Effect of elevated carbon dioxide (eCO\textsubscript{2}) on yield and yield components of different rice cultivars in Odisha

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Abstract
The present study was conducted in collaboration with Department of Agricultural Meteorology, OUAT and Central Research Farm, Bhubaneswar by undertaking a pot experiment in Open Top Chamber (OTC) to study yield and yield attributes of seven kharif rice cultivators to eCO\textsubscript{2} (476 ppm) during Kharif season, 2012. The experiment was explained by three yield components; panicle numbers/hill, filled grain numbers/panicle and 1000-grain weight under eCO\textsubscript{2} conditions. Yield in eCO\textsubscript{2} OTC was found to be more than open field by 2.08 g hill\textsuperscript{-1} (14.5%) associated with increased number of filled grains/panicle (58.8%) and 3.1 g hill\textsuperscript{-1} more dry matter production compared to open field. However, decreased panicle numbers/hill (40%) and increased grain chaffyness (147%) attributed towards smaller increase in yield under eCO\textsubscript{2} than open field condition. So, early and medium maturity cultivars produced more grain yield than the late maturity cultivars and eCO\textsubscript{2} produced less grain yield than ambient CO\textsubscript{2} by 5.76 g hill\textsuperscript{-1}.

Keywords: carbon dioxide, yield, harvest index, rice cultivar, dry matter

1. Introduction
Rice, with an annual production of 0.6 Billion Tonne (BT) is most important cereal crop for feeding world population \cite{1}. More than half of the world population (about 63%) in Asia depends on rice as their staple food. In India, rice is the most important cereal crop with an area of 44.8 Million Hector (MH) and producing about 91.8 Million Tonne (MT) which is contributing about 21% of the global rice production next to China \cite{2}. Odisha is a major rice growing state of India having rice grown area of about 4.4 MH \cite{3}. Carbon dioxide (CO\textsubscript{2}) is one of the key inputs required for photosynthesis, biomass production and yield formation in all agricultural crops. The energy production from fossil fuels has increased atmospheric CO\textsubscript{2} concentration from 280 \textmu molmole\textsuperscript{-1} to 370 \textmu molmol\textsuperscript{-1} since 1750 and may reach 550 \textmu molmol\textsuperscript{-1} by middle of 21\textsuperscript{st} century \cite{4}. The direct effect of increased CO\textsubscript{2} concentration is expected to enhance the growth and yield of many C\textsubscript{3} agricultural crops including rice \cite{5}. Rice plants grown at an elevated CO\textsubscript{2} level have more vegetative growth than rice grown at an ambient level of CO\textsubscript{2} and open field \cite{6}. However, Razzaque \textit{et al.} \cite{7} discovered that growth and yield responses of rice to eCO\textsubscript{2} differed with genotype. The high yield varieties generally responded less than local varieties. Reliable criteria for rice cultivators and eCO\textsubscript{2} studies were not so developed in India neither in Odisha even though it is counted as a rice growing state of the country. So, we have undertaken a pot experiment in Open Top Chamber (OTC) at Central Research Farm, Bhubaneswar during Kharif season of 2012 to study yield and yield attributes of seven kharif rice cultivators to eCO\textsubscript{2}.

2. Materials and Methods
The experiment conducted in Open Top Chamber (OTC) in Central research Station, Orissa University of Agriculture and Technology, Bhubaneswar situated at 20° 15’N and 85°’52 E, 65 km west of Bay of Bengal during kharif season from July-October month of 2012. Top soil 0 to 30 cm depth from commercially cultivated rice plot of 5 year was used to fill pots. Physiochemical analysis of composite soil was found to be loamy, sandy, acidic soil with available Nitrogen (N) and Potassium oxide (K\textsubscript{2}O) was also available with low organic carbon content. The soil was also consists of medium amount of available Phosphorus Pentoxide (P\textsubscript{2}O\textsubscript{5}) content The climatic condition of Central research station was considered to be warm and moist with hot humid summer and a short mild winter.
The region falls in moist hot group with an average rainfall coded as D₁(E₁(B₁A₁B₁)C₁D₁E₂) as established by Lenka \[8\]. The region gets rainfall through south-west monsoon which usually sets on 10th June and recedes by 15th October having an average rain fall of about 1240 mm. The pot experiment conducted in seven varieties Mandakini (95-100 days average grain yield 2583 kg ha\(^{-1}\)), Jyotirmayee (95 days average grain yield 4387 kg ha\(^{-1}\)), Khandagiri (95 days average grain yield 3220 kg ha\(^{-1}\)), Tejaswani (130 days average grain yield 4898 kg ha\(^{-1}\)), Hiranmayee (130 days average grain yield 5453 kg ha\(^{-1}\)), Ramchandi (150-155 days average grain yield 4151 kg ha\(^{-1}\)) and Swarna (140 days average grain yield 3728 kg ha\(^{-1}\)).

Eight OTC in two rows separated by 3.3 m distance in between in East-West direction of circular shape was made up of weather resistant heavy duty UV filtered polycarbonate sheets (100% transmission), 4 m height along with diameter. From a height of 3.5 m CO\(_2\) was supplied to OTCs through micropipeline from 47 Litres (l) gas cylinder containing 22 kg CO\(_2\) at 8 bar pressure in the control room located near OTCs. The temperature and relative humidity sensors inside the OTCs were direct capacitance type according to Ambetronics Company. The center was provided with digital panel output display which was supported by software packages for analysis. Air temperature measured at 1.2 m height by thermometer shielded from direct solar radiation. The gate of first row of OTC s was faced towards south and other towards north.

The pot experiment was conducted in seven variety in Open field, OTCs with ambient CO\(_2\) (380 ppm) concentration and elevated CO\(_2\) (476 ppm) concentration. Seasonal weather in open field was having 20 rainy days with 252.8 mm rainfall. Mean temperature was found to be maximum at 2 PM as 30.8°C and minimum at 7 AM as 19.1°C. The mean maximum temperature in Open field, OTCs with ambient CO\(_2\) (380 ppm) concentration and elevated CO\(_2\) (476 ppm) concentration was established to be 30.8 °C, 31.3 °C and 33.3°C respectively. However, the CO\(_2\) content in ambient OTC (341.9 ppm) was close to outside air (355.3 ppm) but it was revealed that eCO\(_2\) OTC had 24.8% CO\(_2\) more than outside. Pot filling, transplanting, cultural operation and harvesting were done as per normal procedure.

One hill was destructively sampled from each combination for panicle numbers per hill, total grain numbers per panicle (including filled grains and chalky grains) and 1000-grain weight. Panicle number was counted pot wise by detaching it from first node, total grain number of a panicle and 1000-grain weight was counted by selecting a healthy mature panicle. Harvest index was calculated by the ratio of grain yield per pot to total above ground biomass of the pot weighted before weighing for yield.

3. Statistical Analysis
The observed value for growth, yield and yield components were subjected to analysis of variance (ANOVA) following standard statistical procedure for randomized complete block design for interaction effect and completely randomized design for environmental effect \[9\]. All the statistical analyses were conducted using SAS 9.2 software \[10\].

4. Results
The increase in temperature under eCO\(_2\) was higher 2.3°C during whole cropping period. The increased temp was as high as 5.4°C during flowering in medium maturity cultivars and 2.6-3°C during Panicle Initiation (PI) to flowering stage in late maturity cultivar. In ambient OTC the cultivar Khandagiri had higher 1000-grain weight (24.67 g) than Jyotirmayee, Ramchandi and Swarna. Under elevated CO\(_2\) OTC cultivar Ramchandi had higher 1000-grain weight (27.29 g) than all other cultivar. Khandagiri had higher number of total grains per panicle under open field (161) and ambient OTC conditions (261) than all other cultivar. Under eCO\(_2\) condition, the cultivar Khandagiri had higher number of total grains per panicle (230) than all other cultivars except Hiranmayee. Across the environments, varieties differed in total grain number per panicle. The cultivar Khandagiri had higher number of total grains per panicle (202) than all other cultivar. Elevated CO\(_2\) OTC produced significantly higher number of total grains per panicle (185) than the open field condition (103) and ambient OTC. In interaction of variety and environment ambient OTC produced highest number of total grain per panicle with Khandagiri (216) than open field condition with cultivar Swarna. Under open field and eCO\(_2\) conditions, Khandagiri had higher number of filled grain per panicle (130 and 184) than all other cultivars respectively. Under ambient OTC Khandagiri and Hiranmayee produced 191 filled grains per panicle. Across environment cultivar Khandagiri had higher number of filled grain per panicle (169) than other cultivars. Number of filled grains per panicle was higher under ambient OTC (135) and almost same under eCO\(_2\) condition (127) than open field condition (80). Variety of environmental effects was compared with ambient CO\(_2\). OTC produced highest number of filled grains per panicle (193) with the cultivar Khanadagiri and under open field condition swarna had lowest number of filled grains per panicle (62). Environment effect was not significant at maturity stage. Across three environments, the cultivar Jyotirmayee had higher productive panicle numbers per hill (10) than the cultivars Khandagiri (6) and Ramchandi (7). All other cultivar did not differ in productive panicle number. The harvest index of cultivar khandagiri was highest (0.59) across the three environments, but Hiranmayee had the highest HI (0.76) under ambient OTC condition than other cultivars. When yield was considered, ambient OTC produced higher yield (22.13 ghill\(^{-1}\)) than eCO2 OTC (16.37 ghill\(^{-1}\)) and open field condition (14.29 ghill\(^{-1}\)). However, the cultivar Hiranmayee produced highest grain yield (40.29 ghill\(^{-1}\)) under ambient OTC condition than all other cultivars.

5. Discussion
Rice grain yield under eCO\(_2\) was 14.5% higher across the varieties than under open field condition. This result is in agreement with the previous research works showing that increased CO\(_2\) concentration under controlled environment chambers increased the grain yield of rice \[11, 12, 13\]. The increase in yield was primarily influenced by an increase in harvest index (HI, 67%) under eCO\(_2\) \[13, 14\]. In the present study a larger increase in HI but smaller increase in yield can be explained by the three yield components, namely panicle numbers per hill, filled grain numbers per panicle and 1000-grain weight. There was a significant increase in filled grain number per panicle (58%) and a similar increase in 1000 grain weight (13%). Similar result for slight increase in 1000-grain weight was also reported by others \[15, 16, 17\]. However, Shimono et al. \[18\] reported a small decrease in 1000-grain weight under eCO\(_2\) (570±35 μmol mol\(^{-1}\)). In case of filled grains per panicle, the former researchers reported a small increase in filled grain percentage under eCO\(_2\) \[11, 18\]. On the other hand, Cheng et al. \[14\] reported a higher increase in filled grain percentage (29%) under eCO\(_2\), and it was influenced by lower night temperature. In the present study, increase in HI
was greatly contributed by increased number of filled grain per panicle. One of the major yield components, panicle number per hill decreased (40%) under eCO₂ than open field condition. Although tiller number per hill was little higher under eCO₂ but the increased total grain chaffyness (sterility) decreased the productive panicle numbers per hill under eCO₂. Such increase in grain sterility was associated with the higher night temperature (2.3°C higher) and humidity (84%) under eCO₂ compared with outside thermal regimes. The results were almost the similar with the earlier results that spikelet sterility percentage was associated with higher temperature (1 to 2°C) under eCO₂.[15]

Moreover, ambient CO₂ produced higher grain yield than eCO₂ or open field. The main reasons attributed to higher yield under ambient CO₂ were more panicle numbers per hill than eCO₂, higher filled grains per panicle than eCO₂ and open field and lower chaffy grains per panicle than eCO₂ with higher HI both from eCO₂ and open field conditions[16]. The Dry matter production in the present experiment was higher under eCO₂ than under open field. The results are inline of findings of several coworkers that total dry matter per stem was greater under eCO₂.[18, 19, 20].

6. Conclusion
Elevated CO₂ increased yield 2.08 g hill⁻¹ i.e 14.5% in rice cultivar than open field condition but elevated CO₂ produced 5.76 g hill⁻¹ less grain yield than ambient CO₂. Harvest index more under eCO₂ (0.57) than from open field (0.34). Harvest indices of early and medium maturity cultivars were more than in open field condition. 82% and 58% increase in total grains per panicle and number of filled grain per panicle under eCO₂. Panicle number per hill decreased 40% in under eCO₂ than open field and ambient field condition. Grain chaffyness increased 147% than from open field condition. Medium maturity cultivar produced more number of chaffy grains than early and late maturity cultivars.

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8. References

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