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Applications of some compounds to induce resistance against cereal aphids (Hemiptera: Aphididae) in wheat fields

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Abstract

Among the different pests of wheat, cereal aphids are considered important pests that cause economic damage at high densities. Induced resistance by using some chemical and natural products can be an effective tool to control these pests in an integrated pest management (IPM) program. In this study, the effects of some potential resistance inducers, salicylic acid (SA), calcium silicate (CaSi), potassium silicate (PSi), and tea aquatic extract, on some cereal aphid populations were investigated under field conditions. Based on the results, almost no significant difference was observed between the potential resistance inducer treatments and the control on most sampling dates. The obtained results showed that there was no significant difference between the yield parameters, e.g., wheat spike length, spike numbers/m^2, seed numbers/m^2, seed numbers/spike, 1000 seed weight, wheat plant length, total spike weight/m^2 and total seed weight/ha, between the potential resistant inducer treatments and the control. The analysis of defensive compounds like hydrogen peroxide and flavonoids, along with the activities of defensive enzymes peroxidase and catalase, showed that there is no significant difference in the flavonoid and peroxide contents of plants treated with CaSi, PSi, SA, and tea extract. The peroxidase activity assay also indicated no significant difference among the treatments. Furthermore, although plants treated with PSi showed the lowest catalase activity compared to the other treatments, there was no significant difference in peroxidase activities among plants treated with the resistance inducers and control. Therefore, the study indicated that resistance inducers are not significantly effective in pest control.

Keywords: aphids, cultural control, fertilizers, secondary metabolites, enzyme activity

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کاربرد برخی ترکیبات برای القای مقاومت به شته‌های غلات (Hemiptera: Aphididae) در مزارع گندم

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چکیده

از بین حشرات مختلف آفت گندم، شته‌های غلات جزء آفات مهمی هستند که در تراکم‌های بالا قادر به آسیب‌های اقتصادی هستند. مقاومت ایجادشده در نتیجه کاربرد برخی محصولات شیمیایی و طبیعی می‌تواند ابزاری مؤثر برای کنترل این آفات در یک برنامه مدیریت یکپارچه آفات باشد. در این مطالعه، تأثیر برخی از عوامل ایجاد مقاومت احتمالی، اسید سالیسیلیک، سیلیکات کلسیم، سیلیکات پتاسیم و عصاره آبی چای، بر جمعیت شته‌های غلات تحت شرایط مزرعه مورد بررسی قرار گرفت. بر اساس نتایج به دست آمده، تفاوت معنی‌داری بین جمعیت شته‌های غلات در تیمارهای القاکننده بالقوه مقاومت مورد آزمایش و تیمار شاهد در اکثر تاریخ‌های نمونه‌برداری مشاهده نشد. همچنین، نتایج به دست آمده نشان داد که تفاوت معنی‌داری بین پارامترهای عملکرد گندم، مانند طول خوشه گندم، تعداد خوشه بر مترمربع، تعداد دانه بر مترمربع، تعداد دانه در خوشه، وزن ۱۰۰۰ دانه، طول گیاه گندم، وزن خوشه کل بر مترمربع و وزن دانه کل بر هکتار، بین تیمارهای القاکننده بالقوه مقاومت و تیمار شاهد وجود ندارد. تجزیه و تحلیل ترکیبات دفاعی مانند پراکسید هیدروژن و فلاونوئیدها به همراه فعالیت آنزیم های دفاعی پراکسیداز و کاتالاز نشان داد که تفاوت معنی داری در محتوای فلاونوئید و پراکسید گیاهان تیمار شده با سیلیکات کلسیم، سیلیکات پتاسیم، اسید سالیسیلیک و عصاره چای تیمار شده‌اند با تیمار شاهد وجود ندارد. همچنین بررسی فعالیت پراکسیداز نشان داد که تفاوت معنی‌داری بین تیمارها وجود ندارد. اگرچه گیاهانی که با سیلیکات پتاسیم تیمار شده‌اند کمترین فعالیت کاتالاز را نسبت به سایر تیمارها نشان دادند، تفاوت معنی داری در فعالیت پراکسیداز در بین گیاهان تیمار شده با القاء کننده‌های مقاومت و شاهد وجود نداشت. بنابراین، این مطالعه نشان داد که عوامل ایجاد مقاومت تأثیر معنی‌داری در کنترل آفات ندارند.

کلیدواژه‌ها: شته‌ها، کنترل زراعی، کودها، متابولیت‌های ثانویه، فعالیت آنزیمی

دبیر تخصصی: دکتر سید علی اصغر فتحی

Introduction

Wheat, *Triticum aestivum* L., is the most significant cereal crop in the world, with the largest cultivated area and yield. Wheat was arguably one of the earliest plants that humans planted as a food source, and it is thus the most important agricultural plant.

Various pests attack the plant, causing a significant reduction in plant yield. Therefore, any effort to reduce pest damage can be a step toward the country's self-sufficiency in wheat production (Khanjani, 2007). Several species of aphids feed on wheat (Hatchett et al., 1987). The aphids insert their stylets into the leaves and feed on the sap of the plant, leading to the plant turning yellow and withering. Aphids are known as vectors of many viral diseases (Blackman and Eastop, 2000). Due to the host plant's infestation with cereal aphids, the weight of the ears, the weight of one thousand seeds, the weight of the aerial parts, the weight of the roots, the height and the survival rate of the host plant will be decreased (Dixon, 1998; Blackman & Eastop, 2000).

Aphids are among the many pests that can be controlled in an environmentally friendly way by inducing host plant resistance to a pest species (Züst & Agrawal, 2016; Pedigo et al., 2021). Induced resistance is the plant's response to chemical or physical stimuli by a specific pest, leading to a quantitative or qualitative increase in the plant's defense mechanism against it (Kogan and Paxton, 1983). Inducing resistance can directly or indirectly occur in a host plant when a pest species attacks it. Directly, the release of specific proteins or other defensive secondary metabolites due to pest injury reduces pest feeding, oviposition and attraction (Senthil-Nathan et al., 2009). The induction of resistance may indirectly result from the release of volatile synomone compounds to attract natural enemies to locate the host plant pest (Bruinsma & Dicke, 2008). Induction of resistance can be effective in suppressing pest populations by reducing herbivore survivorship and reproduction (Underwood, 1999).

In recent decades, many compounds, such as salicylic acid (SA), calcium silicate (CaSi), and potassium silicate (PSi), have been used to induce resistance against different pests and diseases (Van Poecke & Dicke, 2004; Knerat, 2009). The phenomenon of inducing resistance increases the cell's defense responses. These responses include hypersensitivity responses, oxidative bursts, cell wall strengthening and the expression of different defense genes (Cohen et al., 1994). To cause resistance in a host plant, there are various induction systems, e.g., the SAR (systemic acquired resistance) system (Sticher et al., 1997). To stimulate the activities of a series of PR (pathogenesis-related) genes, SAR induction requires the accumulation of salicylic acid molecules. Therefore, treating the host plant with salicylic acid can stimulate the SAR mechanism (Sticher et al., 1997). For instance, two distinct forms of SAR in tomato to *Macrosiphum euphorbiae* Thomas (Hem., Aphididae), jasmonic acid (JA)-dependent and SA-dependent induced defenses, were examined by Barlow (1962). The expression of a JA-inducible proteinase inhibitor in tomato cultivars with and without Mi-1.2 was triggered by exogenous foliar application of JA, and SA analog, benzothiadiazole. Therefore, the results suggest that both SA- and JA-dependent acquired resistance in tomato have a direct negative effect on this aphid. Furthermore, SAR of cucumber plants to *Bemisia tabaci* Genn. (Hem., Aleyrodidae) by aquatic tea extract was documented (Rajabpour & Zare Bavni, 2021).

This research aimed to investigate some potential, e.g., SA, CaSi, Psi, and tea aquatic extract, to induce wheat resistance against cereal aphids for developing integrated pest management (IPM) programs.

Materials and methods

Experimental design

A research wheat field, 5000 m^2, located in Agricultural Sciences and Natural Resources University of Khuzestan, Mollasani, Khuzestan province, southwest Iran (31°35'32.8"N 48°53'26.9"E), was used to conduct this study. The wheat seeds, cultivar Mehregan®, were cultivated at a planting density of 500 plants/m^2 in mid-September 2021. Agricultural practices were performed according to the advisements of the Agricultural Organization of Khuzestan Province. In this study, four potential inducers of resistance, including SA (Merck Company, Germany), CaSi (Green More (GandG Total Agro S.L., Spain), PSi (Anoca Quimica S.L., Spain) and aquatic extract of black tea (provided based on the protocol described by Yarahmadi and Rajabpour, 2015), were used at concentrations of 1 molar, 9 g/1000 L, 12 L/1000 L and 10 gr/L, respectively. In the control, the plants were sprayed with water. The treatments were performed using an electronic backpack sprayer (Venous Company®, Iran) with 20 psi spray pressure. The size of each block was 120 m^2 (12 m×10 m), and between each block, a ridge with a width of one meter was left without cultivation to prevent aphid migration. The spraying was performed at early-tillering phonological stage of wheat plants at mid-October 2021. Each treatment was repeated four times.

Aphid samplings

The sampling was performed weekly from September 2021, seedling growth phonological stage, to May 2022, grain filling phonological stage. On each sampling date, ten wheat plants were randomly chosen from each plot by moving in the X-pattern throughout the plot, and the number of cereal aphid nymphs and adults on them was recorded using a hand magnifier. The cereal aphids in the Mollasani district include *Sitobion avenae* Fabricius, *Rhopalosiphum padi* L., *R. maidis* Fitch and *Schizaphis graminum* Rondani (Rezaei et al., 2006).

Wheat yield measurement

At the end of the growing season, May 2022, some wheat yield parameters, including wheat spike length, spike numbers/m^2, seed numbers/m^2, seed numbers/spike, 1000 seed weight, wheat plant length, total spike weight/m^2 and total seed weight/ha, were separately measured in each plot.

Chemical analyses

Secondary metabolite measures

Hydrogen peroxide: The hydrogen peroxide concentration was measured from wheat plant leaves in the following procedure (Loreto & Velikova, 2001; Shu-Hsin et al., 2005): 0.2 g of fresh leaf sample was added to 1.8 mL of trichloroacetic acid solution. Then, 1% (W/V) was added and rubbed until the leaf tissue was completely lysed. The homogenized sample was transferred to a 2 ml microtube and centrifuged for 15 minutes at 12000 g acceleration. A total of 0.5 mL was removed from the supernatant of the centrifuged sample and transferred to a 2 ml microtube, and then 0.5 mL of 10 mM potassium phosphate buffer solution (pH = 8) and 1 mL of one molar potassium iodide solution were added. Hydrogen peroxide solutions in concentrations between 2 and 10 mM were used to prepare the standard chart. Finally, the absorbance of the prepared samples (step 3 of this procedure) was measured using a visible-ultraviolet spectrometer (Agilent Cary 100 UV–Vis Spectrophotometer) at a wavelength of 390 nm.

Measurement of total flavonoids: To measure total flavonoids using aluminum chloride soluble in water, the method proposed by Islami et al. (2017) was used. Aluminum chloride solution: To prepare a solution of 2.5% aluminum chloride (weight/volume ratio), 2.5 grams of aluminum chloride powder produced by

Merck (Germany) was dissolved in double distilled water and brought to a volume of 100 ml. The aluminum chloride solution was kept in a dark container at laboratory temperature until the test. Measurement of total flavonoids: 2 ml of 2.5% aluminum chloride was added to two ml of the extract prepared from washing the samples, and the sample was vortexed for 30 seconds. After incubation for 15 minutes at laboratory temperature, the absorbance was read with a spectrophotometer at a wavelength of 430 nm. Pure water was used as a control. The amount of flavonoid was determined based on the standard curve prepared using quercetin.

Enzyme activity assays

To measure the activity of antioxidant enzymes, including catalase and peroxidase, plant tissue samples were taken in different treatments. Then, 300 mg of plant tissue was ground completely in liquid nitrogen, and 1.5 ml of extraction buffer containing potassium phosphate (100 mM) with pH=7, 0.1 mM EDTA and 1% polyvinyl pyrrolidine (PVP) was added (all steps were performed on ice). The microtubes were centrifuged at 12000 × g for 10 minutes to separate the upper phase. The upper phase was kept under the name of enzyme extract at -70°C (Goud & Kachole, 2012).

Peroxidase: The Hamada and Klein (1990) method was used to measure peroxidase activity at 470 nm. The reaction mixture included 250 microliters of 100 mM potassium phosphate buffer (pH = 7), 250 microliters of 10 mM guaiacol dissolved in double distilled water, 250 microliters of 70 mM hydrogen peroxide dissolved in 100 mM potassium phosphate (pH = 7), 34 microliters of double distilled water, and 20 microliters of enzyme extract. All mentioned steps were performed in an ice water bath. The activity of peroxidase enzyme was determined based on the oxidation rate of guaiacol at 470 nm wavelength and using the extinction coefficient of 26.6 mM^{-1} cm^{-1}.

Catalase: The activity of the catalase enzyme was measured according to the method of Aebi (1984) and based on the reduction of hydrogen peroxide absorption at a wavelength of 240 nm. The reaction mixture contains 100 mM potassium phosphate buffer (PH=7) in the amount of 250 microliters, 70 mM hydrogen peroxide dissolved in 100 mM potassium phosphate in the amount of 250 microliters, sterile distilled water in the amount of 500 microliters, and enzyme extract in the amount of 30 microliters. it was prepared. The reaction mixture without enzyme extract was used as a spectrophotometer control. All mentioned steps were performed in an ice water bath. Absorption changes at a wavelength of 240 nm due to the decomposition of hydrogen peroxide during the reaction time of 180 seconds were measured by a UV spectrophotometer. After calculating the decrease in absorbance in one minute (OD/min), enzyme activity was calculated using the Beer–Lambert law and with the extinction coefficient of hydrogen peroxide (0.039 mM^{-1} cm^{-1}).

Data analyses

The experiments were performed in completely randomized design with four replications, and each plot was considered a replication. One-way analysis of variance (one-way ANOVA) by using SAS software, version 9.2 (SAS Institute, Cary, NC) was used to compare the means of the aphid population, the secondary metabolit contents and the enzym activities in different treatments. The mean comparison between different treatments was performed using Duncan’s post hoc test at the 0.05 significance level. Before one-way ANOVA, the validity of the normality assumption was confirmed by using Shapiro-Wilk test.

Results

Cereal aphid density

Seasonal population dynamics of the cereal aphids during the growing season 2022/2023 is presented in Figure 1. The aphid occured on the wheat plants during stem elongation phenological step. The first aphids were observed in 26 January 2023. The aphid denities in SA, PSi, tea extract treatment as well as control peaked at 26 January 2023. In CaSi treatment, the population peak was observed in 2 February 2023. After 2 March 2023, in begening of flowering phenological step of wheat, no aphid was recorded in different experimental treatments.

Moreover, the population densities of the cereal aphids recorded on different sampling dates in the experimental treatments are shown in Table 1. The results showed that there was no significant difference between the potential resistance inducer treatments and the control on most sampling dates (df=4,15; F=2.04; P=0.14). However, on the second sampling date, 21 January 2022, the aphid abundances in CaSi and PSi were significantly lower than those in the other treatments and the control, 83.5 and 82.1%, respectively (Table 1).

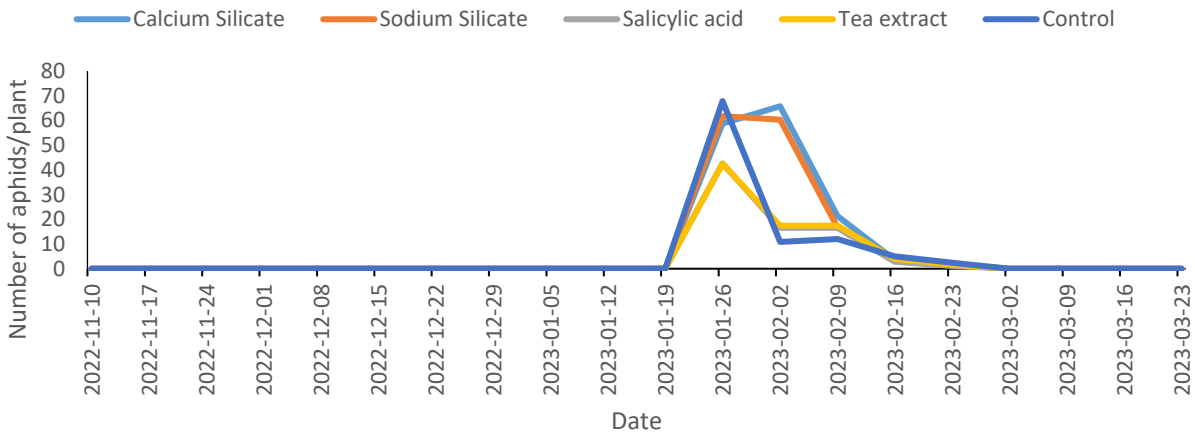

Figure 1. Seasonal population dynamics of the cereal aphids on wheat in Bavi district during seasonal growing season 2022/2023.

Table 1. Mean (±SE) of the cereal aphids per plant in different experimental treatments

Treatment	Sampling date 1	Sampling date 2	Sampling date 3	Sampling date 4	Sampling date 5
Calcium Silicate	58.82±11.78 a*	65.77±9.53a	21.40±5.12a	3.62±0.80 a	1.60±0.39 a
Sodium Silicate	61.77±6.52 a	60.37±8.28a	16.87±1.31 a	3.92±1.58 a	1.52±0.51 a
Salicylic acid	42.64±10.20 a	16.57±2.88 b	16.57±2.88 a	2.80±0.17 a	1.17±0.18 a
Tea extract	42.50±2.71 a	17.40±4.73 b	17.40±4.73 a	4.05±0.57 a	1.67±0.25 a
Control	67.87±5.78 a	10.82±1.39 b	11.97±1.99 a	5.02±0.86 a	2.42±0.44 a
$F_{(df=4,19)}$	2.04	18.34	0.892	0.754	1.438
P-value	0.140	<0.0001	0.493	0.571	0.270

* Same letters in each column indicate none significant difference at P>0.05 (Tukey HSD post-hoc test)

The wheat yield parameters

The effects of different potential inducer treatments on the different wheat yield parameters are presented in Table 2. The ANOVA indicated that there was no significant difference between the yield parameters wheat spike length, spike numbers/m^2, seed numbers/m^2, seed numbers/spike, 1000 seed weight, wheat plant length, total spike weight/m^2 and total seed weight/ha between the potential resistant inducer treatments and the control. Therefore, the treatments had no significant effect on the qualitative and quantitative yields of wheat plants.

Chemical analyses

The contents of flavonoids and peroxides in plants treated with different chemicals were measured, and no significant difference was found among the contents of flavonoids and peroxides in plants treated with CaSi, PSi, SA and tea extract (Figure 2).

Table 2. Mean (±SE) of some wheat plant in different experimental treatments

Treatment	Wheat spike length	Spike no. per m^2	Seeds no. per spike	1000 seeds weight (kg)	Plant length (cm)	Total spike weight (Kg)/m^2	Total seed weight per hectare
Calcium Silicate	9.41±0.56 a*	425±21.01 a	42.15±4.56 a	40±1.08 a	91.59±1.25 a	1.79±0.17 a	6587.5+6.14.87a
Sodium Silicate	8.91±0.16 a	421±41.42 a	39.23±4.55 a	40.25±0.25 a	91.44±0.56 a	1.52±0.09a	5587.5+441.29a
Salicylic acid	8.48±0.31 a	405±32.01 a	38.23±1.37 a	39.75±0.25 a	89.88±3.33 a	1.72±0.22a	6275+609.13a
Tea extract	8.60±0.13 a	381±14.49 a	41.32±2.36 a	40.59±0.47 a	93.83±2.69 a	1.51±0.11a	5387.5+363.07a
Control	9.66±1.15 a	393.75±33.2 a	41.26±6.64 a	41.5±0.64 a	94.46±2.16 a	1.56±0.06 a	6075+227.76a
F $_{(df=4, 15)}$	0.725	0.384	0.144	1.195	0.703	0.749	1.076
P -value	0.588	0.817	0.963	0.353	0.602	0.574	0.403

* Same letters in each column indicate none significant difference at P>0.05 (Duncan test)

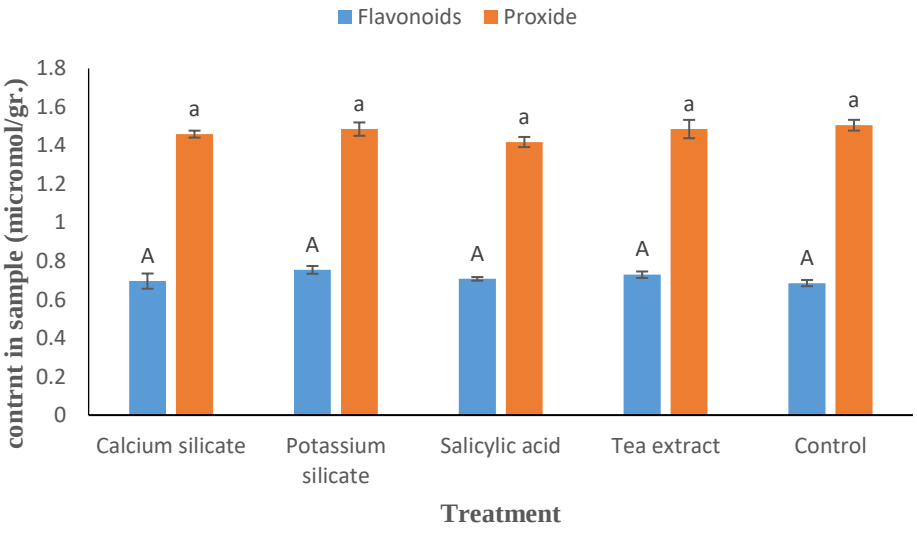

Figure 2. The contents of flavonoids and peroxide in the samples taking from different treatments. Each same capital letter indicates non-significant difference at 0.05 (Duncan post-hoc test) ($F_{df=(4, 15)}$=1.446; P =0.267). Each same lower case letter indicates non-significant difference at 0.05 (Tukey HSD post-hoc test) ($F_{df=(4,15)}$=1.071; P =0.405)

Enzyme activation

The peroxidase activity assay showed that there was no significant difference among the treatments (Figure 3). However, plants treated with PSi exhibited the lowest catalase activity compared to other treatments. No significant difference was found among the catalase activity of plants treated with CaSi, SA and tea extract.

Discussion

Our findings indicated that the potential resistance inducers have no significant effect on the population density of cereal aphids on many sampling dates. Moreover, no significant effect of the treatments was observed on different parameters of wheat yield. Silicon (Si) is a vital nutrient for plants and significantly enhances the herbivore pest resistance (HPR) of certain crops. It can be deposited in plant tissues, as a mechanical barrier against insect feeding. For example, research has shown that silicon induces callose formation in sieve tubes, effectively blocking sap intake by hemipteran pests (Alhousari & Greger, 2018), which disagrees with our expectation in this study. Previous studies have extensively documented the Si-mediated resistance against aphid pests. For instance, silicon treatment has increased host plant resistance (HRP) against the grain aphid *Sitobion avenae* F. and the green wheat aphid *Schizaphis graminum* Rond. (Hemiptera, Aphididae) in wheat under laboratory conditions (Dias et al., 2014; Basagli et al., 2003). The conflicting results may be due to the different environmental and silicon applications among the studies and our field experiments. Furthermore, silicon treatment has also enhanced HRP in other plant species. Additionally, common zinnia plants have exhibited increased resistance to the green peach aphid *Myzus persicae* Sulzer (Hemiptera, Aphididae) with silicon treatment (Ranger et al., 2009). For rapeseed, PSi caused a significant reduction in the population density of *Brevicoryn brassicae* L. (Abdollahi et al., 2021). The effect of exogenous inducers on host plant resistance can be enormously different based on the host plant and the corresponding pest species. Therefore, depending on the host species and the insect pest, the effectiveness of induced resistance should be evaluated separately.

Similar to silicon-based fertilizers, the population density of the cereal aphids and the wheat yield were not affected by SA. Phytohormones, e.g., SA and JA, are recognized for their crucial roles in regulating plant defense mechanisms against insect pests, particularly those that feed on plant sap (Moran & Thompson, 2001). In contrast to the results obtained in the current research, previous studies have documented the induction of resistance in certain host plants against specific insect pests. For instance, barley plants have shown induced resistance against *S. graminum* (Chaman et al., 2003). Similar findings were reported for applying SA to induce resistance against *B. brassicae* in rapeseed plants (Abdollahi et al., 2021). Every plant species possesses specific biochemical processes and enzymatic mechanisms in producing defensive chemicals against herbivores. Therefore, the discrepancy in the effectiveness of salicylic acid in these studies may be attributed to these differences.

Although it has been proven that tea aqueous extract has a positive effect in inducing resistance against certain sucking pests, such as whiteflies (Rajabpour & Zare Bavni, 2021), this effect has not been observed in the case of cereal aphids. For instance, the treatment of greenhouse cucumber with aquatic tea extract significantly affected the survival and reproduction of *B. tabaci* under laboratory conditions. The treatment causes a significant increase in the total contents of some defensive compounds, including tannins, phenols, and flavonoids in the cucumber plants (Rajabpour & Zare Bavni, 2021). This contradictory result can also be attributed to the differences in the biochemical systems of different plant species and the response of each pest species to inducible defensive compounds.

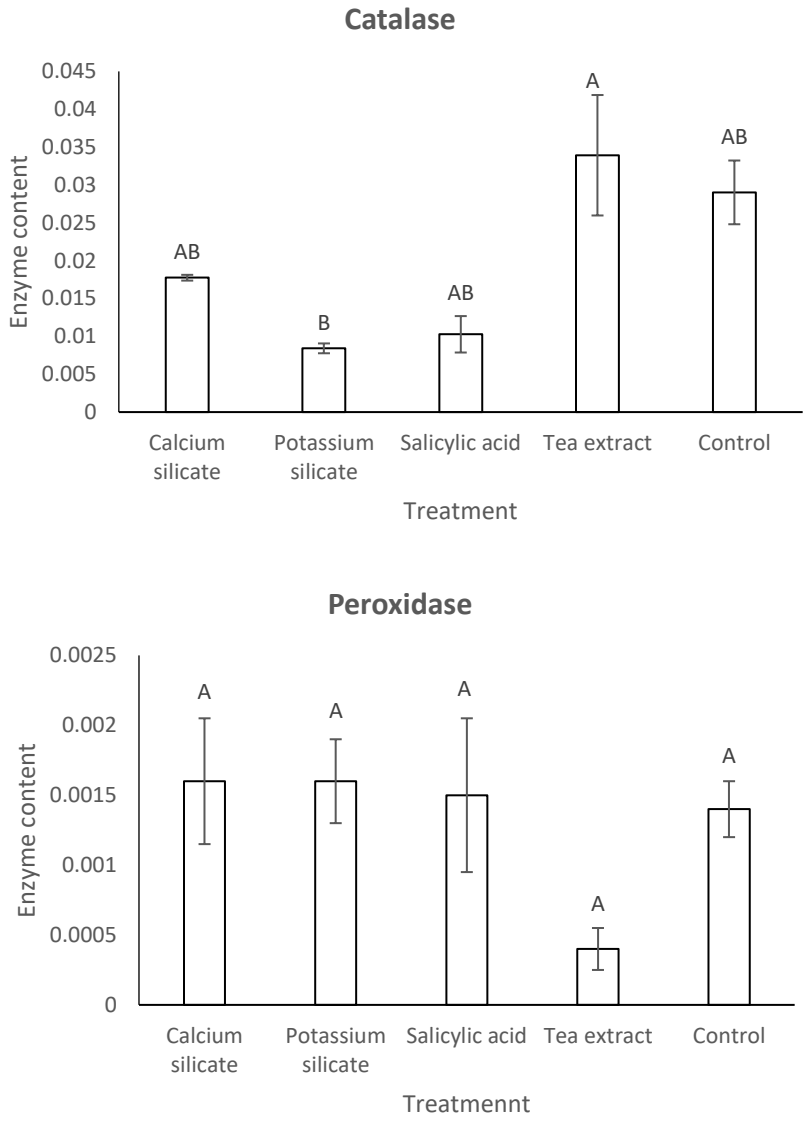

Figure 3. Enzyme contents of catalase and peroxidase in the wheat plant tissues of different experimental treatments (Same letters indicate mom-significant difference at 0.05- Tukey HSD post-hoc test; for catalase ($F_{df=(4, 19)}$: 3.25; P = 0.05) and for peroxidase ($F_{df=(4, 19)}$: 0.417; P= 0.794)

Secondary chemical compounds play a crucial role in plant resistance against pests. The production of various defensive compounds in a plant can be induced by the application of specific stimuli. However, this production varies significantly depending on the plant species and is not universal. Among the secondary defensive metabolites, flavonoids and hydrogen peroxide have been produced in various plants against herbivory insects. Flavonoids are a diverse group of secondary metabolites widely distributed in the plant kingdom. They play a crucial role in plant defense as chemical deterrents against herbivores. Flavonoids can interfere with insect feeding behavior, inhibit insect growth and development, disrupt insect digestion, and even have toxic effects on certain pests. Different types of flavonoids, such as flavones, flavonols, and anthocyanins, have

been identified in various plant species and have shown varying degrees of effectiveness against different insect pests. Hydrogen peroxide (H_2O_2) is a reactive oxygen species produced in plants in response to insect feeding or other types of stress. It acts as a signaling molecule, triggering a cascade of plant defense responses. H_2O_2 can induce the production of defense-related enzymes, such as peroxidases, which play a role in strengthening the plant cell wall and preventing insect penetration. It can also activate the expression of defense-related genes and promote the synthesis of secondary metabolites with insecticidal properties. The production of flavonoids and hydrogen peroxide in plants against insect pests is influenced not only by the type of pest but also by various factors, such as plant genetics, environmental conditions, and the intensity of the pest attack. The specific mechanisms by which these compounds contribute to host plant resistance against insect pests are still being studied, but their importance in plant defense is well recognized (Schaller, 2008). In the current study, the treatment did not influence flavonoid and hydrogen peroxide production.

Peroxidase and catalase play crucial roles in the resistance of host plants against insect pests. Peroxidase is an enzyme involved in plant defense responses, including the response to herbivorous insects. Its main function is to facilitate the oxidation of various compounds, such as phenolic compounds, and reactive oxygen species, such as hydrogen peroxide. By catalyzing these reactions, peroxidase reinforces the plant's cell wall, making it more challenging for insects to penetrate and feed on plant tissues. Additionally, peroxidase contributes to the synthesis of lignin, which provides structural support and acts as a barrier against insect herbivory. Conversely, catalase on the other hand, is an enzyme responsible for breaking down hydrogen peroxide into water and oxygen. Its primary role is to regulate the levels of hydrogen peroxide within plant cells. Catalase helps prevent oxidative damage to plant tissues by efficiently decomposing hydrogen peroxide. It also plays a significant role in modulating reactive oxygen species levels, which are involved in signaling pathways and the activation of defense genes (Taggar et al., 2012; Kaur et al., 2014). Our findings showed that the catalase activities in SA and Psi were at the highest and lowest levels, respectively.

In conclusion, the treatment is not appropriate to induce resistance in wheat plants against cereal aphids. It is recommended to investigate the effect of the inducers on wheat resistance to other ceral pests for the future.

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