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The impact of free-air CO_2 enrichment (FACE) and nitrogen supply on grain quality of rice

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Abstract

Because CO_2 is needed for plant photosynthesis, the increase in atmospheric CO_2 concentration ([CO_2]) has the potential to enhance the growth and yield of rice (*Oryza sativa* L.), but little is known regarding the impact of elevated [CO_2] on grain quality of rice, especially under different N availability. In order to investigate the interactive effects of [CO_2] and N supply on rice quality, we conducted a free-air CO_2 enrichment (FACE) experiment at Wuxi, Jiangsu, China, in 2001–2003. A long-duration rice japonica with large panicle (cv. Wuxiangging 14) was grown at ambient or elevated (ca. 200 μmol mol^{-1} above ambient) [CO_2] under three levels of N: low (LN, 15 g N m^2), medium (MN, 25 g N m^2) and high N (HN, 35 g N m^2 (2002, 2003)). The MN level was similar to that recommended to local farmers. FACE significant increased rough (+12.8%), brown (+13.2%) and milled rice yield (+10.7%), while markedly reducing head rice yield (−13.3%); FACE caused serious deterioration of processing suitability (milled rice percentage −2.0%; head rice percentage −23.5%) and appearance quality (chalky grain percentage +16.9%; chalkiness degree +28.3%) drastically; the nutritive value of grains was also negatively influenced by FACE due to a reduction in protein (−6.0%) and Cu content (−20.0%) in milled rice. By contrast, FACE resulted in better eating/cooking quality (amylose content −3.8%; peak viscosity +4.5%, breakdown +2.9%, setback −27.5%). These changes in grain quality revealed that hardness of grain decreased with elevated [CO_2] while cohesiveness and resilience increased when cooked. Overall, N supply had significant influence on rice yield with maximum value occurring at MN, whereas grain quality was less responsive to the N supply, showing trends of better appearance and eating/cooking quality for LN or MN-crops as compared with HN-crops. For most cases, no [CO_2] $\times$ N interaction was detected for yield and quality parameters. These data suggested that the current recommended rates of N fertilization for rice production should not be modified under projected future [CO_2] levels, at least for the similar conditions of this experiment.

Keywords: Free-air CO_2 enrichment (FACE); Global change; Quality; Rice grain; Yield

1. Introduction

Empirical records provide incontestable evidence of global changes; foremost among these changes is the increasing atmospheric carbon dioxide concentration ([CO_2]), which, as is predicted, will be double the concentration of the pre-industrial era around the mid-21st century (IPCC, 2001). Atmospheric [CO_2] enrichment must directly influences the growth and development of all terrestrial higher plants as a result of increasing the substrate availability for photosynthesis. Rice (*Oryza sativa* L.) is one of the most important plants in the world and the first staple food in Asia, providing nutrition to a large proportion of the world's population. The improvement of grain yield and quality are the two most important objectives in rice production. It is reported that, in order to assure food security in the rice-consuming countries of the world, farmers will have to produce 50% more rice with improved qualities to meet the demand of consumers in 2025 (Peng and Yang, 2003). As rice supplies increase to meet demand, and as incomes rise throughout the region, rice consumers become increasingly concerned with the chemical and physical characteristics of the rice grains that they buy; however, to date, there are far fewer

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observations of the effects of elevated [CO_2] on grain quality compared to growth and grain yield mainly because of the limited number of plants that can be grown under chamber or enclosure conditions. In view of the importance of grain quality in human diet and the lack of available data on the subject, it has become increasingly necessary to evaluate how the inevitable rise in global CO_2 concentrations will affect grain quality of rice.

Grain quality of rice is a composite of several attributes, and its preference generally depends on the countries and regions people lives (Juliano, 2001). In a limited number of studies, elevated atmospheric [CO_2] at levels expected over the next century have been shown to affect grain quality in rice, though the available data was contradictory. Using short duration cultivar Jarrah as test material within a chamber experiment, Seneweera et al. (1996, 1997) reported that rice grains produced under elevated [CO_2] exhibited lower mineral (viz., N, P, Zn and Cu) and protein contents, while amylose content was higher than in those grown under ambient [CO_2], thus resulting in harder grains grown under elevated [CO_2]. In Japanese rice FACE (Free-Air CO_2 Enrichment) experiments with small panicle (average 80 spikelets per panicle) cultivar Akitakomachi, Terao et al. (2005) analyzed for protein and amylose contents as well as the starch pasting properties, finding that FACE decreased the protein content, increased maximum viscosity and breakdown of starch, but did not change amylose content and the palatability measured by sensory taste panels. During the course of the same FACE experiments, Lieffering et al. (2004) reported that only N concentration in rice grains was negatively affected by CO_2 enrichment, with other macro- (viz., P, K, Mg, S) and micronutrient contents (viz., Zn, Mn, Fe, B, Mo) remaining unaffected. These findings indicated that detailed knowledge on rice quality responses to elevated [CO_2] is still lacking to date: (1) The major determinants of rice quality are appearance, milling and cooking/eating and nutritional quality. However, CO_2 enrichment studies cited above investigated only few characteristics of grain quality. Limited measures of grain quality are hard to provide integrated responses of grain quality to CO_2-enriched atmospheres. (2) Nitrogen (N) is the most important element that not only is the biggest amount of elements that plants absorb from the soil, but also contributes to the plant growth, yield as well as quality more than other nutritional elements (Ling et al., 1994; Perez et al., 1996), and may play a important role in the response of plant to [CO_2] (Ziska et al., 1996b; Kim et al., 2003a,b). Surprisingly, no report is available to answer if and how the rice quality responses to rising [CO_2] will be moderated by N supply. (3) With respect to test materials, only cultivars with short-duration or small panicles have been investigated, with no attention given to other cultivars. As we know, the presence of large panicles of high-yielding rice cultivars ensures that a sufficient spikelets number per unit area can be obtained, leading to the increase of the grain yield potential (Ling et al., 1994; Peng et al., 1999). In addition, long-duration rice cultivars generally have higher potential of crop productivity as compared with short-duration ones (Ling et al., 1994). Based on these situations, we carried out the current FACE experiment.

The FACE system provided an opportunity to monitor seasonal trends in morphological and physiology traits of plant grown under fully open-air conditions at an agronomic scale with minimal alteration of plant microclimate, thereby without the limitations often imposed by growth chambers (McLeod and Long, 1999). In 2001 the first rice/wheat rotation FACE platform in the world, which is also the second Rice FACE system in the world, was established at Wuxi city, Jiangsu province, China, with the core objective of investigating the impact of FACE on rice/wheat growth, yield, quality and rice/wheat rotation ecosystem processes under field conditions. As in the Japanese Rice FACE project (also the first rice FACE facility in the world), rice crops were grown from transplanting to grain maturity under two levels of [CO_2] (ambient and ambient plus 200 μmol mol^{-1}) (Kim et al., 2003a,b). By contrast, however, according to the actual Chinese rice production, a cultivar with larger panicle (average 155 spikelets per panicle) that has been used in large-scale production in China was tested and three higher N levels (15, 25, 35 g N m^{-2}, compared with 8 or 9 g N m^{-2} in the Japanese Rice FACE trial) were supplied. In addition to this, the key cultivation technique (such as N application strategy and irrigation management) and environmental conditions (such as air temperature and incident solar radiation) in our experiment are also quite different from those in Japanese Rice FACE experiment. In previous articles, we investigated the effects of elevated [CO_2] and N supply on rice growth and yield formation, include phenology (Huang et al., 2005), photosynthesis (Liao et al., 2002), water relations (Liao et al., 2002; Luo et al., 2002), dry matter production and distribution (Yang et al., 2006a), nitrogen uptake and utilization (Yang et al., 2007) and yield formation (Yang et al., 2006b). As part of the long-term Chinese Rice FACE project, objectives of the present study were to determine whether and to what extent grain quality of rice, including processing suitability, appearance quality, eating/cooking quality and nutritional quality, were changed by alteration of the two important production variables, atmospheric [CO_2] and nitrogen supply using a Chinese rice cultivar with long-duration and large panicle as material. The results obtained here should provide important implications with respect to adaptation strategies of rice under future elevated CO_2 conditions.

2. Materials and methods

2.1. Experiment site description and meteorology

The FACE experimental system was located at the Nianyu Farm of Wuxi, Jiangsu province, China (31°37′N Latitude, 120°28′E Longitude), where the soil is classified as stagnic anthrosols (local name, huangni soil). A rice–wheat rotation system prevails in this region. The details of soil properties, climate and regional agricultural practices can be found in previous publications (Yang et al., 2007).

2.2. FACE system

The China Rice FACE system has eight rings located in different paddies having similar soils and agronomic histories.