogens development measured by LP, AUDPC and CLR to the same statistical level as that for the cultivar AS which is moderately resistant without Si.

Table 1. Influence of silicon in barley resistance to Fusarium head blight measured by latent period (days)

cultivars	Experiment 1		Experiment 2		Experiment 3	
	- Si	+ Si	- Si	+ Si	- Si	+ Si
Arabi Aswad	5.9b	6.9a	5.7b	6.7a	5.6b	6.7a
Arabi Abiad	6.8b	8.6a	6.9b	8.6a	6.8b	8.5a

According to the Fisher's LSD test, means followed by the same letter within a linage are not significantly different at $P<0.05$. In the current study, the disease response of all cultivars infected with fungi without Si were reanalyzed for latent period; however, disease response of all cultivars infected with fungi was

analyzed previously and cited by Sakr (2019). A barley cultivar with higher value of LP was considered as more resistant than a barley cultivar with lower value of LP.

Table 2. Influence of silicon in barley resistance to Fusarium head blight measured by area under disease progress curve

cultivars	Experiment 1		Experiment 2		Experiment 3	
	- Si	+ Si	- Si	+ Si	- Si	+ Si
Arabi Aswad	0.40a	0.34b	0.41a	0.35b	0.41a	0.35b
Arabi Abiad	0.34a	0.27b	0.32a	0.26b	0.33a	0.26b

According to the Fisher's LSD test, means followed by the same letter within a linage are not significantly different at P<0.05. In the current study, the disease response of all cultivars infected with fungi without Si were reanalyzed for area under disease progress curve; however, disease response of all cultivars infected was analyzed previously and cited by Sakr (2019, Sakr and Al-Attar, 2022). A barley cultivar with lower value of AUDPC was considered as more resistant than a barley cultivar with higher value of AUDPC.

Table 3. Influence of silicon in barley resistance to Fusarium head blight measured by coleoptile length reduction (%)

cultivars	Experiment 1		Experiment 2		Experiment 3	
	- Si	+ Si	- Si	+ Si	- Si	+ Si
Arabi Aswad	42a	35b	40a	34b	41a	35b
Arabi Abiad	33a	26b	32a	26b	31a	25b

According to the Fisher's LSD test, means followed by the same letter within a linage are not significantly different at P<0.05. In the current study, the disease response of all cultivars infected with fungi without Si were reanalyzed for coleoptile length reduction; however, disease response of all cultivars infected was analyzed previously and cited by Sakr (2020b). A barley cultivar with lower value of CLR was considered as more resistant than a barley cultivar with higher value of CLR.

Table 4. Single degree of freedom contrasts for comparisons between a group of barley cultivars non-amended and amended with Si on severity of head blight measured by latent period (LP), area under disease progress curve (AUDPC) and coleoptile length reduction (CLR)

Cultivar groups	Significancy of P-values								
	LP			AUDPC			CLR		
- Si- + Si	Exp. 1	Exp. 1	Exp. 1	Exp. 1	Exp. 1	Exp. 1	Exp. 1	Exp. 1	Exp. 1
Arabi Aswad vs. ArabiAbiad	ns	ns	ns	ns	ns	ns	ns	ns	ns

Exp. = experiment, not significant (ns) at P<0.05.

DISCUSSION

From the start, absorption of Si by the root system in barley is a prerequisite for decreasing symptom development in destructive fungal diseases associated with Si feeding, i.e., powdery mildew, spot blotch as well as FHB (Wiese *et al.,* 2005; Sakr, 2021b; Holz *et al.,* 2022). Since the expressing of influx and efflux transporters *HvLsi1* and *HvLsi2* (Chiba *et al*. 2009; Mitani *et al*. 2009) in barley challenged with *Fusarium* species causing head blight has not been analyzed, it can be hypothesized that variations in Si concentrations in Si-treated plants versus non-Si-treated plants did account for positive effects of Si feeding to decrease *Fusarium* development in barley heads under controlled conditions (Wiese *et al.,* 2005; Sakr, 2021b; Holz *et al.,* 2022). Taken into account that the early development stages are logistically more convenient to elucidate the influence of Si on barley challenged with FHB pathogens (Browne, 2009; Purahong *et al.,* 2012; Soresi *et al.,* 2015; Sakr, 2020b; Sakr and Al-Attar, 2022), the usefulness of three different *in vitro* bio-experiments (varying in incoculum concentration, infection methods, growth conditions and target young plant parts) to decrease *Fusarium* development on young barley parts, i.e., detached leaves and seedlings, was elucidated for the first time.

Although quantitative barley resistance to *Fusarium* infection is most often observed under field conditions (Bai and Shaner, 2004; Dahl and Wilson, 2018; Fernando *et al.,* 2021), it may be (and often is) expressed in detached leaves and seedlings identifying by longer LP and lesser AUDPC and CLR (Browne, 2009; Purahong *et al.,* 2012; Soresi *et al.,* 2015; Sakr, 2020b, Sakr and Al-Attar, 2022). At the early development stage, differences in LP, AUDPC and CLR were observed on barley detached leaves and seedlings of Si-*Fusarium*-inoculated treatments relative to fungal-inoculated-controls, highlighting the beneficial role played by this element in decreasing head blight disease symptoms on young plant

parts under *in vitro* conditions. Overall, these results suggest that Si application on detached leaves and seedlings enhances resistance to diverse *Fusarium* pathogens in barley plants. On adult plants under controlled conditions, *F. culmorum*, *F. solani*, *F. verticillioides*, and *F. equiseti* causing head blight in barley were inhibited by both: the addition of Si to the barley nutrient solution and foliar spraying (Sakr, 2021b). In parallel, previous reports showed that notable differences were found between treatments non-supplied and supplied with Si on young plant parts in some fungal-plant associations, i.e., *Mycosphaerella pinodes (*leaf spot)/pea seedlings (Dann*et al.,* 2002), *Pyricularia grisea* (blast)/ rice seedling (Hayasaka *et al.,* 2005), *F. oxysporum* f. sp. *vasinfectum* (Fusarium wilt)/cotton seedlings (Whan *et al.,* 2016), and *Phytophthora infestans* (late blight)/potato detached leaves (Xue *et al.,* 2021).

In this study, Si treatment of barley plants was found to enhance FHB resistance in detached leaves and seedlings following Si feeding, showing that Si applications at 1.7 mM protected barley plants against *Fusarium* development. This observation suggests that in barley young parts supplied with Si in the current research, the development of the FHB pathogens was slowed down at the early development stages. Our results theoretically suggest that the two widely accepted mechanisms of Si effect on fungal pathogens may act additively and/or synergistically on *Fusarium* development in young barley parts: physical barrier and biochemical defenses after taking into account that Si did not act directly on the pathogen (Sakr, 2021a). The three components evaluated in this study were negatively impacted by silicon. These smallest values indicate that the advance of the disease in plant tissues was slower, a fact that allowed the plant to maintain a healthy leaf area for a longer period. A similar finding was also observed in barley supplied with Si and defeated several destructive fungal pathogens through alteration of their monocyclic components such as incubation period, infection efficiency, lesion expansion rate, lesion size, and number of lesions per unit leaf area (Wiese *et al.,* 2005; Sakr, 2021b; Holz *et al.,* 2022). Since Si is known to reduce the intensity of fungal diseases in different crops (Debona *et al.,* 2017; Wang *et al.,* 2017), the level of this element in the young barley organs was carefully equilibrated in all treatments to express its potential ability in the suppression of FHB. In field studies to determine the efficacy of Si for the prevention of plant diseases, Si concentration does not exceed 1.67mM (Deshmukh *et al.,* 2016). Such Si concentration was fulfilled under growth chamber conditions to enhance Type I and Type II in the spikes of barley to head blight (Sakr, 2021b).

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 young barley parts. Compared to higher levels of FHB symptoms in the detached leaves and seedlings of barley without Si, application of this element enhanced the resistance of host plants to head blight infection during this investigation, demonstrating that *HvLsi1* expression may be found predominantly in the root and be activated at the early development stages. *HvLsi1*, an influx transporter, is responsible for Si uptake from the external solution to the root cells, and is therefore considered to play a crucial role in overall Si uptake (Guo-Chao *et al.,* 2018; Kaur and Greger, 2019). In roots of barley seedlings treated with root Si application in the current work, *HvLsi2*, efflux transporter may be expressed in roots and may take Si further across the aerenchyma. Also, Si could further move up the aerial parts of the barley plants treated with Si in the present study, by another influx transporter, *Lsi6*; xylem loading of H_4SiO_4 is mediated by *Lsi6* in shoots (Guo-Chao *et al.,* 2018; Kaur and Greger, 2019). In parallel, putative Si transporter, *CMLsi1*, is localized in the roots in pumpkin (Mitani *et al.,* 2011).

Quantitative resistant barley cultivars are identified by long LP and less AUDPC and CLR determined *in vitro* (Browne, 2009; Purahong *et al.,* 2012; Soresi *et al.,* 2015; Sakr, 2020b; Sakr and Al-Attar, 2022). More importantly, Si increased resistance measured by LP, AUDPC and CLR on less resistant barley cultivar, AB, to levels comparable to this of cultivar highly resistant to FHB, AS, and not amended with Si, suggesting that Si absorption by the roots is necessary to avoid negative impact of *Fusarium* infection. The greatest control of FHB was obtained with the moderately resistant cultivar, i.e., AS, supplied with Si. Taken into account that the moderate resistance observed is associated with stronger plant defense through increased biochemical defense mechanisms (Dahl and Wilson, 2018; Janssen *et al.,* 2018; Fernando *et al.,* 2021), it seems that the effect of Si in AS may be associated with higher activation of the plant's capacity to defend itself against pathogen attack compared to AB. However, in this study, we demonstrated that Si reduced head blight development in AB which shows a moderately susceptibility to FHB. This suggests that enhanced head

blight resistance by Si is not limited to moderately resistant cultivar, AS. In accordance with our findings, Rodrigues *et al.,* (2001) demonstrated that Si reduced sheath blight development of susceptible and moderately susceptible US rice cultivars to levels comparable to those observed in cultivars high in partial resistance to sheath blight but, not fertilized with Si.

CONCLUSION

Most of our knowledge of the benefits of Si has been gained from cereals, such as the two tested barley cultivars, that are high-Si accumulators. To our best knowledge, these three distinct *in vitro* bio-experiments presented the first pathogenic evidence associated with the positive effect of Si at the concentration of 1.7 mM on enhancing barley resistance against FHB, showing that the three components evaluated in this study, i.e., LP, AUDPC and CLR, were negatively impacted by Si. In the current investigation, Si absorption and transport in barley detached leaves and seedlings infected with diverse *Fusarium* species were elucidated. Si increased resistance measured by LP, AUDPC and CLR on moderately susceptible to level comparable to moderately resistant not amended with Si, suggesting that Si feeding increase host resistance to FHB development. Thus, Si supply could be a valuable tool in integrated pathogen management by suppressing *Fusarium* development on barley.

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Contribution of Authors:

Nachaat Sakr : Design experiment, conduct research and writing manuscript