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RESEARCH ARTICLE

Effect of weed interference on rice yield under elevated CO_2 and temperature

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ABSTRACT

Rice (*Oryza sativa* L.) is one of the major staple food source for more than half of the global population. To attain the food needs of the world's growing population, further increase in rice productivity is needed. To assess the sensitivity of agricultural output, a greater comprehension of the possible interactions amongst crops and weeds in the face of climate change, especially under elevated CO_2 (EC) and elevated temperature (ET), is essential. This study was conducted to quantify the influence of elevated temperature, CO_2, weed density and their interactions on crop-weed competition, rice yield parameters and grain yield. The experiment was conducted in four separate Open Top Chambers (OTCs), *viz.* with ambient CO_2 (A), elevated CO_2 [550±50 ppm] (EC), elevated temperature (ambient±2 °C) (ET) and combined effect of elevated CO_2 and temperature (EC+ET) with and without weed competition. The EC alone enhanced the rice grain yield by 42.30% in weed-free conditions when compared to ambient CO_2, however substantial change was not observed under ET. In the EC+ET condition, however, regardless of weeds presence or absence, crop output was reduced by 22.02 percent. *Alternanthera paronychioides* A. St.-Hil. competition caused rice yield reduction of 79.72, 83.04, 62.98 and 62.01% at A, EC, ET, EC+ET, respectively. The EC and ET interactions will certainly exert a profound influence on weed growth and competition against crops, which ultimately enhances crop yield losses in futuristic climate change scenario.

Keywords: Climate change, Crop-weed interaction, Rice, Elevated CO_2, Elevated temperature, Weed competition

INTRODUCTION

The rising CO_2 levels and temperatures are of major concern to agriculture in the era of climate change. Atmospheric CO_2 levels have increased at a record-breaking rate (https://www.co2.earth/). Atmospheric CO_2 levels are already rising and will potentially exceed 800 ppm by the ending of the 21st century. Global surface temperature was estimated to rise by 1.5 °C relative to 1850 by the end of the 21st century (IPCC 2014). The increasing levels of CO_2 and predicted climate change may benefit the establishment and proliferation of weeds over crops which can have negative consequences for agricultural productivity (Peters *et al*. 2014, Ziska 2007). Therefore, for the assessment of the vulnerability of crop production in different parts of the world and a broader perception of the possible interactions between crops and weeds under the climate change scenario, especially CO_2, high temperatures and drought, is important (Valerio *et al.* 2013). Changes in weed distribution have also been caused by climate change. The establishment of *Marsilea* spp. in India under wet rice conditions was attributed to climate change (Kathiresan and Gualbert 2016). The drought and the transition to direct-seeded rice, favored the predominance of recalcitrant grass weeds such as *Dactyloctenium aegyptium* (L.) PB, *Eleusine indica* (L) Gaertn and *Leptochloa chinensis* (L.) Nees (Chauhan *et al.* 2014, Matloob *et al*. 2015). Elevated atmospheric temperature changes have also triggered shifts in weed flora. For instance, *Ischaemum rugosum* Salisb. primarily seen in the tropical regions of India is now very widespread in northern India (Mahajan *et al.* 2012). Hence, in the climate change scenario, it is imperative to look at crop-weed competition case by case to establish successful weed management practices for the emerging species.

Rice (*Oryza sativa* L.) is a major food crop, being consumed every day by 50% of the population of the world (Wei and Huang 2019). It is also a main food in Asia, which is home to more than half of the world's poorest population. Losses in rice yield range

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from 10 to 79% globally in competition with *Echinochloa* spp. (Chin 2001, Rao *et al.* 2017, Rao 2021). In general, high temperatures and CO_2 levels can alter dominant weed species and exacerbate weed growth (Ziska and Dukes 2011). Nakagawa *et al.* (2002) observed about 14 per cent increase in the production of rice biomass due to elevated CO_2 in CO_2 temperature gradient tunnels compared to 9% in the FACE experiment. However, Kim *et al.* (1996) and Baker *et al.* (1990) recorded lower rice biomass accumulation in FACE investigations as compared to that of open top chambers (OTCs) and CO_2 temperature gradient tunnels. The doubling of CO_2 concentration resulted in a 30% increase in rice yield (Horie *et al.* 2000). The elevated CO_2 concentration was reported to promote tillering, rate of photosynthesis, biomass accumulation and yield in rice (Kobayashi *et al.* 1999, Sakai *et al.* 2001, Chakrabarti *et al.* 2012).

In order to maintain sustained rice productivity, to meet the increasing global food needs, it is vital to evaluate the influence of prospective changes in the climate on rice yield. Therefore, this study was conducted with an objective to quantify the interactive effect of high CO_2 and temperature, as well as their combinations, on rice crop under the interference of weeds. This study will help to understand the impacts of changing climatic factors, under changing climate scenario, on yield and yield attributes of rice and will provide a scientific basis for optimizing weed management practices and maintaining stable rice yields in the futuristic climate change scenario.

MATERIALS AND METHODS

Experiment site and weather conditions

The experiment was carried out in Open Top Chambers (OTCs) during the *Kharif* (rainy) season of 2020 and 2021 at ICAR-DWR, Jabalpur 23°13'58.62" N latitude and 79°58'05.03" E longitude). Climatic condition is humid subtropical, summer set about late March and lasts until June, and summer followed by South-West monsoon which lasts until early October and produces average yearly rainfall of ~1386 mm.

Crop management and plant sampling

The experiment was conducted in four different OTCs (5.30 m^2), each with its own set of environmental variables: Ambient temperature and ambient CO_2 [415 ± 30 ppm], ambient temperature (24-34 ºC) + elevated CO_2 [550±50 ppm], elevated temperature (ambient+2 ºC) + ambient CO_2, elevated temperature (ambient+2 ºC) + elevated CO_2 [550±50 ppm]. During the crop growing season, chambers were equipped with temperature sensors to control the temperature and the area in both chambers was further divided into three parts along the chamber to grow the rice crop with and without infestation of selected weeds. Rice variety '*IR-64*' was sown (seed rate of 20 kg/ha and 25 cm row-to-row spacing) in the first week of July and all the standard agronomic practices were followed. Seeds of *L. chinensis* and *A. paronychioides* were dispersed in the OTCs and weed density of 50/m^2 was maintained throughout the season. Under elevated CO_2 treatment, 550±50 ppm was maintained inside the OTC by releasing the CO_2 gas from compressed CO_2 gas cylinders. The CO_2 gas was released with 45 kg capacity CO_2 cylinder using a perforated 13 diameter PVC pump. The required levels of CO_2 levels were maintained within the chambers by solenoid valves. Throughout the experiment, the elevated CO_2 and elevated temperature were maintained for up to 12 hours a day.

Observations

At maturity rice plants were uprooted and data were recorded for yield related criteria such as plant height (cm), number of tillers/plant, number of grains/panicle, yield/plant (g) and 1000-grain weight (g) were observed in rice. Five plants were randomly selected and considered as replication for observation of rice per treatment.

Statistical analysis

The data were analyzed and evaluated by Statistical Program for Social Science (SPSS v16.0) software with general linear model (GLM) for completely randomized design (CRD). All results were expressed as an average of five replications. Principal component analysis (PCA) was performed using Minitab software. Significant differences (P= 0.05) between treatments were determined using Duncan's multiple range test.

RESULTS AND DISCUSSION

Effect of elevated CO_2

CO_2 concentration in the atmosphere is rising and increased CO_2 level is generally thought to promote rice biomass production (Kumar *et al.* 2017) but may inhibit growth of plants in some circumstances by affecting the primary metabolism (Takatani *et al.* 2014). Plant senescence, leaf withering and anthocyanin buildup, is also accelerated by higher CO_2 levels in combination with inadequate nitrogen (Aoyama *et al.* 2014).

In this study, increase in grain yield of rice (40.13%) was observed under higher CO_2 concentrations (550±50 ppm). The increased production corroborated with increase in number of grains/panicle (21.56%), plant height (14.52%), panicle length (11.21%), number of tillers/plant (27.27%) and 1000-grain weight (16.65%). Horie *et al*. (2000) observed around 30% increase in rice output with doubled CO_2 level due to enhancement in the plant height, panicle length, and no. of tillers/ plant. A significant increase in grains/panicle (21.50%), plant height (16.61%), panicle length (11.21), number of tillers/plant (9.09%) and 1000-grain weight (2.5%) of rice was observed under elevated CO_2 as observed earlier by Kobayashi *et al.* (1999); Sakai *et al.* (2001); Chakrabarti *et al.* (2012). The enhanced growth may be because of enhanced photosynthesis due to competitively inhibition of the *Rubisco* catalyzed oxygenation at increased CO_2 levels (Ainsworth *et al.* 2003).

Effect of elevated temperature

Increase in temperature by 2 ºC had significant negative effect resulting in 17.03% reduction in yield/ plant of rice compared to ambient condition. The increased temperature also reduced the plant height, panicle length, number of grains/panicle, number of tillers/plant, and 1000-grain weight of rice by 16.42, 6.64, 24.61, 13.64 and 9.34%, respectively, over the ambient condition as reported earlier by Rani and Maragatham (2013).

Combined effect of elevated CO_2 and temperature interactions on rice yield

Under the combined effect of elevated CO_2 levels and temperature the rice yield/plant has increased by 13.47% as reported by Krishnan *et al.* (2007), Satapathy *et al*. (2015) and Madan *et al*. (2012). The plant height of rice was increased by 7.18% due to the combined effect of elevated CO_2 levels and temperature as reported by Dwivedi *et al.* (2015) and Kaur *et al.* (2019).

The no. of tillers/plant of rice increased by 18.18% as observed earlier by Jitla *et al*. (1997) and Kim *et al.* (2003). The 1000-grain weight of rice was also increased by 12.61% as reported by Dwivedi *et al.* (2015) and Rosalin *et al.* (2018) in rice. Other attributes like panicle length, number of grains/ panicle of rice were also increased by 7.84%, 16.21%, respectively, under the combined effect of elevated CO_2 and elevated temperature.

Effect of weeds on yield and yield attributes of rice under elevated CO_2 and temperature

This is the first report of effect of weed interference on rice yield attributes under the climate change scenario. The competitive interference of two weeds, *A. paronychioides* and *L. chinensis*, caused significant variation in yield and yield attributes of rice across different treatments. Weed interference causes higher yield losses since weeds and the crop plants have identical photosynthetic pathways and nutritional levels (Pagare *et al*. 2017). Weeds, as with most crop plants, have stronger physiological adaptations, higher interspecific genomic diversity, and physiological adaptability under dynamic environmental conditions (Upasani *et al*. 2018).

Plant height: Plant height of rice was reduced by 20.78, 15.56, 21.72, and 23.20%, at A, EC, ET and EC+ET, respectively in association with *A. paronychioides* when compared to weed free. Similarly, the plant height also decreased by 18.05, 11.24, 15.51 and 10.09% at A, EC, ET and EC+ET, respectively, in association with *L. chinensis* plot when compared to rice grown in weed free condition (**Figure 1a**).

Panicle length: Panicle length of rice was reduced by 26.64%, 31%, 11.81% and 26.54% at A, EC, ET and EC+ET, respectively, when raised with *A. paronychioides* plots when compared to weed free rice. Similarly, *L. chinensis* caused reduction in panicle length by 13.71, 27.52, 3.69 and 6.39% at A, EC, ET and EC+ET, respectively, as compared to weed free rice (**Figure 1b**).

Number of grains/panicle: Number of grains/ panicle of rice were greatly reduced by 56.27, 60.88, 47.87 and 78.42% at A, EC, ET and EC+ET, respectively, in *A. paronychioides* plots as compared to weed free condition rice. Similarly, number of grains/panicle were also reduced by 21.71, 20.75, 38.95 and 51.45% at A, EC, ET and EC+ET, respectively, in *L. chinensis* plots as compared to weed free condition rice (**Figure 1c**).

Number of tillers/plant: Number of tillers/plant of rice were reduced by 36.36, 25, 31.58 and 53.85%, at A, EC, ET and EC+ET, respectively in *A. paronychioides* plot as compared to weed free condition. Similarly, number of tillers/plant were reduced by 22.72, 17.86, 15.79 and 23.08%, at A, EC, ET and EC+ET, respectively in *L. chinensis* plots as compared to weed free condition rice (**Figure 1d**).

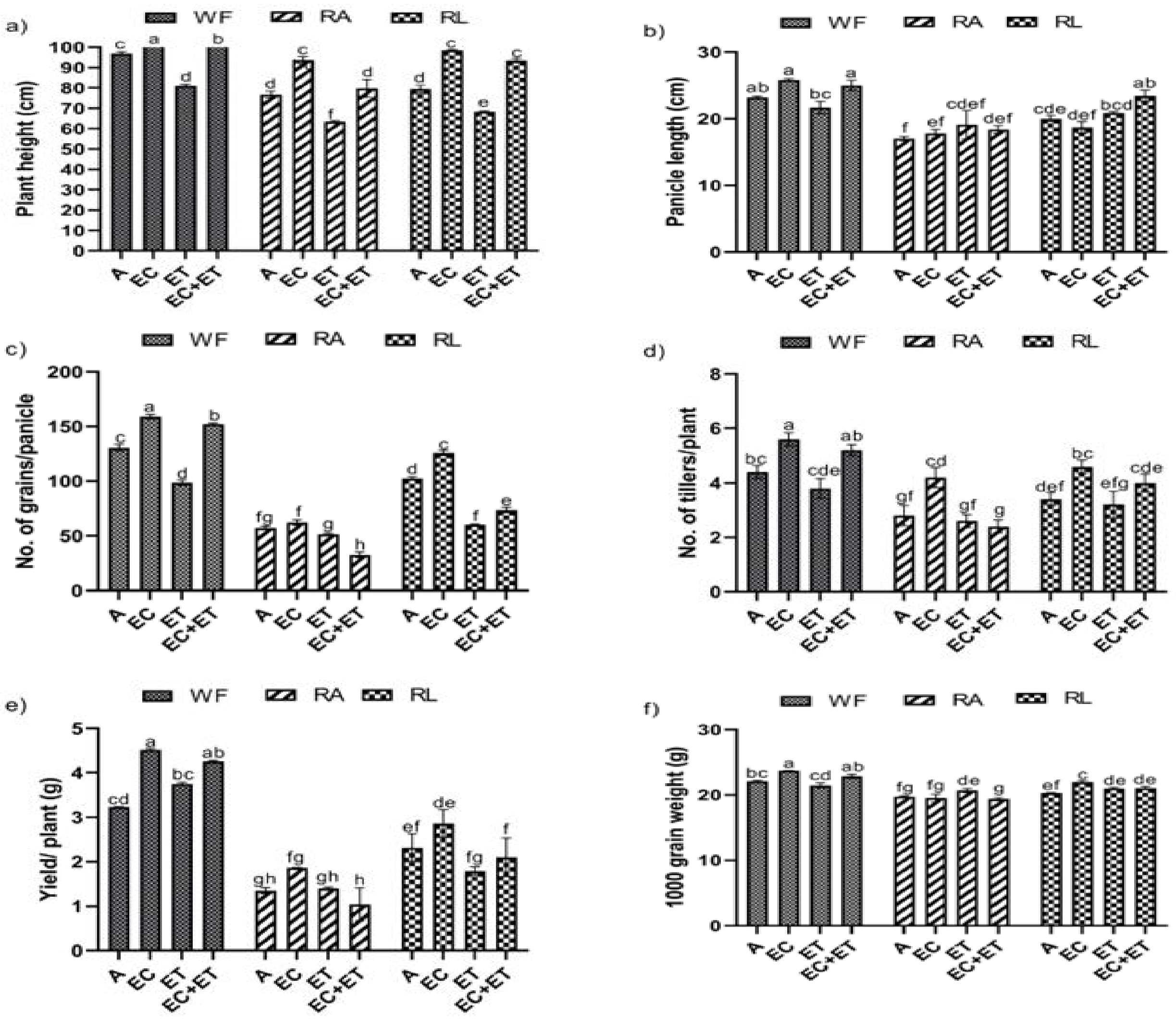
Yield/plant: Yield/plant of rice was found to be reduced by 58.04, 58.77, 62.73 and 75.65% at A, EC, ET and EC+ET, respectively, in *A. paronychioides* plots as compared to weed free condition rice plot. Similarly, yield/plant was found to be reduced by 28.05%, 36.69%, 52.38% and 50.68% at A, EC, ET and EC+ET, respectively, in *L. chinensis* plots as compared to weed free condition rice (**Figure 1e**).

1000-grain weight: 1000-grain weight was found to be reduced by 10.47, 17.65, 3.63 and 15.31% at A, EC, ET and EC+ET, respectively, in *A. paronychioides* plots as compared to weed free condition rice. Similarly, 1000-grain weight was found to be reduced by 7.99, 7.26, 2.24 and 7.87%, A, EC, ET and EC+ET, respectively, in *L. chinensis* plots as compared to weed free condition rice (**Figure 1f**).

Effect of elevated CO_2 and temperature on *L. chinensis* and *A. paronychioides*

The growth and biomass of weeds was significantly increased under elevated CO_2 and temperature compared to ambient. However, the positive influence was more on *A. paronychioides* in comparison to *L. chinensis* under elevated CO_2 and temperature. Therefore, *A. paronychioides* may become a major problematic weed in futuristic climate change scenario (**Table 1**).

Principal component analysis (PCA): In weed free condition, the PCA resulted in three independent principal components had a cumulative variance of 92%. Corresponding eigen values attribute for the importance of character. The first two principal components having an eigen values greater than



EC = elevated CO_2; *ET* = elevated temperature; *EC+ET* = combined effect of elevated CO_2 and temperature. *WF* = weed free Rice; *RL* = rice in association with *L. chinensis*; *RA* = Rice in association with *A. paronychioides*. Vertical bars represent the mean ± SE of five replicates. Means denoted by the same letter were not significantly different at P = 0.05 level according Duncan's test

Figure. 1 Effect of *L. chinensis* and *A. paronychioides* competition on rice yield and yield attributes under elevated CO_2 and temperature (pooled data of two years)

Table 1. Effect of elevated CO_2 and temperature on weed biomass characteristics

Weed biomass characteristics	Climatic factor	*Alternanthera paronychioides*	*Leptochloa chinensis*
Shoot fresh weight (g)	Ambient	63.40 ± 2.84d	9.43 ± 1.88d
	EC	80.00 ± 2.08a	12.83 ± 0.39c
	ET	74.67 ± 3.18c	13.77 ± 0.18b
	EC+ET	78.33 ± 3.51b	15.13 ± 1.04a
Shoot dry weight (g)	Ambient	1.35 ± 0.08d	1.35 ± 0.27d
	EC	2.23 ± 0.20b	2.21 ± 1.10c
	ET	1.96 ± 0.34c	2.52 ± 0.20a
	EC+ET	2.27 ± 0.21a	2.22 ± 0.15b
Root fresh weight (g)	Ambient	1.33 ± 0.18d	0.13 ± 0.03b
	EC	2.18 ± 0.02a	0.17 ± 0.07b
	ET	1.90 ± 0.66c	0.23 ± 0.03a
	EC+ET	2.00 ± 0.20b	0.20 ± 0.06a
Root dry weight (g)	Ambient	0.13± 0.01a	0.03 ± 0.01a
	EC	0.18 ± 0.00a	0.05 ± 0.02a
	ET	0.15 ± 0.06a	0.06 ± 0.02a
	EC+ET	0.16 ± 0.01a	0.04 ± 0.01a

EC Elevated CO_2; *ET* Elevated temperature; *EC+ET* combined effect of elevated CO_2 and temperature. Means denoted by the same letter were not significantly different at p=0.05 level according Duncan's test

0.4974accounting for 92% of variation among 6 selected parameters. In PC-1 maximum variation contributed by number of tillers per plant (0.427), PL (0.426) and test weight (0.423), however, least variation contributed by Yield (0.334). Similarly, in PC-2 the highest variation contributed by plant height (0.340), whereas yield (-0.882), and test weight (-0.050) contributed least variation. (**Table 2; Figure 2a, b**).

In the presence of *A. paronychioides*, the PCA resulted in three independent principal components had a cumulative variance of 87.8%. Corresponding eigen values attribute for the importance of character. The first two principal components having an eigen values greater than 1 accounting for 87.8% of variation among 6 selected parameters. In PC-1, maximum variation contributed by number of tillers per plant (0.507), plant height (0.455) and yield (0.44), however, least variation contributed by panicle length (-0.332) and test weight (-0.251).

Table 2. Principal components showing the eigenvalues, the proportion of variation and principal component analysis for yield and yield attributes of weed-free rice under different environmental conditions (pooled data of two years)

Variable	PC1	PC2	PC3
PH	0.415	0.340	-0.208
PL	0.426	0.081	0.241
NSP	0.415	0.309	0.526
NTP	0.427	0.029	0.075
Yield	0.334	-0.882	0.172
TW	0.423	-0.050	-0.766
Eigenvalue	5.4727	0.4974	0.0298
Proportion	0.912	0.083	0.005
Cumulative	0.912	0.995	1.000

PH = Plant height, *PL* = Panicle length, *NSP* = Number of seeds per panicle, *NTP* = Number of tillers per plant, *TW* = Test weight

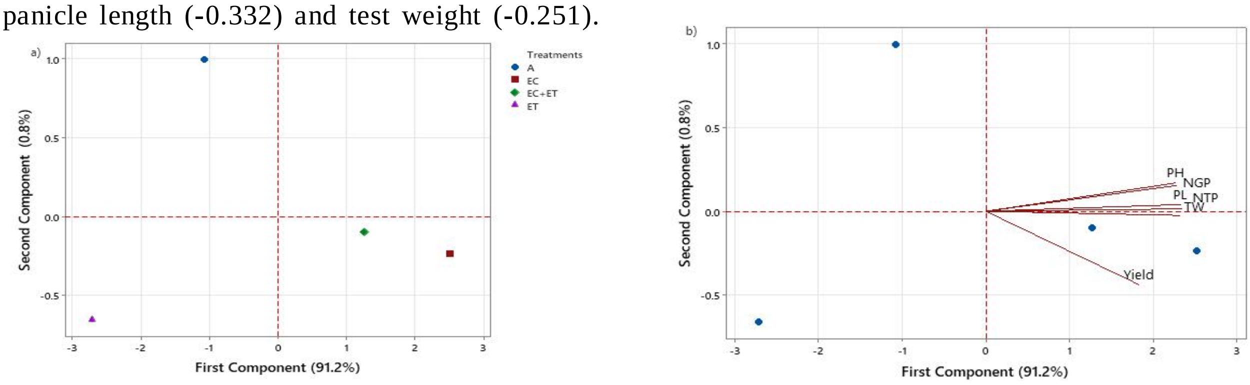


Figure 2. Score plot (a) and Biplot plot (b) analysis between various yield and yield attributes in weed-free rice under different climatic conditions. *PH* = plant height, *PL* = panicle length, *NGP* = number of grains per panicle, *NTP* =number of tillers per plant, *TW* = test weight

Similarly, in PC-2, the highest variation contributed by plant height (0.341), whereas test weight (-0.656) and number of grains per panicle (-0.441) contributed least variation (**Table 3; Figure 3a, b**).

In rice, in the presence of *L. chinensis*, the PCA resulted in six independent principal components and had a cumulative variance of 90.8%. Corresponding eigen values attribute for the importance of character. The first two principal components having an eigen values greater than 1.2568 accounting for 90.8% of variation among 6 selected parameters. In PC-1 maximum variation contributed by yield (0.472), number of tillers per plant (0.455) and plant height (0.414) and least variation contributed by panicle length (-0.271). Similarly, in PC-2 the highest variation contributed by panicle length (0.710), whereas, number of seeds per panicle (-0.335) and yield (-0.173) contributed least variation (**Table 4; Figure 4a, b**).

Pearson's correlation analysis: The results were further confirmed with Pearson's correlation analysis. In weed free rice, a strong positive correlation was observed between all the yield and yield attributes at P=0.01 (**Table 5**). In rice, with the presence of *A. paronychioides*, a strong positive correlation was observed between number of seeds per panicle and yield at P=0.01. Similarly, plant height showed a positive correlation with yield and number of tillers per plant at P=0.05 (**Table 6**). In rice the presence of *L. chinensis*, PH showed a strong positive correlation with number of seeds per panicle and number of tillers per plant at P=0.01. Similarly, yield was

Table 3. Principal components showing the eigenvalues, the proportion of variation and principal component analysis for yield and yield attributes of rice in the presence of *A. paronychioides* under different environmental conditions (pooled data of two years)

Variable	PC1	PC2	PC3
PH	0.455	0.341	0.314
PL	-0.332	-0.305	0.786
NSP	0.397	-0.441	-0.378
NTP	0.507	-0.145	0.307
Yield	0.454	-0.381	0.181
TW	-0.251	-0.656	-0.121
Eigenvalue	3.4804	1.7890	0.7307
Proportion	0.580	0.298	0.122
Cumulative	0.580	0.878	1.000

PH = plant height, *PL* = panicle length, *NSP* = number of seeds per panicle, *NTP* = number of tillers per plant, *TW* = test weight

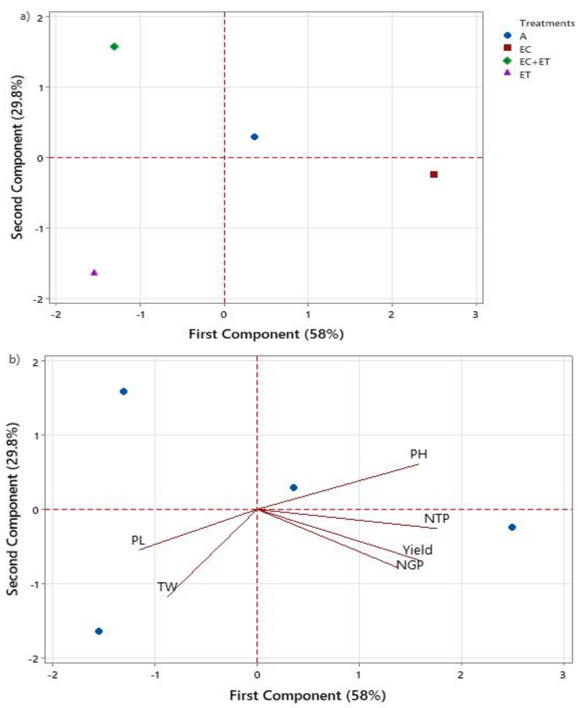


Figure 3. Score plot (a) and Biplot plot (b) analysis between various rice yield and yield attributes in the presence of *A. paronychioides* under different treatments. *PH* = plant height, *PL* = panicle length, *NSP* = number of seeds per panicle, *NTP* = number of tillers per plant, *TW* = test weight

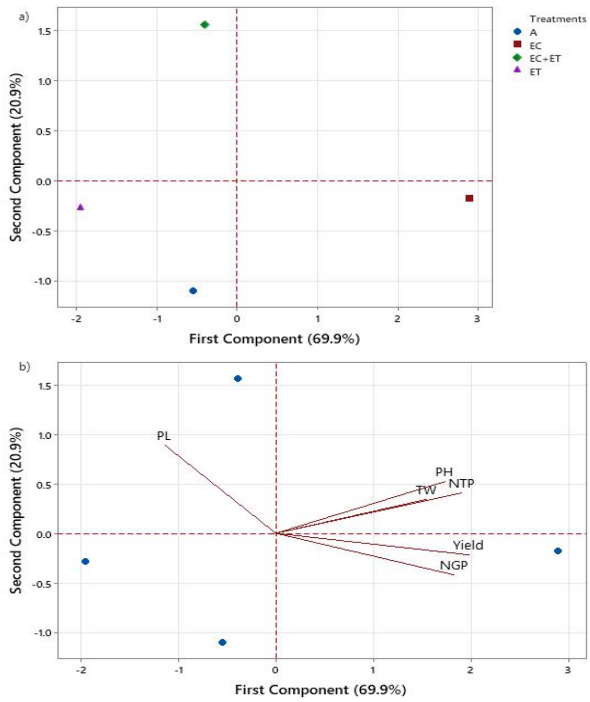


Figure 4. Score plot (a) and Biplot plot (b) analysis between various rice yield and yield attributes in the presence of *L. chinensis* different treatments. *PH* = plant height, *PL* = panicle length, *NSP* = number of seeds per panicle, *NTP* = number of tillers per plant, *TW* = test weight

Table 4. Principal components showing the eigenvalues, the proportion of variation and PCA for yield and yield attributes of rice in the presence of *L. chinensis* under different environmental conditions (pooled data of two years)

Variable	PC1	PC2	PC3
PH	0.414	0.417	0.343
PL	-0.271	0.710	0.327
NSP	0.437	-0.335	0.329
NTP	0.455	0.325	-0.033
Yield	0.472	-0.173	0.227
TW	0.368	0.273	-0.784
Eigenvalue	4.1934	1.2568	0.5498
Proportion	0.699	0.209	0.092
Cumulative	0.699	0.908	1.000

PH = Plant height, *PL* = Panicle length, *NSP* = Number of seeds per panicle, *NTP* = Number of tillers per plant, *TW* = Test weight

Table 5. Pearson's correlation coefficients of yield and yield attributes in weed free rice (pooled data of two years)

Attribute	PH	PL	NSP	NTP	YIELD	TW
PH	1					
PL	.757**	1				
NSP	.977**	.764**	1			
NTP	.758**	.817**	.787**	1		
YIELD	.594**	.565**	.604**	.574**	1	
TW	.851**	.579**	.820**	.675**	.658**	1

**. Correlation is significant at the 0.01 level (2-tailed).

PH = plant height, *PL* = panicle length, *NSP* = number of seeds per panicle, *NTP* = number of tillers per plant, *TW* = test weight

Table 6. Pearson's correlation coefficients of rice yield and yield attributes in the presence of *A. paronychioides* (pooled data of two years)

Attribute	PH	PL	NSP	NTP	Yield	TW
PH	1					
PL	-.071	1				
NSP	.290	-.081	1			
NTP	.534*	-.089	.480*	1		
Yield	.545*	.161	.647**	.327	1	
TW	-.500*	.293	.106	-.003	-.124	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

PH = plant height, *PL* = panicle length, *NSP* = number of seeds per panicle, *NTP* = number of tillers per plant, *TW* = test weight

positively correlated with number of seeds per panicle at P=0.05. However, panicle length showed a negative correlation with number of seeds per panicle p=0.01) and yield (p=0.05) (**Table 7**).

This study revealed that weed interference severely impaired rice grain yield and yield attributes under elevated CO_2 and temperature. It was also observed that the response of *A. paranochioides* was more under elevated CO_2 compared to *L. chinensis*. Elevated CO_2 had a positive effect on yield and yield attributes of weed free rice, whereas, elevated temperature had deleterious effect. Under the combined effect of elevated CO_2 and temperature the negative effect of elevated temperature was negated by elevated CO_2 in weed free rice.

Table 7. Pearson's correlation coefficients of rice yield and yield attributes in the presence of *L. chinensis* (pooled data of two years)

Attribute	PH	PL	NSP	NTP	Yield	TW
PH	1					
PL	.007	1				
NSP	.619**	-.593**	1			
NTP	.565**	-.034	.392	1		
Yield	.370	-.512*	.491*	.365	1	
TW	.534*	-.142	.284	.412	.209	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

PH = plant height, *PL* = panicle length, *NSP* = number of seeds per panicle, *NTP* = number of tillers per plant, *TW* = test weight

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