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EVALUATION OF THE EFFECT OF ELEVATED CO_2 ON BIOEFFICACY OF BUPROFEZIN INSECTICIDE AGAINST BROWN PLANT HOPPER, *Nilaparvata lugens* (STÅL)

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ABSTRACT

The effect of elevated CO_2 (570±25ppm) on the brown plant hopper (BPH) population, rice yield parameters, and efficacy of buprofezin (0.05%) in terms of spray volume was studied in an open top chamber (OTCs) during rainy season 2017 and 2018. The pest population was observed to be higher during 2017 compared to the rainy season of 2018. Under elevated CO_2, rice plants had more vegetative tillers (18%) and reproductive tillers (22.1%), but there was a decrease in 1000-seed weight (11.2%), seed number per panicle (3.91%), and grain yield (18.8%) in comparison to ambient CO_2 grown rice plants. The spray volumes of 700, 600, 500, and 400 l/ha each caused higher BPH mortality under ambient CO_2 compared to elevated CO_2. A spray volume of 500 l/ha did not prove as effective under elevated CO_2 as under ambient CO_2. Lower efficacy of spray volume of 500 l/ha under elevated CO_2 could be ascribed to higher canopy size under elevated CO_2 due to higher tillering. Increased crop canopy size under elevated CO_2 may thus require higher spray volume to ensure proper coverage. Results of the study suggested a need to revise spray volume recommendations to facilitate effective management of BPH under climate change.

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1 Introduction

Rice (*Oryza sativa* L.) is one of the important cereals of the world particularly in Asian countries and forms a staple diet for more than 50 percent of the population (Khush, 2004). It is grown on 33.3% of the area with 41% of total food grain production in India and with the productivity of 2404 kg/ha (DAC, 2016-17). Among important insect pests of rice, brown plant hopper, (BPH) *Nilaparvata lugens* (Stål) is a serious pest, wherein both nymphs and adults suck the phloem sap from the plants causes yellowing and drying of plants results "hopper burn"(Figure 1a). Besides, it also causes harm indirectly as a vector for rice grassy stunt and ragged stunt diseases of rice (Anjaneyalu, 1974; Zheng et al., 2014). Before the green revolution, BPH was a minor pest, but, post 1970 it attained major pest status due to the growth of susceptible high yielding varieties (HYVs) of rice and indiscriminate use of insecticides that killed natural enemies of BPH in Asia (Dale and Kenneth, 2012). In the northern part of India also, it caused several outbreaks since 2008 (Chander & Hussain, 2018). Further, many studies indicate that under elevated CO_2 the BPH problem will be aggravated (Pandi et al., 2017 and 2019).

According to the Intergovernmental panel on climate change (IPCC) the earth's temperature has already increased by 0.74°C between 1906 and 2005 and CO_2 is expected to increase up to 445–640 ppm by 2050 due to an increase in anthropogenic emissions of greenhouse gases (IPCC, 2007). Climate change will have an impact on insects through temperature, which affects the insect's pests directly while CO_2 affects them indirectly through host plants and natural enemies (Netherer & Schopf, 2010). Under elevated CO_2, an increase in carbon: nitrogen (C:N) ratio in plants resulted in the accumulation of carbon that forced herbivores to feed more to acquire the required amount of amino acids (Coviella & Trumble, 2000; Rao et al., 2009), which in turn inflicted more crop damage as compared to ambient CO_2. Although under elevated CO_2 and a combination of elevated CO_2 and temperature, rice plants produced more vegetative and reproductive tillers and grains per panicle but suffered higher yield loss due to a higher BPH population (Prasannakumar et al., 2012: Pandi et al., 2018). Besides affecting insect population, climate change is expected to have a significant influence on pest management tactics such as host plant resistance (Guo et al., 2012 and 2017), biological control (Coll & Hughes, 2008; Yin et al., 2009) and insecticide efficacy. Many studies have been mostly concentrated on the impact of climate change on insect pests (Sudderth et al., 2005; Reddy et al., 2010; Prasannakumar et al., 2012) while the information on the impact of climate change on the efficacy of insecticides is meager. Delcour et al. (2015) opined that increased pesticide use is expected in the form of higher doses, frequency, and different products under climate change scenarios. Pandi et al. (2019) reported that the spray of 400 and 500 l/ha was not sufficient to manage the BPH under elevated temperature and CO_2 with imidacloprid 17.8SL @ 0.006%. Insecticides that are effective against insect pests but relatively innocuous to non-target organisms including biological control agents are known as biorationals. Among these, an insect growth regulator (IGR) buprofezin is a promising one against BPH compared to neonicotinoids (Uchida et al.,1985; Hegde & Nidagundi, 2009; Shivashankar & Gowda, 2015). Keeping this in view, this biorational pesticide was evaluated in the present study against BPH under elevated CO_2 conditions to determine future requirements with regards to its spray volume.

2 Materials and Methods

2.1 Maintenance of Rice plants

The effect of different spray volumes of buprofezin 25SC(0.05%) against BPH under elevated CO_2 (570±25ppm) *vis-à-vis* ambient CO_2 (400±25ppm) was investigated on potted rice plants kept in open top chambers (OTCs) during rainy season 2017 and 2018 at the Division of Plant Physiology, ICAR-Indian Agricultural Research Institute, New Delhi (28.6377° N, 77.1571° E). Twenty-two days old seedlings of scented rice Pusa Basmati 1121 were transplanted in 100 plastic pots (22.5 X 15 cm^2) on 20^{th} July and 18^{th} July during 2017 and 2018, respectively, and raised further by following recommended agronomic practices.

2.2 Plant exposure to CO_2, BPH infestation and insecticide

The study was undertaken in two OTCs one having ambient CO_2 (400±25ppm) and the other had elevated CO_2 (570±25ppm). Seedlings were transplanted in 100 pots and 15 days after transplanting (DAT) 50 pots were kept in each OTCs. The CO_2 was released in OTC during day time only between 9.30 AM to 4.30 PM until the maturation of paddy grains as only during daytime plants utilize CO_2 for photosynthesis. Under elevated CO_2, potted rice plants were exposed to elevated CO_2 (570±25ppm) for 15 days before the release of 5 pairs of laboratory reared BPH adults in each potted plants to acquire infestation under both ambient and elevated CO_2 condition. The BPH population was monitored regularly in the OTCs to ensure the insecticide application at peak incidence of the pest. The BPH population was found to peak after 45 days of its release in OTCs and thus treated at this stage. The insecticidal treatments comprised four spray volumes *viz.*, 400, 500, 600, and 700 l/ha along with untreated control (spray with plain water), each treatment have 10 replicates each. The different spray volumes of buprofezin (0.05%) were applied using hand held mist sprayer and observations on BPH mortality were recorded on three, six, and ten days after the application as it's being an IGR acts only at the nymphal stage of the pest (Uchida et al., 1985; Alam & Das 2017). The plant growth and yield parameters such as vegetative tiller number, reproductive

Figure 1(a) Hopper burn symptoms on rice caused by rice planthoppers in Delhi: 1(b) Difference rice yield parameters under elevated and ambient CO_2

tiller number, 1000-seed weight, and seeds per panicle were recorded across the treatments. BPH mortality was compared among different spray volumes both under ambient and elevated CO_2. However, yield parameters were pooled across the spray volumes and compared broadly between ambient and elevated CO_2.

2.3 Statistical Analysis

Pre spray BPH populations across different treatments were averaged. The pre-spray BPH populations and BPH mortality with different spray volumes of buprofezin (0.05%) under ambient and elevated CO_2 were analysed using one-way analysis of variance (ANOVA) and Tukey's honest significant difference (HSD), while the effect of elevated CO_2 on growth and yield parameters of BPH infested plants was analysed through t-test.

3 Results

3.1 Effect of elevated CO_2 on BPH population

The BPH population at peak infestation (45 days after infestation) was found to be higher in different treatments during rainy season 2017 both under elevated (135.3±25.9 to 239±28.68/hill) and ambient CO_2 (115.6±12.3 to 278.2±34.02/hill) compared to rainy season 2018 with respective peak populations ranging from 75.3±9.9 to 93.8±12.5/hill and 76.5±9.20 to 91.6±11.98/hill. The pest population was thus non-significantly higher under elevated CO_2 than the ambient CO_2 during 2017 but did not differ between two CO_2 levels during 2018 (Table 1).

3.2 Effect of elevated CO_2 on rice yield parameters

Different yield parameters of BPH-infested rice plants differed significantly under ambient and elevated CO_2 during both the years of study (Table 2). Pooled data of two years indicated that rice plants grown under elevated CO_2 had more number vegetative tillers (18%) and reproductive tillers (22.1%) than ambient CO_2 (Table. 2). However, grain yield (18.8%), seed number per panicle (3.91%), and 1000-seed weight (11.29%) were observed to be lower under elevated CO_2 than ambient CO_2 (Table 2; Figure1b).

3.3 Effect of elevated CO_2 on bio-efficacy of buprofezin insecticide

During 2017, the BPH mortality data revealed that buprofezin (0.05%) at 3 days after spraying (DAS) resulted in very low BPH mortality under both ambient and elevated CO_2 that remained around 18% under both the CO_2 conditions with all the spray volumes (Table 3). Likewise, during the rainy season, 2018 buprofezin (0.05%) resulted in poor mortality (≤13%) at 3DAS under both ambient and elevated CO_2 with all the spray volume (Table 4)

At 6 DAS also, the mortality was low and was observed to be 31 and 26% under ambient and elevated CO_2 conditions respectively with 700 l/ha spray volume during 2017 (Table 3). Similarly, the mortality remained low at 6 DAS during 2018 and was recorded to be 27 and 24% under ambient and elevated CO_2condition, respectively with 700 l/ha spray volume (Table 4)

However, at 10 DAS, buprofezin (0.05%) caused the highest mortality with a spray volume of 700 l/ha (45.6±2.5%) followed by 600 (42.2±1.99%), 500 (38.7±4.64%), and 400 (31.8±2.71%) l/ha under ambient CO_2 compared to corresponding mortalities under elevated CO_2 as 40.61±3.50, 36.92±2.49, 32.65±1.9 and 28.44±2.16 % during the rainy season 2017 respectively (Table 3). The same trend was observed during 2018 and buprofezin (0.05%) at 10 DAS inflicted the highest mortality with a spray volume of 700 l/ha (44.2±2.4%) followed by 600 (37.93±2.5%), 500 (33.50±2.29%), and 400 (21.75±1.5%) l/ha under ambient CO_2 compared to corresponding mortalities under elevated CO_2 as 41.25±1, 33.51±1.9, 25.04±1.7 and 20.68±.59 during rainy season 2018respectively (Table 4)

Table 1 Brown planthopper (BPH) peak population (Number/hill) prior to buprofezin (0.05%) application

Treatment	No. of BPH/hill during 2017		No. of BPH/ hill during 2018	
	Ambient CO_2 (400 ± 25 ppm)*	Elevated CO_2 (570 ± 25 ppm)*	Ambient CO_2 (400 ± 25 ppm)*	Elevated CO_2 (570 ± 25 ppm)*
400 l/ha	191.9±23.04[ab]	194.8±25.33[ab]	79.3± 5.7[a]	88.3±10.21[a]
500 l/ha	278.2±34.02[a]	239±28.68[a]	76.5±9.20[b]	91.8±5.51[a]
600 l/ha	115.6±12.36[b]	220.8±21.72[ab]	91.6±11.98[a]	79.5±4.1[a]
700 l/ha	220.2±16.57[a]	208.1±19.37[ab]	81.1±9.83[a]	75.3±9.9[a]
Control Average	198.3±20.69[ab] 200.8±23.4	135.3±25.59[b] 199.6±15.7	80.8±11.36[a] 81.8±2.2	93.8±12.5[a] 85.74±3.20
F value	6.070	2.688	.227	1.42
P value	0.001	0.043	0.889[NS]	0.264[NS]

Brown planthopper counts with different lowercase letter in the same column differ significantly at P=0.05%, NS:Nonsignificant. * mean of ten replicates.

Table 2 Rice growth and yield parameters under elevated and ambient CO_2

Parameter	Rainy season 2017			Rainy season 2018			Average	
	Ambient CO_2* (400 ± 25 ppm)	Elevated CO_2* (570 ± 25 ppm)	t-Statistics	Ambient CO_2* (400 ± 25 ppm)	Elevated CO_2* (570 ± 25 ppm)	t-Statistics	Ambient CO_2 (400 ± 25 ppm)	Elevated CO_2 (570 ± 25 ppm)
No. of tillers per hill	20.3±0.53	24.1±0.79	t= -3.7(p=0.001)	17.2±0.72	19.7±1.11	t= -1.7(p=0.103)[NS]	18.79±1.5	22.18±1.9
No. of reproductive tillers per hill	18.3±0.42	22.5±0.55	t= -5.7(p<.0001)	16±0.61	18.8±1.10	t= -2.1 (p=0.050)	17.15±1.1	20.95±1.5
1000 seed weight (g)	19.7±0.28	16.9±0.37	t= 5.7(p<0.0001)	17.4±0.38	15.8±0.38	t= 2.9 (p=0.009)	18.51±1.8	16.42±0.5
Seeds per panicle	79.12±0.85	73.27±1.36	t= 3.18(p=0.005)	80.8±2.75	75.9±2.50	t=1.04(p=0.310)[NS]	77.50±3.3	74.58±3.9
Yield per hill (g)	27.2±0.30	23.1±0.62	t= 5.6(p<0.0001)	25.2±0.38	20.8±0.52	t= -6.40 (p<0.001)	26.21±0.9	22.05±1

Yield parameters were mean±SE, significant at 5% level of significance *: average of ten replicates. NS, Non-significant

Table 3 Mean BPH mortality (%) at different intervals after buprofezin (0.05%) application during rainy season 2017

Treatment	3 DAS		6 DAS		10 DAS	
	Ambient CO_2* (400 ± 25 ppm)	Elevated CO_2* (570 ± 25 ppm)	Ambient CO_2* (400 ± 25 ppm)	Elevated CO_2* (570 ± 25 ppm)	Ambient CO_2* (400 ± 25 ppm)	Elevated CO_2* (570 ± 25 ppm)
400 l/ha	13.59±1.14 (21.45[a])	11.15±2.58 (18.57[b])	19.41±1.8 (25.84[b])	18.50±2.35 (25.08[b])	31.79±2.71 (34.03[b])	28.44±2.16 (32.05[b])
500 l/ha	14.91±1.78 (22.33[a])	11.83±1.19 (19.89[ab])	24.03±2.87 (28.96[ab])	20.90±1.65 (27.02[ab])	38.72±4.64 (38.17[ab])	32.65±1.95 (34.75[ab])
600 l/ha	17.64±1.80 (24.59[a])	14.88±1.37 (22.45[ab])	27.88±1.6 (31.76[a])	24.07±1.92 (29.18[ab])	42.20±1.99 (40.46[ab])	36.92±2.49 (37.27[ab])
700 l/ha	18.61±1.63 (25.36[a])	17.15±1.01 (24.37[a])	31.362.38 (33.70[a])	26.18±2.09 (30.61[a])	45.62±2.53 (42.44a)	40.61±3.50 (39.46[a])
Control	0.72±0.22 (3.67[b])	1.78±0.37 (7.27[c])	2.46±0.38 (8.73[c])	3.530.56 (10.52[c])	3.51±0.53 (10.45[c])	5.61±1.02 (13.18[c])
F value	50.91	25.31	47.12	37.24	50.08	45.69
P Value	P<0.0001	P<0.0001	P<0.0001	P<0.0001	P<0.0001	P<0.0001

DAS: Days After Spray. *= average of ten replicates (mean±SE) mortality data with different lowercase letters in same column differ significantly. Data in parenthesis are arc sin transformed values. Arc sign transformed values were used in ANOVA followed by Tukey HSD test at 5% significance.

Table 4 Mean BPH mortality (%) at different intervals after buprofezin (0.05%) application during rainy season 2018

Treatment	3DAS		6DAS		10DAS	
	Ambient CO_2*(400 ± 25 ppm)	Elevated CO_2*(570 ± 25 ppm)	Ambient CO_2*(400 ± 25 ppm)	Elevated CO_2*(570 ± 25 ppm)	Ambient CO_2*(400 ± 25 ppm)	Elevated CO_2(570 ± 25 *ppm)
400 l/ha	7.10±0.85 (15.33^{b})	7.10±0.59 (15.37^{b})	13.92±1.38 (21.76^{b})	12.62±1.10 (20.70^{c})	21.75±1.54 (27.72^{c})	20.68±0.59 (27.03^{c})
500 l/ha	8.08±0.65 (16.44^{ab})	9.04±0.87 (17.36^{ab})	18.68±1.08 (25.55^{ab})	15.34±0.47 (23.04^{bc})	33.50±2.29 (35.30^{b})	25.04±1.71 (29.96^{bc})
600 l/ha	10.80±1.26 (19.01^{ab})	10.78±1.02 (19.08^{ab})	23.73±3.13 (28.91^{a})	20.45±1.98 (26.71^{ab})	37.93±2.59 (37.96^{ab})	33.51±1.96 (35.31^{ab})
700 l/ha	13.08±1.44 (21.07^{a})	12.31±0.45 (20.51^{a})	27.03±2.03 (31.24^{a})	24.53±0.91 (29.65^{a})	44.2±2.42 (41.67^{a})	41.25±1.50 (39.93^{a})
control	0.93±0.40 (4.20^{c})	1.396±0.35 (5.98^{c})	3.18±0.58 (10.01^{c})	2.023±0.15 (8.14^{d})	4.56±0.72 (12.13^{d})	2.76±0.40 (9.44^{d})
F value	25.16	28.80	29.92	67.14	66.10	51.85
P Value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

DAS: Days After Spray. *= average of ten replicates (mean±SE) mortality data with different lowercase letters in same column differ significantly. Data in parenthesis are arc sin transformed values. Arc sign transformed values were used in ANOVA followed by Tukey HSD test at 5% significance.

4 Discussion and Conclusions

Increased pesticide use is being projected in the form of higher doses and frequencies to effectively combat crop pests under climate change scenarios (Chen & McCarl, 2001). An increase in temperature, ultraviolet radiation (UV), and decrease in relative humidity may render plant protection techniques like natural plant products, entomopathogenic viruses, bacteria, fungi, nematodes, and synthetic pesticides less effective because these are highly sensitive to environmental variation (Sharma, 2014) and such effects would be more pronounced on biopesticides (Isman, 1997). In the present study, elevated CO_2 increased the number of tillers and reproductive tillers that resulted in increased rice crop canopy, and the pest population was recorded to be non-significantly higher under elevated CO_2 than ambient CO_2 during 2017. Earlier studies have reported a higher BPH population under elevated CO_2 (Prasannnakumar et al. 2012) and under the combination of elevated CO_2 and temperature (Pandi et al., 2019) than ambient CO_2, because of a more favourable microenvironment for the pest multiplication. In the present study, the pest-induced yield loss was observed to be higher under elevated CO_2 than ambient CO_2 mainly due to the higher sucking rate of the pest under elevated CO_2 as the pest population did not differ significantly under two CO_2 levels. In previous studies, higher yield loss due to BPH under elevated CO_2 was ascribed to both higher pest population and sucking rate than under ambient CO_2 (Prasannnakumar et al., 2012; Pandi et al., 2019). Buprofezin (0.05%) proved to be most effective against the pest at a spray volume of 700 l/ha followed by 600, 500, 400 l/ha under both ambient and elevated CO_2 conditions. However, BPH mortality always happened to be higher under ambient than elevated CO_2 at respective spray volumes. The buprofezin application did not produce significant mortality under both the CO_2 conditions at 3 and 6 DAS which could be perhaps ascribed to insect growth regulatory (IGR) activity of buprofezin, which is slower compared to neurotoxic insecticides, which act faster resulting in the instant kill of the pest. Similarly, slow action of buprofezin against plant hoppers of rice has also been reported earlier (Uchida et al.,1985; Shivashankar & Gowda, 2015; Alam & Das, 2017). A spray volume of 500 l/ha, which is currently recommended for the management of rice insect pests did not prove to be effective under elevated CO_2. Ineffectiveness of spray volume of 500 l/ha could be ascribed to increased canopy size due to increased tillering under elevated CO_2 that resulted in increased canopy circumference. Increased crop canopy might thus require higher spray volume to ensure proper coverage against the pest. In this context, earlier also pesticides are more effective against insect pests at higher spray volumes under elevated CO_2 and temperature in the case of imidacloprid (0.006%) against BPH (Pandi et al., 2019) and at ambient conditions in the case of *Beauveria bassiana* against western flower thrips, *Frankliniella occidentalis* (Ugine et al., 2007), methoxyfenozide or fenpropathrin against grape berry moth, *Paralobesia viteana* (Wise et al., 2010) and buprofezin (15%) +acephate (35%) against rice plant hoppers (Ghoshal et al., 2018). Another study also indicated the reduced efficacy of triazophos under elevated CO_2 against BPH (Ge et al., 2015). The current study revealed that elevated CO_2 may have a nutritive effect on rice yield through increased tillering and greater canopy size thereby turning the microenvironment more favourable for the pest. Consequently, the presently recommended spray volume may not suffice to ensure proper spray coverage of foliage to safeguard the crop against insect pests. There may thus be a need to revise spray volume recommendations to facilitate effective management of BPH under changing climatic conditions.

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Conflict of Interest

Authors declare that they have no conflict of interest

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