Does elevated CO_2 concentration affect lamina length of rice cultivars?

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Abstract

This study demonstrates that a contrasting response of lamina length to elevated CO_2 exists among rice (*Oryza sativa* L.) genotypes. Four cultivars of different earliness were grown under ambient (A) and elevated CO_2 (200 ?mol/mol above ambient, E) for a whole developmental cycle, and lamina lengths were compared according to their leaf position. The ratio of lamina length under E to A (E:A ratio) ranged from 0.93 to 1.05. Elevated CO_2 had a significant positive effect on lamina length of an early variety (Bouzu 5), with a higher E:A ratio in the main stem and primary tillers than in the secondary tillers. A negative effect of E was found in medium (Akitakomachi) and late (Sasanishiki) cultivars. The reduction in lamina length by E for these varieties was largely due to the decreased length in relatively upper positioned leaves. Developmental responses to elevated CO_2 may have a link to the contrasting effects of elevated CO_2 on lamina length among genotypes. The negative effect of E on lamina length in some varieties may partly explain the limited response of plant or canopy leaf area to elevated CO_2 observed in the past experiments. Whether the positive response found in an early variety could confer a greater biomass and yield responsiveness to elevated CO_2 remains to be tested.

Media summary

A contrasting response of final lamina length to elevated CO_2 was found among rice genotypes of different maturity group.

Key Words

Oryza sativa L. CO_2, lamina length, genotypic variation

Introduction

The response of leaf growth to CO_2 concentration is one of the key determinants for biomass and yield under elevated CO_2. Previous studies reported that in many species the rate of leaf expansion and whole-plant leaf area development is stimulated by elevated CO_2 concentration (e.g. Malse 2000; Ferris et al. 2001). In rice (*Oryza sativa* L.) as in other major crops, various experimental methods were used to determine the growth response to CO_2. It has been observed that, in many cases, lamina area is less responsive to elevated CO_2 than biomass and/or tiller numbers (e.g. Imai et al. 1985; Baker et al. 1990; Kim et al. 1996; Sakai et al. 2001; Kim et al. 2003). One of the reasons for the limited response of plant or canopy leaf area to elevated CO_2 despite more tillers being produced, may be related to the individual lamina size. The lamina size is generally sensitive to many environmental factors, but the direct effect of CO_2 on rice lamina size has not been examined in detail, partly because leaf position and genotype often modulate the effect as reported by Malse (2000) for wheat. The present study therefore aims to determine the effect of elevated CO_2 (ambient +200 ?mol/mol) on lamina length of different leaf positions using four rice genotypes of different earliness.

Methods

Plant culture and growth conditions

The experiments were conducted in two pre-air-conditioned temperature gradient chambers at the National Agricultural Research Center for Tohoku Region, Morioka, Japan (39°45' N, 141°08' E) and were repeated for two years (2002 and 2003). Germinated seed of two early (Bouzu 5 and Kirara 397), one medium (Akitakomachi) and one late (Sasanishiki) cultivars were sown on cell trays on May 7 in 2002 and May 13 in 2003. Seedlings were raised in each chamber and were transplanted to pots of 7.5 L (one plant per plant) filled with alluvial soil mixed with 0.30 g of N, 0.44g of P and 0.83 g of K on June 7 in 2002 and June 13 in 2003. Four and three pots for each variety were used in each chamber in 2002 and 2003, respectively.

Each chamber had a growth room of 6 m in width, 26 m in length and 3m in maximum height and was covered with 0.05-mm thick ethylene-tetrafluoro ethylene copolymer film (Okada et al. 2000). Air was taken from the pre-air-conditioning room to the growth room and was exhausted at the other end of the growth room. In one chamber, CO_2 was released in the pre-air-conditioning room, which was flown in the growth room from the air inlet. CO_2 concentration in the growth room was controlled at the target of 200 ?mol/mol above the ambient (E). Ambient air was flown in the other chamber (A). In the growth room, air temperature was set to increase with the distance from the air inlet with the maximum difference of about 7 °C. In the current trials, the pots were placed at 10.5 m from the air inlet in both chambers. Air temperature from June to August at the pot location averaged 22.6 °C in E and 22.7 °C in A in 2002 and 22.0 °C in both chambers in 2003. CO_2 concentration in A averaged 380 and 377 ?mol/mol in 2002 and 2003, respectively, and in E 580 ?mol/mol in both 2002 and 2003.

Measurements

Lamina lengths of all leaves in 2002 and of leaves on main, primary and secondary stems in 2003 were measured fortnightly until the heading stage with a 3-D digitizer (FASTRAK, Polhemus, Colchester, VT USA) which was interfaced with a software FLORADIG ? developed by Hanan and Room (1997). The software recorded 3D coordinates of the leaves labeled according to position on the respective tiller. Lamina length was estimated based on the 3D coordinates of five equally spaced points on the midrib of each lamina (Watanabe et al. 1999).

Results

The date when 50 % of the panicles emerged (HD) was July 28 for Bouzu 5, July 30 for Kirara 397, August 11 for Akitakomachi and August 15 for Sasanishiki on the average over treatments and years. The difference in HD between A and E was within 4 days, E generally having earlier HD. The difference between CO_2 concentration was larger in medium and late cultivars.

The effect of E on lamina length was generally small compared to responsive species but appeared different among cultivars, and the genotypic effects were mostly consistent over the years (Table 1). When all the leaves were compared, the mean ratio of lamina length under E to A as shown in the regression slope ranged from 0.93 to 1.05. The positive effect of E (the ratio larger than 1) was observed in Bouzu 5 for both years, though significant only in 2003. There was no significant effect in Kirara 397. On the other hand, elevated CO_2 significantly decreased lamina lengths of medium and late varieties of Akitakomachi and Sasanishiki (2-7 %). Among the four varieties tested, Akitakomachi showed the largest reduction in lamina length by E for both years (4- 7 %).

Table 1. Comparisons of lamina lengths of four cultivars grown under ambient (A) and elevated (E) CO_2 concentrations in 2002 and 2003. In each CO_2 concentration, lamina length at the same leaf position was averaged over plants, and the mean lengths under E were regressed on those under U for the respective leaf position. The regression line was forced to go through the origin and the slope represents the ratio of E to A. The means of more than three (2002) and two (2003) plants were used, and n is the number of pairs used for the regression.

Cultivar	2002					2003				
	Regression slope	95% Confidence Intervals			n	Regression slope	95% Confidence Intervals			n
Bouzu 5	1.04	0.99	<	1.08	38	1.05	1.00	<	1.10	32
Kirara 397	0.99	0.97	<	1.02	74	1.02	0.99	<	1.05	71
Akitakomachi	0.93	0.90	<	0.96	66	0.96	0.93	<	0.98	100
Sasanishiki	0.98	0.97	<	1.00	121	0.96	0.94	<	0.99	114

Another common observation across two years was that the E:A ratio generally decreased from the main stem to secondary tillers in early varieties. Indeed, there was no significant enhancement by E in the secondary tillers in Bouzu 5 and Kirara (even a significant reduction was observed in 2002), while we found a significant enhancement in the main stem or primary tiller in these varieties in one year. In medium and late varieties, on the other hand the E:A ratio was similar across different tiller orders.

Figure 2 is an example of lamina lengths on the primary tillers attached to the different nodes of the main stem of Akitakomachi in 2002. In all stems shown, final lamina length increased from the lower to upper positions almost linearly toward the 3rd or 4th leaf from the top, then decreased toward the flag leaf (to the right end). Elevated CO_2 concentration did not decrease lamina length at lowers positions. Even a slight positive effect of E on lamina length was observed in some cases. As leaf position increased, lamina under A tended to become longer than under E. In other words, the reduction in lamina length by E typically observed in Akitakomachi (Table 1 and Figure 1) was largely due to the difference in relatively upper positioned leaves.

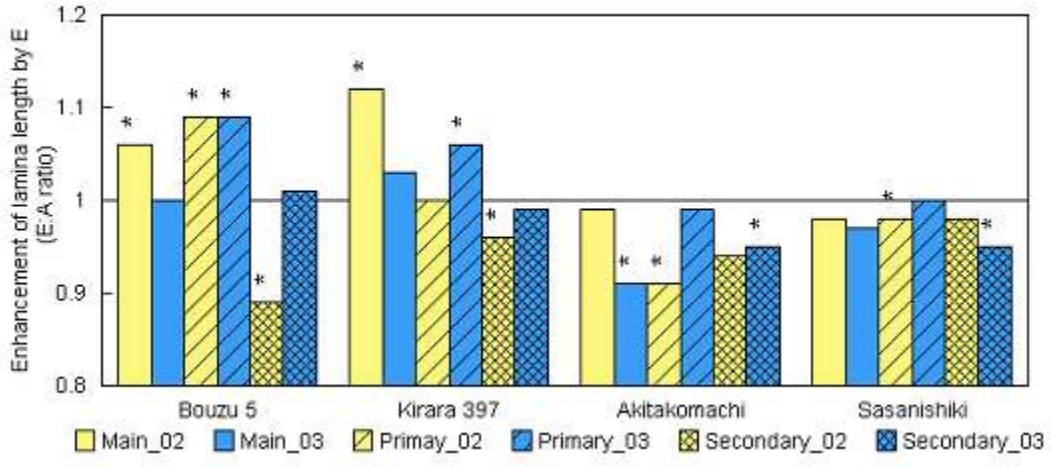

Figure 1. Comparisons of lamina lengths on the main stem, primary and secondary tillers of four cultivars grown under ambient (A) and elevated (E) CO_2 concentrations in 2002 (yellow) and 2003 (blue). The enhancement by E was obtained by the regression the slope as in Table 1. * indicates that the E:A ratio differs significantly from 1 at the 5 % probability level.

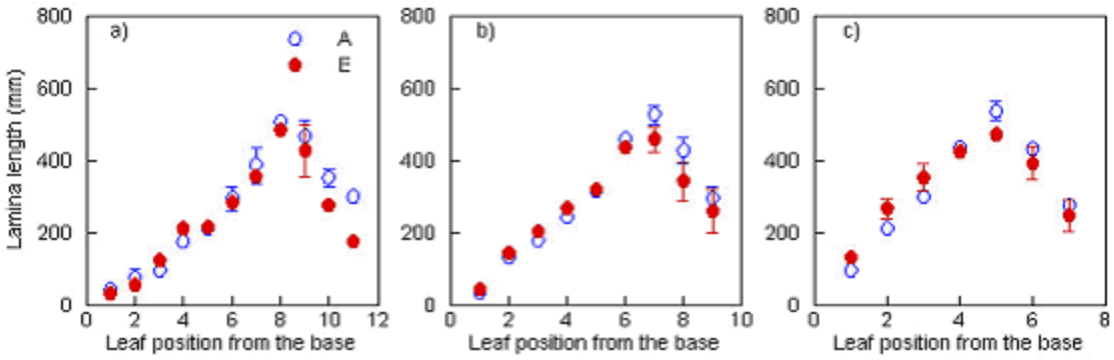

Figure 2. Lamina lengths of primary tillers on the 2nd (a), 4th (b) and 6th (c) node of the main stem of Akitakomachi grown under ambient (A) and elevated (E) CO_2 concentrations in 2002. Vertical bars are standard errors of the mean (n=4).

Implication and conclusion

The present study reports for the first time that a contrasting response of lamina length to elevated CO_2 exists among rice genotypes. The magnitude of the effect (0.93 to 1.05) was smaller compared to that observed in highly responsive species such as *Populus* (Ferris et al. 2001), but the change in lamina length might result in a larger impact on lamia area. Although we did not measure lamina breadth in the present study, evidence exists that length is positively correlated with breadth (e.g. Watanabe et al. 2002). If this relation holds for the effect of CO_2, then the effect on lamina area might be significantly more than that on length.

It is not yet conclusive whether the contrasting response was a result of the difference in earliness of the cultivars because the number of cultivars tested is quite limited. The reduction in lamina length by E in a medium variety occurred mostly in upper leaves. Even with early varieties, E could reduce lamina length of the higher order tillers. These may suggest that the reduction in lamina length is a result of competition for assimilates or nutrients. If the competition is the major reason for the negative effects on lamina length, then the timing of panicle initiation may have a significant impact. Namely, young developing panicles may compete for assimilates with lamina development. Of the four varieties tested, heading date was advanced by elevated CO_2 in medium and late varieties, while not so in early varieties. Therefore, phonological response to elevated CO_2 may have a link to the contrasting effects of elevated CO_2 on lamina length among genotypes.

The negative effect of E on lamina length found in medium and late varieties may partly explain the limited response of plant or canopy leaf area to elevated CO_2 observed in the past experiments. The positive influence on lamina length found in an early variety, on the other hand, may confer a greater responsiveness to elevated CO_2. Field trials are under way to determine the performance of these varieties under elevated CO_2 using the free air CO_2 enrichment (FACE) system in Shizukuishi, Japan.

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