AGRONOMY SCIENCE AND BIOTECHNOLOGY

SHORT COMMUNICATION

Carrageenan as an elicitor of wheat's mechanisms of defense

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ABSTRACT

Wheat represents an important staple food for human and animal nutrition. However, it constantly suffers from the incidence of biotic and abiotic stresses which reduce yields and kernels quality. The goal with this study was to use the elicitors Acibenzolar-S-Methyl and Carrageenan to elicit the mechanisms of defense of wheat to increase kernels quality and yields. The work was conducted as a random block design with six treatments and two wheat cultivars (TBIO Audaz and TBIO Noble) in Chapecó, SC, Brazil during the harvest season of 2020. Parcels had a size of 5.0 m^2 and were spread apart by 80 cm of distance. The incidence of foliar/ear diseases, seed pathological and mycotoxicological (deoxynivalenol - DON) analyses were performed. The best dosage of carrageenan (Algomel PUSH®) for wheat plants has been accessed during this work. The use of the elicitors combined with the time of application, the proximity of the parcels and the drastic climatic conditions encountered in 2020 for the area of study did not result in significant yield gain nor in kernels quality. A weak correlation between *Fusarium* Head Blight and DON accumulation was observed. The elicitors showed to be a great tool for the suppression of foliar diseases for a period of roughly 20 days. The best dose-response of carrageenan is of 1.21 L ha^{-1}.

Keywords: ASM, mycotoxins, powdery mildew, *Solieria chordalis*, *Triticum aestivum*.

INTRODUCTION

Wheat (*Triticum* spp.) corresponds to the most important staple food for humankind (Dixon, Braun, Kosina, & Crouch, 2009). This crop occupies the second largest area of cultivation in all five continents (Food and Agriculture Organization [FAO], 2021) and it is believed that wheat has been one of the first plants to be entirely domesticated, around nine thousand years a.C. (Cooper, 2015).

Although highly cultivated, wheat constantly suffers from the incidence of biotic and abiotic stresses that causes yields to drop and kernels quality to decrease (Randhawa, Bhavani, Singh, Huerta-Espino, & Singh, 2019). Many attempts, using a diverse array of possibilities have been put into practice to prevent yield losses associated with these stresses in many crops, including wheat (Choudhury, Panda, Sahoo, & Panda, 2013; Shukla, Borza, Critchley, & Prithiviraj, 2016; Ducatti et al., 2021a; Ducatti, Tironi, & Mazaro, 2021b).

The use of products associated with agricultural pesticides aiming at stimulating the primary and secondary metabolism of plants have been gaining space around the world. Carrageenans, for example, are sulphated marine polysaccharides exclusive from red seaweed with a large potential to elicit the primary and secondary metabolisms of plants (Shukla et al., 2016). Although few is known about the metabolic pathways through which carrageenan elicits plant growth/defense, it is noted that the use of these polysaccharides increases the quality of kernels and the yield of wheat and barley fields (Ducatti et al., 2021a,b).

The incidence of diseases such as the *Fusarium* Head Blight (FHB) in wheat fields, caused by the fungus *Fusarium graminearum* Schwabe 1839 (sexual phase: *Gibberella zeae* (Schweinitz) Petch 1936), largely affects wheat yield and quality (McMullen et al., 2012). Furthermore, it is believed that this fungus biosynthesizes and accumulates, in cereal kernels, a mycotoxin known as deoxynivalenol (DON) as a stress-response mechanism of defense against biotic/abiotic stresses (Ponts, 2015).

Therefore, this study aimed to use a carrageenan-rich product (Algomel PUSH®) in contrast to Acibenzolar-S-Methyl (ASM) to elicit the defense mechanisms of wheat, reduce pathogen contamination, and reduce the incidence of mycotoxins in wheat kernels.

MATERIAL AND METHODS

The research was conducted in 2020 in the experimental area of the Company of Agricultural Research and Rural Extension of Santa Catarina (EPAGRI), located in Chapecó, SC, Brazil (27°06'34"S; 52°40'18" O and altitude of 623m). The area presents a typical dystrophic oxisol and is in a Cfa Köppen climatic location. The monthly climatic conditions from the sowing until the harvest dates can be found in Table 1.

Table 1. Monthly mean climatic conditions for the experimental area. EPAGRI, Chapecó, SC, Brazil, 2020.

Parameter	Jun.	Jul.	Aug.	Sept.	Oct.
Mean Minimum Temperature (º C)	12.84	10.56	12.29	15.25	16.06
Mean Maximum Temperature (º C)	20.85	20.30	22.99	26.52	28.60
Mean Relative Humidity (%)	78.51	73.61	65.62	65.61	59.92
Total Precipitation (mm)	333.00	128.60	117.80	40.20	19.20

The research was conducted under a random block design. Parcels were spread 80 cm from each other and had a standard size of 1.0 m x 5.0 m. The sowing lines were spread 20 cm apart from each other within each parcel. The area received the application of 62 kg ha^{-1} of urea, 100 kg ha^{-1} of 09-33-12 NPK fertilizer and 16 kg ha^{-1} of KCl at sowing and was sown with the cultivars TBIO Audaz and TBIO Noble to achieve a final plant density of 330 plants m^{-2}. The area also received 100 kg ha^{-1} of urea 30 and 40 days after sowing. The experiment was composed of 6 treatments and 4 replicates per cultivar. The description of the treatments can be found in Table 2. Sowing happened on June 29th, germination was registered on July 8th and harvesting took place on October 22nd.

Table 2. Description of the treatments and applications. EPAGRI, Chapecó, SC, Brazil, 2020.

Treatment*	Algomel Push®[1]**	Bion®[1]	Fungicide[2]	Insecticide[3]
Negative control (NC)	-	-	-	Imidacloprid + Bifenthrin (200 mL ha^{-1})
Positive control (PC)	-	-	Trifloxystrobin + Prothioconazole (500 mL ha^{-1})	
ASM	-	25 g ha^{-1}		
Carrageenan 0.5	0.5 L ha^{-1}	-		
Carrageenan 1.0	1.0 L ha^{-1}	-		
Carrageenan 1.5	1.5 L ha^{-1}	-		

[1]Application happened at the beginning of the elongation stage. [2]Applications (4x) occurred at the beginning of the tillering, elongation, booting and flowering stages. [3]Applications (2x) occurred at 32 and 47 days after sowing.
*Weeding was performed manually. **Algomel Push is a commercial carrageenan-rich product based on the red algae *Solieria chordalis*.

Foliar diseases were checked every 14 days starting from the beginning of the tillering stage. The two last analyses (readings 5 and 6) were performed 7 days apart from each other. For the analysis of foliar diseases, ten plants from each parcel were carefully analyzed for powdery mildew (*Blumeria graminis*), spot blotch (*Bipolaris sorokiniana*) tan spot (*Drechslera tritici-repentis*) and leaf rust (*Puccinia triticina*). The incidence of these diseases was given in percentage of contamination in the plants (Domiciano, Duarte, Moreira, & Rodrigues, 2013; Alves et al., 2015). For *Fusarium* Head Blight (FHB), ten ears from the central line of each parcel were carefully analyzed during the readings 5 and 6 (Stack & McMullen, 2011). Six analyses were performed to check the incidence of diseases. Mycotoxin analyses were performed in duplicates for each parcel through Enzyme-Linked Immunosorbent Assays (ELISA – Reveal Q+ MAX Biogen® kit) to detect concentrations greater than 50 µg kg^{-1} (ppb) of DON. The pathological analyses of seeds were performed using 100 kernels per parcel. These kernels were disinfected with NaClO (50%), and they were transferred to germ-box containing BDA + antibiotic medium and incubated for seven days (25 °C and 12-hour photoperiod). Kernels were considered infected when mold growth was observed. Kernels were analyzed in a dissecting microscope to check the percentage of incidence of the following microorganisms *Bipolaris sorokiniana*, *Dreschlera tritici repentis, Fusarium graminearum* and *Helmintosporium* spp.

The activity of catalase (CAT – mmol H_2O_2 min^{-1} mg FM^{-1}), superoxide dismutase (SOD – U SOD mg FM^{-1}) and phenylalanine ammonia lyase (PAL – mmol min^{-1} mg FM^{-1}) was analyzed at 0, 24, 48, 96 and 192 hours after the application of the elicitors. The methodologies used for the extraction and analysis of the activity of these enzymes followed the procedures described by Monteiro and Lima (2017a, b, c).

All data were checked for normality using the Shapiro-Wilk normality test. Data were analyzed through ANOVA to check whether a significant ($p \leq 0.05$) difference existed between the means of all treatments. When a significant difference was found, Tukey's HSD pairwise ($p \leq 0.05$) statistical test was used. When an anormal distribution was found in the data, non-parametric analyses were performed using the Kruskal-Wallis analysis followed by the Mann-Whitney pairwise test ($p \leq 0.05$). Pearson linear correlation tests were performed to check the relationship between FHB and DON. All statistical analysis was performed through SAS JMP® Pro 14.0.0 (RRID:SCR 014242).

RESULTS AND DISCUSSION

The incidence of foliar diseases was very pronounced in this study, mainly in respect to powdery mildew (Tables 3 and 4) for both cultivars. This high incidence of diseases was encountered due to the fungicide chosen for disease control and the climatic conditions for the year (Costamilan & Scheeren, 2006). The choice to use this fungicide was to create more conditions for the development of diseases and to cause greater stress to plants, allowing better conditions for the elicitors to show their capacity in eliciting plants mechanisms of defense.

Although Görlach et al. (1996) have reported that the eliciting effect linked to ASM, for powdery mildew in wheat, would last for long periods of time, this was not seen in this work. The eliciting effects for disease control linked to carrageenan and ASM was of roughly 20 days after their application (elongation stage – 2^{nd} reading), demonstrating this is the period in which the elicitor can fully act and bring some benefits in respect to the suppression of foliar diseases.

Ducatti et al. (2021a, b) have reported that carrageenan could have a long-lasting effect on cereal plants because of its different degrees of solubility (Shukla et al., 2016), which would allow plants to slowly absorb carrageenan over time. This long-lasting effect would provide interesting results in respect to kernel quality. However, when analyzing the incidence of *B. sorokiniana*, *D. tritici repentis*, *F. graminearum* and *Helmintosporium* spp. (Table 5) in harvest kernels no statistical differences could be observed and correlated to the application of these elicitors.

Carrageenan and ASM had a positive effect on the activity of the enzyme CAT. However, no differences were observed for the enzymes SOD and PAL, as seen in Table 6, below.

Although many researchers (Saucedo. Contreras. & Moenne. 2015; Shukla et al.. 2016; Ducatti et al.. 2021a.b) have shown the positive effects that elicitors have on plant development by promoting an increase in plants' height, leaf biomass, chlorophyll content, net photosynthesis, carbon fixation and nitrogen assimilation. These effects were not observed during the present study, probably due to the drastic climatic conditions encountered in the harvest season of 2020 (Table 1). The total precipitation seen between the months of September and October was of only 59.4 mm. way below the ideal amount necessary for the normal development of the crop. which is around 130 to 150 mm from the beginning of the following period (Guerra et al.. 2003).

Table 3. Leaf diseases incidence (%) (powdery mildew, spot botch, tan spot and leaf rust) for the cultivar TBio Audaz. EPAGRI, Chapecó, SC, Brazil, 2020.

Parameter analyzed	Treatment	1st reading ± SE	2nd reading ± SE	3rd reading ± SE	4th reading ± SE	5th reading ± SE	6th reading ± SE
Powdery mildew	Positive Control	0	12.025 ± 2.338 a[1]	24.750 ± 2.222 ac	22.000 ± 1.242 ab	25.250 ± 3.597 ab	78.467 ± 0.775 a
	Negative Control	0	25.925 ± 2.514 b	32.667 ± 2.682 c	45.500 ± 2.558 c	74.500 ± 0.979 c	94.033 ± 0.088 b
	ASM	0	11.075 ± 0.686 a	10.850 ± 1.609 b	14.750 ± 2.420 b	17.125 ± 2.641 ab	77.025 ± 1.235 a
	Carrageenan 0.5	0	12.200 ± 1.942 a	22.000 ± 2.255 a	21.750 ± 2.570 a	27.625 ± 1.161 ab	80.850 ± 1.148 a
	Carrageenan 1.0	0	9.650 ± 1.763 a	17.425 ± 1.645 ab	21.500 ± 0.736 ab	23.750 ± 4.728 ab	81.625 ± 2.115 a
	Carrageenan 1.5	0	12.000 ± 0.551 a	17.175 ± 1.538 ab	21.375 ± 3.023 ab	36.250 ± 4.922 b	82.800 ± 1.875 a
	p-statistical	-	<0.001	<0.001	<0.001	<0.001	<0.001
Spot botch	Positive Control	0.45 ± 0.00	0.00 ± 0.00	0.138 ± 0.062 ns	3.875 ± 0.948 ns	7.900 ± 3.477 ns	3.725 ± 1.111 a
	Negative Control	0.45 ± 0.00	0.738 ± 0.738	0.450 ± 0.253	4.000 ± 2.453	1.267 ± 0.842	0.775 ± 0.250 b
	ASM	0.45 ± 0.00	0.075 ± 0.032	0.138 ± 0.043	2.500 ± 0.877	4.675 ± 1.436	1.800 ± 0.265 ab
	Carrageenan 0.5	0.45 ± 0.00	0.362 ± 0.212	0.175 ± 0.109	3.450 ± 0.504	5.000 ± 1.875	4.150 ± 0.568 a
	Carrageenan 1.0	0.45 ± 0.00	0.152 ± 0.102	0.100 ± 0.041	4.138 ± 1.197	4.183 ± 0.303	3.000 ± 0.592 ab
	Carrageenan 1.5	0.45 ± 0.00	0.038 ± 0.024	0.038 ± 0.013	2.700 ± 0.662	4.300 ± 0.962	2.700 ± 0.589 ab
	p-statistical	-	-	0.246	0.849	0.400	0.020
Tan spot	Positive Control	0	0.013 ± 0.013	0.100 ± 0.020 a	0.00 ± 0.00	0.087 ± 0.072 ns	0.00
	Negative Control	0	0.090 ± 0.059	0.300 ± 0.068 b	0.025 ± 0.014	0.163 ± 0.163	0.013 ± 0.013
	ASM	0	0.163 ± 0.118	0.087 ± 0.031 a	0.013 ± 0.013	0.188 ± 0.090	0.138 ± 0.055
	Carrageenan 0.5	0	0.007 ± 0.007	0.088 ± 0.038 a	0.00 ± 0.00	0.175 ± 0.092	0.00
	Carrageenan 1.0	0	0.00 ± 0.00	0.125 ± 0.032 ab	0.038 ± 0.024	0.075 ± 0.048	0.100 ± 0.058
	Carrageenan 1.5	0	0.092 ± 0.040	0.100 ± 0.046 a	0.038 ± 0.013	0.100 ± 0.054	0.100 ± 0.041
	p-statistical	-	-	0.014	-	0.922	-
Leaf rust	Positive Control	0	0.250 ± 0.250 ns	0.00 ± 0.00	0	0	0
	Negative Control	0	1.540 ± 0.837	0.013 ± 0.013	0	0	0
	ASM	0	0.212 ± 0.166	0.013 ± 0.013	0	0	0
	Carrageenan 0.5	0	0.278 ± 0.245	0.00 ± 0.00	0	0	0
	Carrageenan 1.0	0	0.225 ± 0.193	0.00 ± 0.00	0	0	0
	Carrageenan 1.5	0	0.427 ± 0.189	0.025 ± 0.025	0	0	0
	p-statistical	-	0.172	-	-	-	-

[1]Different letters within each column represent means that were statistically different according to Tukey's HSD statistical test (confidence level of 95%). ns = not significant. SE = standard error.

Moreover, according to Moreno-Pérez, Martínez-Ferri, Pliego-Alfaro and Pliego (2020) plant elicitation works as a vaccine for plants, and to be fully effective it must be performed before the incidence of stresses. This is not what happened in this work, as elicitors were applied in the beginning of the elongation stage, a long time after the incidence of stress in plants, which affected plants until harvest (Table 2).

Even though the common sense correlates the incidence of FHB with greater DON accumulation in wheat kernels, many reviews and research manuscripts report the opposite (Ponte, Garda-Buffon, & Badiale-Furlong, 2012; Wegulo, 2012). In the present work, a week correlation was also observed (Figure 1).

Table 4. Leaf diseases incidence (%) (powdery mildew, spot botch, tan spot and leaf rust) for the cultivar TBio Noble. EPAGRI, Chapecó, SC, Brazil, 2020.

Parameter analyzed	Treatment	1st reading ± SE	2nd reading ± SE	3rd reading ± SE	4th reading ± SE	5th reading ± SE	6th reading ± SE
Powdery mildew	Positive Control	0.650 ± 0.00 ns	15.425 ± 1.632 a[1]	29.875 ± 2.115 c	27.125 ± 1.297 a	39.875 ± 5.573 a	82.825 ± 0.969 a
	Negative Control	0.650 ± 0.00	39.667 ± 0.441 b	37.875 ± 0.515 d	43.550 ± 1.860 b	70.250 ± 1.963 b	91.850 ± 0.569 b
	ASM	0.650 ± 0.00	15.200 ± 1.299 a	23.375 ± 1.161 ab	22.125 ± 2.014 a	36.500 ± 0.866 a	80.450 ± 0.320 a
	Carrageenan 0.5	0.650 ± 0.00	15.475 ± 1.499 a	26.875 ± 0.515 ac	25.500 ± 0.289 a	28.500 ± 1.848 a	81.950 ± 1.076 a
	Carrageenan 1.0	0.650 ± 0.00	16.600 ± 1.001 a	23.500 ± 1.390 ab	25.500 ± 2.010 a	32.500 ± 1.848 a	78.525 ± 2.846 a
	Carrageenan 1.5	0.650 ± 0.00	19.025 ± 1.935 a	21.225 ± 0.813 b	25.875 ± 2.357 a	29.733 ± 0.145 a	82.175 ± 1.227 a
	p-statistical	-	<0.001	<0.001	<0.001	<0.001	<0.001
Spot botch	Positive Control	0.100 ± 0.00 ns	0.450 ± 0.433 ns	0.287 ± 0.038 ab	3.112 ± 0.766 ns	8.500 ± 1.242 ns	7.450 ± 0.782 ns
	Negative Control	0.100 ± 0.00	0.087 ± 0.059	0.675 ± 0.237 b	6.013 ± 1.522	2.288 ± 0.577	1.750 ± 0.171
	ASM	0.100 ± 0.00	0.075 ± 0.075	0.388 ± 0.038 ab	4.338 ± 1.068	8.600 ± 2.112	3.925 ± 0.938
	Carrageenan 0.5	0.100 ± 0.00	0.313 ± 0.133	0.138 ± 0.055 a	4.263 ± 0.564	8.250 ± 1.515	3.450 ± 0.777
	Carrageenan 1.0	0.100 ± 0.00	0.375 ± 0.215	0.225 ± 0.078 ab	3.675 ± 0.715	7.263 ± 1.915	4.550 ± 1.093
	Carrageenan 1.5	0.100 ± 0.00	0.115 ± 0.072	0.188 ± 0.113 ab	5.588 ± 1.263	9.325 ± 1.911	3.250 ± 0.763
	p-statistical	-	0.690	0.046	0.373	0.069	0.161
Tan spot	Positive Control	0	0.003 ± 0.003	0.163 ± 0.052 a	0.038 ± 0.024 ns	0.138 ± 0.094 ns	0.063 ± 0.037 ns
	Negative Control	0	0	0.487 ± 0.097 b	0.038 ± 0.024	0.200 ± 0.200	0.025 ± 0.025
	ASM	0	0.028 ± 0.028	0.175 ± 0.014 a	0.025 ± 0.025	0.325 ± 0.325	0.025 ± 0.025
	Carrageenan 0.5	0	0.038 ± 0.024	0.200 ± 0.068 a	0.138 ± 0.055	0.258 ± 0.537	0.075 ± 0.048
	Carrageenan 1.0	0	0	0.175 ± 0.025 a	0.038 ± 0.024	0.500 ± 0.134	0.050 ± 0.050
	Carrageenan 1.5	0	0	0.133 ± 0.024 a	0.013 ± 0.013	0.325 ± 0.214	0.025 ± 0.025
	p-statistical	-	-	0.002	0.102	0.751	0.869
Leaf rust	Positive Control	0.100 ± 0.00	1.500 ± 1.016 a	0.025 ± 0.025	0	0	0
	Negative Control	0.100 ± 0.00	9.600 ± 1.238 b	0.225 ± 0.120	0	0	0
	ASM	0.100 ± 0.00	2.288 ± 0.547 a	0	0	0	0
	Carrageenan 0.5	0.100 ± 0.00	2.450 ± 1.167 a	0.050 ± 0.029	0	0	0
	Carrageenan 1.0	0.100 ± 0.00	1.725 ± 0.659 a	0.100 ± 0.071	0	0	0
	Carrageenan 1.5	0.100 ± 0.00	2.438 ± 0.963 a	0.138 ± 0.069	0	0	0
	p-statistical	-	<0.001	-	-	-	-

[1]Different letters within each column represent means that were statistically different according to Tukey's HSD statistical test (confidence level of 95%). ns = not significant. SE = standard error.

According to Ponts (2015), DON biosynthesis and accumulation by *Fusarium graminearum* might be a consequence of a stress-response mechanism of the fungi, i.e. the more stress the fungi is submitted to, the more DON it will biosynthesize and accumulate. One of the agricultural practices that stresses fungi the most is the application of inefficient fungicides (Ducatti et al., 2021a).

Table 5. Incidence (%) of fungi in harvest kernels from the cultivars TBio Audaz and TBio Noble. EPAGRI, Chapecó, SC, Brazil, 2020.

Cultivar	Treatment	*B. sorokiniana* (%)	*D. tritici* repentis (%)	*F. graminearum* (%)	*Helmintosporium* spp. (%)
TBIO Audaz	Positive Control	2.50 ± 0.54	5.37 ± 1.78	0.00 ± 0.00	0.375 ± 0.375
	Negative Control	3.26 ± 0.72	8.37 ± 1.24	0.125 ± 0.125	0.375 ± 0.375
	ASM	2.12 ± 0.59	3.62 ± 0.85	0.00 ± 0.00	0.00 ± 0.00
	Carrageenan 0.5	3.12 ± 0.42	5.00 ± 0.67	0.00 ± 0.00	0.00 ± 0.00
	Carrageenan 1.0	2.87 ± 0.94	5.50 ± 0.64	0.00 ± 0.00	0.25 ± 0.25
	Carrageenan 1.5	3.37 ± 0.55	4.37 ± 0.12	0.12 ± 0.12	0.00 ± 0.00
	P-stat[1]	0.7358	0.1395	0.5640	0.6877
TBIO Noble	Positive Control	2.75 ± 0.47	3.00 ± 0.61	0.12 ± 0.12	0.00 ± 0.00
	Negative Control	2.62 ± 0.62	3.50 ± 0.88	0.37 ± 0.23	0.12 ± 0.12
	ASM	2.65 ± 0.47	2.87 ± 0.94	0.12 ± 0.12	0.00 ± 0.00
	Carrageenan 0.5	4.00 ± 1.02	2.37 ± 0.47	0.00 ± 0.00	0.00 ± 0.00
	Carrageenan 1.0	3.37 ± 0.96	3.87 ± 0.85	0.00 ± 0.00	0.00 ± 0.00
	Carrageenan 1.5	2.12 ± 0.80	3.00 ± 0.79	0.25 ± 0.14	0.00 ± 0.00
	P-stat[1]	0.5860	0.8088	0.3612	0.4457

[1]*B. sorokiniana* was analyzed via ANOVA and the other parameters through Kruskal-Wallis.

Table 6. Enzyme activity (CAT, PAL and SOD) at 0, 24, 48, 96 e 192 hours after the application of the elicitors on wheat cultivars TBIO Noble e TBIO Audaz. EPAGRI, Chapecó, SC, 2020.

TBIO Audaz[1]					
Tratamento	PHENYLALANINE AMMONIA LYASE (mmoles min^{-1} mg FM^{-1})				
	0 hour	24 hours	48 hours	96 hours	192 hours
Positive Control	0,089 ± 0,003 ^{ns}	0,087 ± 0,005 ^{ns}	0,098 ± 0,048 ^{ns}	0,143 ± 0,017 ^{ns}	0,209 ± 0,017 ^{ns}
Negative Control	0,117 ± 0,007	0,073 ± 0,008	0,113 ± 0,018	0,145 ± 0,031	0,164 ± 0,060
ASM	0,069 ± 0,012	0,175 ± 0,021	0,169 ± 0,032	0,243 ± 0,035	0,263 ± 0,012
Carrageenan 0.5	0,092 ± 0,018	0,113 ± 0,026	0,141 ± 0,007	0,168 ± 0,027	0,145 ± 0,068
Carrageenan 1.0	0,135 ± 0,001	0,123 ± 0,015	0,124 ± 0,004	0,137 ± 0,034	0,223 ± 0,014
Carrageenan 1.5	0,092 ± 0,045	0,149 ± 0,042	0,219 ± 0,033	0,184 ± 0,014	0,171 ± 0,060
P-stat	0,327	0,073	0,807	0,136	0,460
	SUPEROXIDE DISMUTASE (U SOD mg MF^{-1})				
	0 hour	24 hours	48 hours	96 hours	192 hours
Positive Control	22,502 ± 0,47 ^{ns}	23,425 ± 0,82 ^{ns}	23,254 ± 0,24 ^{ns}	23,410 ± 0,11 ^{ns}	23,930 ± 0,58 ^{ns}
Negative Control	23,152 ± 0,71	22,908 ± 0,33	23,041 ± 0,67	24,166 ± 0,29	24,247 ± 0,19
ASM	22,724 ± 0,40	22,526 ± 0,15	25,198 ± 0,41	23,725 ± 0,46	23,814 ± 0,29
Carrageenan 0.5	22,667 ± 0,76	23,802 ± 0,82	23,753 ± 0,42	23,565 ± 0,52	23,687 ± 0,24
Carrageenan 1.0	23,529 ± 0,71	23,278 ± 0,65	23,920 ± 0,32	23,063 ± 0,61	23,589 ± 0,16
Carrageenan 1.5	22,733 ± 0,74	23,610 ± 0,50	23,286 ± 0,89	24,129 ± 0,77	23,633 ± 0,50
P-stat	0,881	0,691	0,216	0,638	0,759

	CATALASE (mmol H2O2 min-1 mg MF-1)				
	0 hour	24 hours	48 hours	96 hours	192 hours
Positive Control	0,787 ± 0,02 ns	1,010 ± 0,06 ns	1,896 ± 0,45 ns	1,805 ± 0,29 ns	2,675 ± 0,31 ns
Negative Control	0,908 ± 0,17	0,804 ± 0,17	1,799 ± 0,16	1,779 ± 0,10	2,397 ± 0,54
ASM	0,547 ± 0,03	1,571 ± 0,58	2,302 ± 0,53	2,435 ± 0,16	2,950 ± 0,07
Carrageenan 0.5	0,699 ± 0,18	1,360 ± 0,24	2,467 ± 0,34	1,957 ± 0,22	3,132 ± 0,22
Carrageenan 1.0	0,707 ± 0,07	1,463 ± 0,29	2,181 ± 0,38	1,822 ± 0,06	2,381 ± 0,54
Carrageenan 1.5	1,082 ± 0,04	1,254 ± 0,36	2,360 ± 0,18	1,646 ± 0,30	4,092 ± 0,52
P-stat	0,066	0,596	0,757	0,133	0,098

TBIO Noble[1]					
Tratamento	PHENYLALANINE AMMONIA LYASE (mmoles min-1 mg FM-1)				
	0 hour	24 hours	48 hours	96 hours	192 hours
Positive Control	0.062 ± 0.020 ns	0.066 ± 0.010 ns	0.149 ± 0.012 ns	0.143 ± 0.008 ns	0.181 ± 0.031 ns
Negative Control	0.082 ± 0.027	0.116 ± 0.009	0.137 ± 0.038	0.171 ± 0.030	0.168 ± 0.052
ASM	0.084 ± 0.017	0.136 ± 0.027	0.164 ± 0.046	0.200 ± 0.014	0.148 ± 0.045
Carrageenan 0.5	0.095 ± 0.012	0.147 ± 0.025	0.166 ± 0.007	0.241 ± 0.030	0.229 ± 0.020
Carrageenan 1.0	0.074 ± 0.043	0.154 ± 0.031	0.163 ± 0.029	0.196 ± 0.031	0.243 ± 0.031
Carrageenan 1.5	0.116 ± 0.010	0.155 ± 0.007	0.161 ± 0.008	0.157 ± 0.017	0.205 ± 0.038
P-stat	0.709	0.069	0.971	0.113	0.490
	SUPEROXIDE DISMUTASE (U SOD mg FM-1)				
	0 hour	24 hours	48 hours	96 hours	192 hours
Positive Control	24.014 ± 0.86 ns	22.914 ± 0.56 ns	23.400 ± 0.14 ns	24.232 ± 0.39 ns	24.116 ± 0.25 ns
Negative Control	22.513 ± 0.34	24.015 ± 0.52	23.714 ± 0.37	23.637 ± 0.10	23.857 ± 0.54
ASM	23.434 ± 0.48	22.972 ± 0.27	23.452 ± 0.86	23.152 ± 0.64	23.890 ± 0.60
Carrageenan 0.5	22.197 ± 0.37	23.053 ± 0.91	22.862 ± 0.49	22.849 ± 0.41	23.913 ± 0.23
Carrageenan 1.0	22.201 ± 0.31	22.821 ± 0.98	23.183 ± 1.05	22.383 ± 0.48	23.711 ± 0.41
Carrageenan 1.5	23.202 ± 0.70	24.229 ± 0.22	24.391 ± 0.07	22.723 ± 0.35	23.644 ± 0.51
P-stat	0.165	0.581	0.627	0.075	0.986
	CATALASE (mmol H2O2 min-1 mg MF-1)				
	0 hour	24 hours	48 hours	96 hours	192 hours
Positive Control	1.059 ± 0.21 ns	1.159 ± 0.04 a	2.309 ± 0.04 ab	1.673 ± 0.13 ns	2.924 ± 0.48 ns
Negative Control	0.918 ± 0.08	0.784 ± 0.06 a	1.430 ± 0.07 a	1.817 ± 0.04	2.148 ± 0.32
ASM	0.641 ± 0.04	0.923 ± 0.05 a	1.888 ± 0.08 ab	2.176 ± 0.15	2.597 ± 0.14
Carrageenan 0.5	0.798 ± 0.17	0.927 ± 0.15 a	2.305 ± 0.06 ab	1.849 ± 0.24	2.636 ± 0.15
Carrageenan 1.0	0.689 ± 0.08	1.168 ± 0.03 ab	2.406 ± 0.40 ab	1.859 ± 0.09	1.873 ± 0.08
Carrageenan 1.5	1.125 ± 0.15	1.426 ± 0.14 b	2.672 ± 0.52 b	1.788 ± 0.24	2.082 ± 0.07
P-stat	0.160	0.006	0.037	0.453	0.065

A regression was run to see the best dose-response for carrageenan as a function of wheat yield for the experiments performed during 2020. As it can be seen in Figure 2, the best dose found for the experiment was of 1.21 L ha^{-1}, very close to the dose reported by Ducatti et al. (2021a).

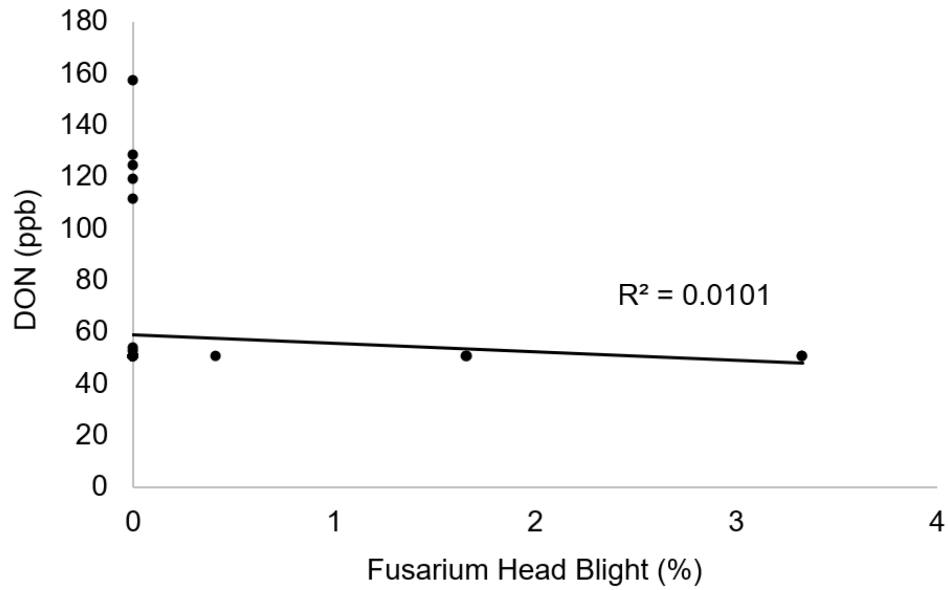

Figure 1. Mean correlation between the incidence of DON (ppb) and *Fusarium* Head Blight (%) for the cultivars TBIO Noble and TBIO Audaz. EPAGRI, Chapecó, SC, 2020.

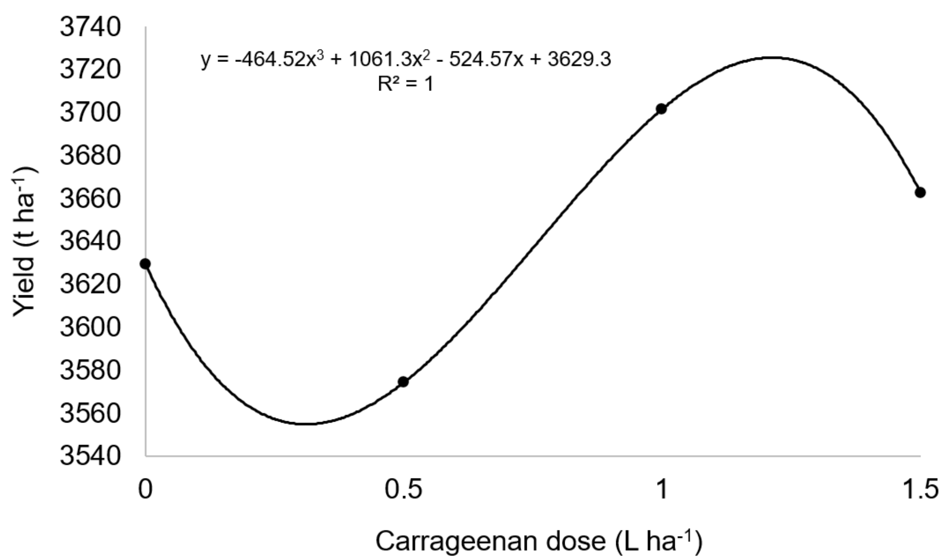

Figure 2. Identification of the best dose-response for carrageenan as a function of wheat yield for the cultivars TBIO Audaz and TBIO Noble. EPAGRI, Chapecó, SC, 2020.

CONCLUSIONS

The elicitors showed to be a great tool for the suppression of foliar diseases for a period of roughly 20 days. The best dose-response of carrageenan (Algomel PUSH®) is of 1.21 L ha^{-1}.

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