HIGH ATMOSPHERIC CO_2 CONCENTRATION ON HERBICIDE SELECTIVITY IN RICE

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INTRODUCTION

Atmospheric CO_2, temperature and availability of water or nutrients are important abiotic variables that directly affect the physiology and development of both crops and weeds. The increase in atmospheric CO_2 concentration ([CO_2]), driven by the consumption of fossil fuels, wood combustion and industrial activities, changes the supply of primary carbon available to plants, and may interfere with their metabolism. In addition, it is estimated that [CO_2] can reach levels close to twice that it was reported a few decades ago (IPCC, 2014).

As for the rice crop, climate change may have a major impact on the world's population, since the grain is a major source of carbohydrates in many countries. These changes can have a negative impact on rice production. In addition, the increase in [CO_2] may affect where and how the weeds grow and subsequently, how weeds will impact production of crops such as rice. Competition between crop and the weeds is imperative for a good productivity. The weeds, however, have the ability to respond quickly to changes in climatic factors due to its greater physiological plasticity and genetic variability in comparison with the crop, bringing negative consequences for agricultural productivity (Ziska and Mcconnell, 2015).

Besides of possible influencing plants' morphology and physiology, environmental conditions play an important role in determining the efficacy of herbicides. Herbicides absorption in the plant depends largely on their interaction with the atmosphere, soil and soil-atmosphere interface. Several environmental factors such as temperature, humidity, relative humidity and solar radiation influence the plant physiological state and its susceptibility to herbicides. Thus, climate change, especially in relation to increasing in the [CO_2], to modification in the precipitation pattern and to elevation temperature may have a significant impact on plants management and the herbicide activity. In this sense, the success of weed control in rice crops and other crops, depends not only on the herbicide chemical properties, but also on their interaction with the plant and the environment.

Thus, understanding the effects of climate changes on the weeds growth/development and herbicide activity is crucial to optimize the chemical control of weed in rice and of other crops. The objective of this study was to evaluate the herbicide selectivity and the response of rice when subjected to a high concentration of atmospheric CO_2.

MATERIALS AND METHODS

Experiment was conducted in a growth chamber at the Universidade Federal de Pelotas, Capão do Leão - RS, Brazil during 2015. The [CO_2], photoperiod (14 hours), humidity (70%) and temperature (night/day of 25/32 °C) were controlled automatically. The plots consisted of 800 ml capacity plastic pots, filled with soil classified as Solodic Eutrophic Hydromorphic Planosol, sandy loam texture class, removed from the A horizon, and herbicide residue-free.

The rice cultivar sown was the "BRS Pampa/EMBRAPA". Fertilization was performed according to the rice research recommendations in order to obtain high yields (SOSBAI, 2014). Experiment was conducted in a completely randomized design with four replications, using two factors. Factor A was constituted by atmospheric CO_2 concentration (a[CO_2] = 400 ± 50 ppm) and elevated CO_2 concentration (e[CO_2] = 700 ± 50 ppm) preview to 2100 (IPCC,

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2014). Factor B was constituted of herbicides metsulfuron-methyl (2.4 g ai ha^{-1}), saflufenacil (147 g ai ha^{-1}), quinclorac (375 g ai ha^{-1}), bispyribac-sodium (50 g ai ha^{-1}), penoxsulam (60 g ai ha^{-1}) and a treatment without herbicide (control). For the herbicides application treatments, we used a CO_2 pressurized backpack with flow rate of 150 L ha^{-1}.

Variables evaluated were the antioxidant enzymes activity of the catalase (CAT), ascorbate peroxidase (APX), superoxide dismutase (SOD) and the hydrogen peroxide (H_2O_2). Also it was evaluated lipid peroxidation content, plant height, total protein content and phytotoxicity. All evaluations were performed 10 days after treatment (DAT). Lipid peroxidation was determined indirectly by measuring the malondialdehyde (MDA) content. Material for analysis that consisted of rice leaves were collected and stored at -80 °C until analysis.

CAT activity was determined according to the methodology described by Azevedo et al. (1998), APX activity by Nakano and Asada (1981) and SOD activity by Giannopolis and Ries (1977). H_2O_2 and lipid peroxidation were determined using hydrogen peroxide content (H_2O_2), as Loreto and Velikova (2001) and the thiobarbituric acid reactive species (TBARS) by malondialdehyde accumulation (MDA), as described by Health and Packer (1968). For total proteins content was used the method of Bradford (1976).

The data were tested for normality and homogeneity of variance and subjected to analysis of variance. When significant differences were observed the Tukey test ($P \leq 0.05$) and F test ($P \leq 0.05$) were used to compare means.

RESULTS AND DISCUSSION

Plants grown in *e*[CO_2] environment showed higher CAT activity without differentiating among the herbicide treatments (Table 1). These observation suggest that rice plants grown under *e*[CO_2] might better be able to compensate environmental stresses than plants grown at *a*[CO_2]. Pritchard et al. (2000) observed lower catalase activity in plants submitted to *e*[CO_2]. The enzymatic activity and gene expression for CAT decreased in wheat plants under *e*[CO_2], possibly due to inhibition of photorespiration, while increased in response to a water restriction (Vicente et al., 2015). The highest CAT activity observed in *e*[CO_2] can be related to the greater H_2O_2 degradation capacity. In general, plants exposed to abiotic stress, such as the action of herbicides, show increased production of ROS (reactive oxygen species) (Xia et al., 2015). The CAT enzyme inhibition was also observed in wheat plants subjected to high doses of the herbicide chlorotoluron (Song et al., 2007).

Table 1. Catalase (CAT), ascorbate peroxidase (APX) and superoxide dismutase (SOD) on rice grown in *a*[CO_2] (400 ± 50 ppm) and *e*[CO_2] (700 ± 50 ppm).

Herbicides	CAT (μmol H_2O_2 min^{-1} mg^{-1} prot.)	SOD (U mg^{-1} prot.)	APX (μmol ASA min^{-1} mg^{-1} prot.)	
			a[CO_2]	*e*[CO_2]
metsulfuron-methyl	4.5	491 ab	29.3 Aa	34.8 Ab
quinclorac	4.8	438 ab	22.0 Aa	33.4 Ab
bispyribac-sodic	5.0	474 ab	26.8 Ba	60.0 Aa
penoxsulam	5.5	544 a	33.4 Aa	47.6 Aab
saflufenacil	4.0	484 ab	27.7 Aa	29.2 Ab
control	5.3	338 b	35.7 Aa	29.4 Ab
a[CO_2]	4.3 B	463 A		
e[CO_2]	5.4 A	460 A		

* Medias followed by the same letters and/or without letters do not differ statistically. The uppercase letters comparing different [CO_2] (F-test, $P \leq 0.05$) while lowercase letters compare herbicides (Tukey's test, $P \leq 0.05$). Capão do Leão, RS, 2015.

Hiher SOD activity was observed in most plants treated with penoxsulam relative to control plants, regardless of the [CO_2] (Table 1). A higher SOD expression may suggest a better control of ROS that trigger an efficient electrons transfer and C fixation. Abdelgawad et al. (2016) reported that at high levels of atmospheric CO_2, during exposure to stress, almost all antioxidant enzymes levels and activities increased. In the same study the authors report increased SOD activity of 29% when in *e*[CO_2].

Regarding the APX, the highest activity was observed in the plants treated with bispyribac-sodic in *a*[CO_2] that was not different for the plants treated with penoxsulam (Table 1). The observed difference in relation to the response by treatment with herbicides, can probably be correlated with the CAT performance speed compared to APX. Moreover, the different isoforms of APX may respond differently to each herbicide action.

A lower content of H_2O_2 was observed in rice plants treated with quinclorac and bispyribac-sodium in *a*[CO_2] (Table 2). Furthermore, in *a*[CO_2], metsulfuron-methyl produced the higher amounts of H_2O_2. In *e*[CO_2], penoxsulam showed the lowest H_2O_2 content but did not differ from the control treatment. H_2O_2 is a stable molecule and with high ability to cross membranes, which makes a good signaling molecule (Vranova, 2002). Hassan and Nemat (2005), found that the H_2O_2 content in bean plants treated with atrazine and corn with rimsulfuron (ALS inhibitors) did not differ of the control plants content.

Table 2. Hydrogen peroxide (H_2O_2) and malondialdehyde (MDA) contents in rice grown in *a*[CO_2] (400 ± 50 ppm) and *e*[CO_2] (700 ± 50 ppm).

Herbicides	H_2O_2 (μmol g^{-1} MF)		MDA (μmol g^{-1} MF)	
	a[CO_2]	*e*[CO_2]	*a*[CO_2]	*e*[CO_2]
metsulfuron-methyl	1.64 Aa	1.64 Aa	17.03 Aa	12.81 Bab
quinclorac	1.47 Bb	1.61 Aa	9.38 Bc	11.30 Abc
bispyribac-sodium	1.27 Bc	1.55 Aab	6.38 Bd	9.34 Ac
penoxsulam	1.28 Ac	1.23 Ad	13.29 Ab	9.89 Bc
saflufenacil	1.42 Abc	1.44 Abc	9.77 Bc	14.34 Aa
control	1.38 Abc	1.29 Acd	10.00 Ac	9.58 Ac

* Medias followed by the same letters and/or without letters do not differ statistically. The uppercase letters comparing different [CO_2] (F-test, $P \leq 0.05$) while lowercase letters compare herbicides (Tukey's test, $P \leq 0.05$). Capão do Leão, RS, 2015.

The MDA content, was higher in plants treated with the herbicide metsulfuron-methyl when subjected to *a*[CO_2] (Table 2). The lowest MDA content was measured in the plants treated with bispyribac-sodium at the same atmospheric condition. At *e*[CO_2], the greatest MDA content was observed in the plants treated with saflufenacil and metsulfuron-methyl. On the other hand, the smaller MDA values were obtained for quinclorac, bispyribac-sodium and penoxsulam. For the saflufenacil, that result could be relationed with faster ROS production caused by a metabolism accelerate in *e*[CO_2].

As for the rice plants height, was observed difference when compared the different [CO_2], it not being possible observe difference among herbicides tratment (data not shown). These results may be correlated to the "fertilization" effect, caused by the additional [CO_2], which results in a higher growth rate (Ziska, 2002). No differences were observed in total protein content and phytotoxicity (data not shown).

Preliminary results indicated that influence of climate changes in the herbicides action still needs to be better explored considering the relative small range of information in the literature and the complexly of the subject. Disregard the system as a whole may lead to erroneous conclusions. Each herbicide may be influenced differently from others in each ambient and species/biotype must be considered.

CONCLUSION

Different [CO_2] do not change SOD activity. APX activity could be high in rice plants trated with bispyribac-sodic and grown in *e*[CO_2]. Elevated [CO_2] does not increase injury of selective herbicides on rice. Rice plant height is higher when grown in elevated [CO_2].

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