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ARTICLE

Response of Elevated CO_2 on Biochemical Grain Quality Characteristics of Rice Cultivar in Free Air Carbon Dioxide Enrichment (FACE) Technology

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Study was conducted to understand the changes in grain quality parameters of tropical rice cultivar cv. *Naveen*, a high yielding variety of CRRI, Orissa, to elevated CO_2 concentration of 600 μmol CO_2 μmol^{-1} using Free Air Carbon dioxide Enrichment (FACE) technology at IARI, New Delhi. It was compared with ambient CO_2 concentration of 370 μmol mol^{-1}. Elevated CO_2 resulted in significant changes in the yield and grain quality of rice cultivar, in comparison to plants grown under the ambient conditions. Head rice recovery, WUE, amylose content, grain elongation ratio after cooking were increased by 25.5%, 27%, 4.5% and 3.9% respectively under elevated CO_2 grown plants. Reducing sugar, non-reducing sugar, total sugar content and total non-structural carbohydrate were significantly increased in grains under elevated CO_2 condition. Elevated CO_2 brought about significant decrease in the protein content of the grain which might be due the dilution effect. The micro nutrient of the rice-grain was also studied which showed increase in Zn and Fe content, but not up to significant level in elevated CO_2 grown plants. The increased CO_2 concentration in the growing environment facilitated by FACE technology may help breeders to select rice genotypes, which are responsive to the elevated CO_2 with better sink potential. This study will help in developing rice cultivars positively responding to elevated CO_2 up to 600 μmol mol^{-1} for changing climatic conditions on the basis of realistic biological data obtained using facilities close to near natural conditions.

Keywords: FACE, quality traits, rice cultivar.

Introduction

Rice plays a pivotal role in Indian economy and is the staple food for two thirds of the population. With 44.62 million hectares, India ranks first in area, second in production with 31% of calories to Indian diet supplied by rice. Although the protein content of rice is relatively low (8.5%) compared to other cereals like wheat (12.3%), barley (12.8%) and millet (13.4%), it is considered as one of the highest quality cereal protein being rich in lysine (3.8%) – the first limiting amino acid. True protein digestibility (TD) and the biological value (BV) of rice are also high as compared to other cereals. Notwithstanding the nutritive properties, consumer preference plays a dominant role in localization and adoption of varieties. Socio-religious traditions also play a major role in adding diversity to morphological features especially to grain characters, aroma and endosperm properties for specialist preparation products and even medicinal use. It is uncertain that possible quality considerations, food consumption patterns and taste preferences had overwhelming influence on farmers of Indian subcontinent, to carefully select and improve the best qualities of rice which are most preferred. Consumers base their concept of quality on the grain appearance, size and shape of the grain, behaviour upon cooking, taste, tenderness and flavour of cooked rice. The cooking quality preferences vary within the country, within ethnic groups and from one country to another and within different geographical regions (Juliano *et al.*, 1971).

The current atmospheric concentration of CO_2 has increased exponentially from 274 μmol mol^{-1} to 370 μmol mol^{-1} since pre industrial period. It is expected to rise up to 600 μmol mol^{-1} by the end of next century due to anthropogenic changes (Keeling *et al.*, 1995). Agricultural crop production was affected significantly by the rise in atmospheric CO_2. The

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innovative approaches for conducting long-term experiments were developed to study the impact of the elevated CO_2 on crops. The response of crop plants to the CO_2 enrichment has been studied since last few years using open top chambers (Idso and Kimball, 1997). The long-term experiments have been done in India to study the effect of elevated CO_2 on important crops like rice and *Brassica* (Uprety and co-workers, 1995, 1998, 1999, 2000, 2001, 2002, 2003). However, due to smaller size, manual maintenance of CO_2 concentration and slightly different light and temperature inside OTC, may make them less natural than open fields. Thus attempts were made to develop techniques, which could maintain elevated CO_2 concentration over open field plots, despite the challenges imposed by winds causing rapid dispersal of CO_2 (Drake *et al.*, 1989; Lawlor and Mitchell, 1991; Uprety *et al.*, 1995).

The limitations of OTC technology have been overcome by developing the Free Air CO_2 Enrichment (FACE) technology for fumigation of CO_2 in open fields (Hartley *et al.*, 2000). The design of FACE system was based on the principles of injecting additional CO_2 gas in open fields suitably to attain a pre-determined elevated level of gas concentration with uniform distribution in the fields under the varying meteorological conditions of wind, temperature and humidity.

Materials and method

FACE technology

Rice (cv. *Naveen,* photoperiod non sensitive) was grown in a kharif cropping season in 8 m diameter octagon-shaped FACE ring. The plenum was made of flexible irrigation pipe having 20 cm diameter and the 600 $\mu mol\ mol^{-1}$ CO_2 was injected through the large number of holes made in the pipe. All eight nodes of the octagon have independent control of CO_2 with the help of computer controlled PID valves. CO_2 was injected from 25 gas cylinders storage with manifold, valves and flow meters containing CO_2 regulating system to the input blower for mixing. The fumigation of the gas from the plenum was made at the center of the field 10×15 cm above the crop canopy level to reduce CO_2 gradients and made the CO_2 concentration uniform. The plenum height was adjusted time to time to the height of the canopy with the help of adjustable stands. A PC-based system controller was used to control the PID valves for achieving the required CO_2 concentration in the FACE ring. The system controller controls as well as analyses and displays the data on graphic terminal. Daily mean temperature, CO_2 concentration, relative humidity, wind speed, wind direction, light intensity data were recorded for the crop season.

After three months of harvest, samples were cleaned thoroughly using winnower to remove the chaff and other foreign matters and dried in hot air oven up to 12–14% moisture content. Analysis of all traits was done in three replications.

Physical properties

Kernel length, kernel breadth and length–breadth ratio were measured by dial micrometer (Ramiah, 1969). Hulling and milling were done by using standard rice huller (Merca and Juliano, 1981) and rice polisher (Satake TMO5A) respectively. After cleaning and weighing the dehusked kernel (brown rice) the hulling percentage was calculated. Dehusked kernels were polished to remove bran and the milling percentage was calculated.

Chemical properties

Alkali spreading value was analysed following Little *et al.* (1958) and Amylose content was analysed following Juliano (1971).

Cooking characters

Water uptake and volume expansion ratio were calculated (Anonymous, 2004; Beachell and Stansel, 1963). Similarly kernel length after cooking and elongation ratio were measured following Azeez and Shafi (1966).

Biochemical analysis

The reducing and total sugars were determined calorimetrically by arsenomolybdate method (Nelson *et al.*, 1944). Non-reducing sugar was obtained by subtracting the amount of reducing sugar by that of total sugar. Starch content was estimated by anthrone method (McCready *et al.*, 1950). Percentage of protein was estimated using Bradford method (1976).

Table 1. Grain quality parameters of rice cultivar *Naveen* under ambient CO_2 and elevated CO_2 (FACE) conditions

	Grain type	Hull (%)	Mill (%)	HRR (%)	KL (mm)	KB (mm)	L/B ratio	Al-value (ASV)	WU (ml)	VER	KLAC (mm)	ER	AC (%)
Amb FACE	SB	75.33	68.33	48.03	5.06	2.1	2.4	5.5	80.3	4	9.2	1.76	23.2
Elev FACE	SB	79.6	73.53	60.3	5.35	2.42	2.23	6	102	4	9.2	1.83	24.3
CD 5%		2.54	3.94	6.95	NS	0.17	NS	NS	5.5	NS	NS	NS	NS
SE (d)		0.54	0.85	1.5	0.18	0.03	0.09	0.57	1.2	0.57	0.2	0.04	0.25
SE (m)		0.38	0.6	1.06	0.13	0.02	0.07	0.4	0.8	0.4	0.14	0.03	0.18
CV		0.86	1.46	3.39	4.31	2.08	5.21	12.2	1.6	17.67	2.66	2.89	1.31

SB = Short bold; HRR = Head rice recovery%; KL = Kernel Length (mm); KB = Kernel breadth (mm); L/B = Length breadth ratio; Alk-Val = Alkali spreading value (ASV); WU = Water Uptake (ml); VER = Volume expansion ratio; KLAC = Kernel Length after expansion (mm); ER = Elongation ratio; AC = Amylose content %.

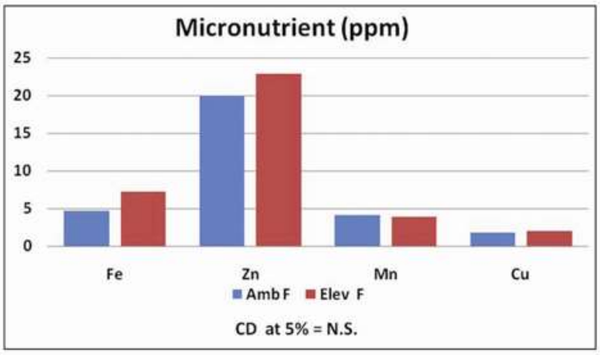

Figure 1. Micronutrient content in rice cultivar Naveen under ambient CO_2 and elevated CO_2 (FACE) conditions.

Percentage of total lipids was estimated using Bligh and Dyer (1959) method.

Results and discussion

Atmospheric CO_2 concentration has risen from 280 μmol mol^{-1} in pre-industrial era to 372 μmol mol^{-1} today (http://www.esrl.noaa.gov/gmd/ccgg/trends/). Elevated CO_2 alone can increase crop productivity but the accompanying changes in temperature and humidity may have negative effects. Elevated CO_2 in FACE treatment resulted significant changes in the grain composition of rice (cv. *Naveen*) as compared to the ambient (372 μmol mol^{-1}) condition. The plants grown under elevated CO_2 showed increase in the productivity as observed from the grain yield parameters. Changes in temperature, RH%, light intensity, wind speed, wind direction and rainfall had an important role throughout the cropping season. Head rice recovery, water use efficiency (WUE) and amylose content were increased, about 25.5%, 27% and 4.5% respectively. Apart from this an increase of 3.9% in the grain elongation ratio, after cooking, was also observed (Table 1). Linear elongation ratio less than 1.32 is undesirable (Dipti *et al.*, 2003; Krishnaveni and Rani, 2008). However, there are evidences suggesting the sustenance of the CO_2 induced changes in the composition of amylose in rice grains, resulting into easy gelatinization and higher viscosity on cooking (Khush *et al.*, 1988; Shikari *et al.*, 2008; Uprety *et al.*, 2010).

Reducing sugar, non-reducing sugar and total sugar content in grains significantly increased under elevated CO_2 condition. Elevated CO_2 brought about significant decrease in the protein content of the grain which might be due the dilution effect of increase in biomass. Kernel length and L/B were not significant, but the Kernel breadth slightly increased under elevated CO_2 condition. Alkali spread value and water uptake was found significantly higher in the elevated CO_2 grown plants (Table 1). Micro nutrient study of the rice grain was also conducted. There was a slight increase in Zn and Fe content, but not up to the significant level at the elevated CO_2 condition (Figure 1). Hence, the rising atmospheric CO_2 affects the grain quality and also resulted in slightly higher micronutrient content like Fe, which can be exploited to produce Fe-rich rice grains for the future mal-nutritive world (Vanaja and Babu, 2006).

The synthesis of the CO_2 induced changes in the chemical composition and nutritional qualities of the grains have been discussed (Uprety *et al.*, 2010). It was demonstrated that the rise in atmospheric CO_2 affects the nutritional and industrial application properties of the grains of crop plants. The grain proteins and other nutritionally important constituents were significantly reduced, thereby adversely affecting the

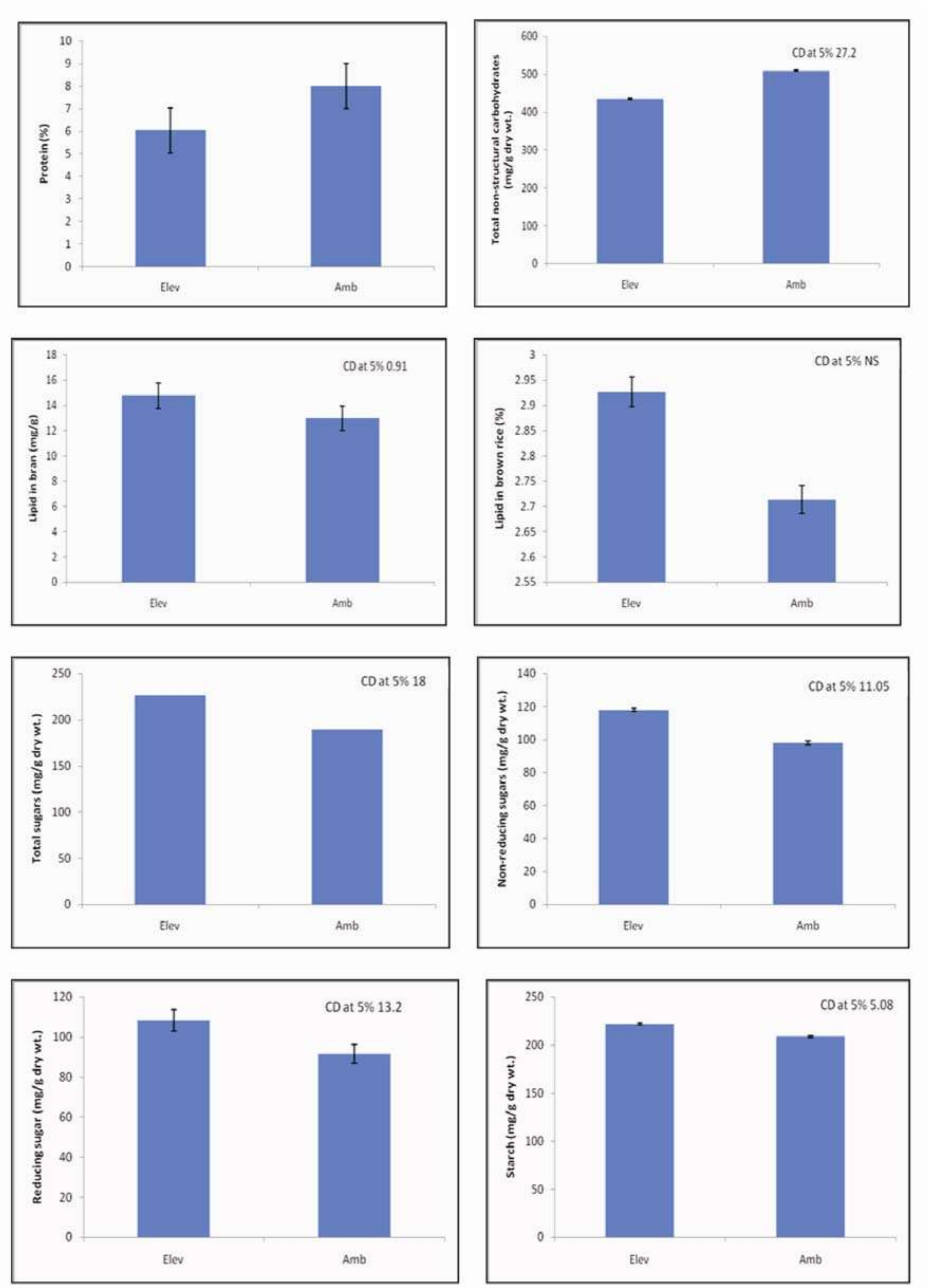

Figure 2. Grain bio-chemical parameters of rice cultivar Naveen under ambient CO_2 and elevated CO_2 (FACE) conditions.

nutritional and bread making quality in wheat. However, there are evidences suggesting the sustenance of the bread making properties by fertilizer application. Similarly, the CO_2-induced changes in the composition of starch in rice grains resulted into easy gelatinization and higher viscosity on cooking (Cagampang *et al.*, 1973). These grains bring firmness due to increase in amylose content. Adequately larger size of grains was the outcome of the elevated CO_2 effects, in *Brassica* species. It increased the oil content due to greater acetyl CoA enzyme activity and also helps in regulating fatty acid biosynthesis. Some of the nutritionally undesirable fatty acids were significantly reduced in this process, making this oil less harmful for heart patients.

The elevated CO_2 treatment significantly increased the total sugar, non reducing sugar, reducing sugar and starch content in *Naveen* cultivar. The increase in total sugar was 19.3%. The CO_2-induced enhancement in reducing and non-reducing sugars was 20.4%. Lipid and starch content in rice grains were increased by 13.8% and 6.2% respectively and lipid in bran and brown rice was increased by 13.5 and 9.3% respectively in elevated CO_2 treatments. But contents of protein and TNC were reduced by 24.6% and 14.6% respectively under elevated CO_2 (Figure 2) conditions. The adequate use of fertilizer application and selection pressure of breeders may significantly contribute in developing cultivars, which will counter the adverse effect of rising atmospheric CO_2 on grain quality.

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