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Effects of 1-methylcyclopropene on function of flag leaf and development of superior and inferior spikelets in rice cultivars differing in panicle types

Junhua Zhang[a], Yujiong Lin[a], Lianfeng Zhu[a], Shengmiao Yu[a], Sanjoy K. Kundu[b], Qianyu Jin[a,*]

[a] State Key Laboratory of Rice Biology, China National Rice Research Institute, Hangzhou 310006, Zhejiang, PR China
[b] Dow Chemical Company, Mumbai 400079, Maharashtra, India

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ABSTRACT

High ethylene production usually slackens spikelets development in compact panicled rice (*Oryza sativa* L.) cultivars. 1-Methylcyclopropene (1-MCP) is a potent inhibitor of ethylene action that has been shown to prevent ethylene-induced effects in fruits. However, effects of 1-MCP on spikelets development in rice cultivars differing in panicle types are unclear. This study explored whether 1-MCP is involved in regulating rice flag leaf function, and superior and inferior spikelets development. Four rice cultivars were field grown in 2012 and 2013, including two lax-panicled cultivars, Liangyoupeijiu (LYP9) and Guodao 6 (GD6), and two compact-panicled cultivars, Yongyou 9 (YY9) and Yongyou 12 (YY12). Results showed that 1-MCP played a positive role in regulating photosynthetic rate of rice flag leaf. Application of 1-MCP was more effective on enhancing grain filling rate of LYP9, GD6, and YY9. 1-Aminocyclopropane-1-carboxylic acid synthase (ACS) activity and ethylene production of inferior spikelets were more sensitive to the regulation of 1-MCP comparing to that in superior spikelets. Compared to other cultivars, ACS activity and ethylene production in inferior spikelets of LYP9 with 1-MCP treatment were significantly lower than that in control (CK). Effect of 1-MCP on starch content in superior and inferior spikelets varied with rice cultivars, but application of 1-MCP significantly enhanced starch content of inferior spikelets for LYP9. To compare with CK, application of 1-MCP greatly increased grain yield, spikelet fertility, and harvest index for LYP9, GD6, and YY9, especially for LYP9. Results indicate that 1-MCP favorably regulated flag leaf photosynthesis and inferior spikelets development in rice cultivars used in this trial, and LYP9 showed the best performances after application of 1-MCP.

1. Introduction

In the quest for high grain yield, spikelet number of panicle was increased significantly in the recently introduced rice cultivars (Duan et al., 2013). However, growth and development of spikelets in these large-panicled rice cultivars are asynchronous (Wang et al., 2012). Earlier-flowering superior spikelets located on apical primary branches usually develop very fast after anthesis and produce larger and heavier grains (Mohapatra et al., 1993; Yang et al., 2006). In contrast, later-flowering inferior spikelets located on basal secondary branches generally produce poorly filled grains (Subhakara et al., 2011). In the heavy panicled rice cultivars, the problem is more acute because nearly half of the inferior spikelets of panicle remain unfilled or partially filled (Lee et al., 2007). Heterogeneous development of spikelets has been a severe impediment to maximizing grain yield potential (Fu et al., 2011).

Spikelets especially for inferior spikelets produce more ethylene at anthesis (Yang et al., 2007). Ethylene production and the related enzyme activities in grains during the grain filling period correlated negatively with rice production (Zhang et al., 2009). Suppression of ethylene action or synthesis prior to anthesis enhanced inferior spikelets development (Naik and Mohapatra, 2000; Yang et al., 2006). When ethylene concentration was reduced by application of inhibitors like silver or amino-ethoxyvinylglycine (AVG, an inhibitor of ethylene synthesis by inhibiting ACC synthesis), dry

Abbreviations: 1-MCP, 1-methylcyclopropene; LYP9, rice cultivar, Liangyoupeijiu; GD6, rice cultivar, Guodao 6; YY9, rice cultivar, Yongyou 9; YY12, rice cultivar, Yongyou 12; P_n, net photosynthetic rate; ACC, 1-aminocyclopropane-1-carboxylic acid; ACS, ACC synthase.

* Corresponding author at: State Key Laboratory of Rice Biology, China National Rice Research Institute, 359 Tiyuchang Road, Hangzhou 310006, PR China.
Tel.: +86 571 63370122; fax: +86 571 63370122.
E-mail addresses: zhangjunhua@caas.cn (J. Zhang), jinqianyu@caas.cn (Q. Jin).

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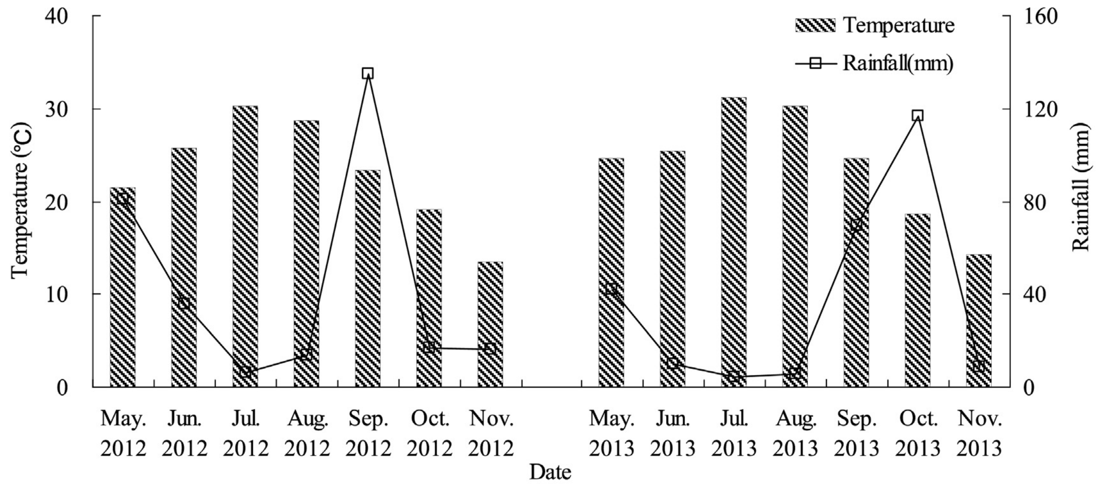

Fig. 1. Monthly temperatures and precipitations during the experimental period in 2012 and 2013.

mass as well as development increased in the inferior spikelets (Naik and Mohapatra, 1999). Decreasing ethylene production for rice also plays a positive role in enhancing photosynthesis of plant leaf (Panda et al., 2009). High photosynthesis is beneficial to assimilate partitioning and sink strength of spikelets in panicle (Li et al., 2012; Chen et al., 2013). Therefore, there is a need for inhibitors to reduce ethylene production in rice plants and to improve rice grain yield (Kuanar et al., 2010).

Ethylene perception is mediated by a family of endoplasmic reticulum membrane localized receptors (Wuriyanghan et al., 2009; Zhang et al., 2013). The gaseous compound 1-methylcyclopropene (1-MCP) is a competitive inhibitor of ethylene binding with ethylene receptors and prevents ethylene responses (Li et al., 2014; Su and Finlayson, 2012). It is being commercially used in many countries on mango, apple, pear, banana, and other horticultural crops (Wang et al., 2009). 1-MCP may inhibit fruits ripening by occupying irreversibly ethylene-binding sites, and then ethylene is unable to bind and elicit subsequent signal transduction and translation (Blankenship and Dole, 2003). 1-Aminocyclopropane-1-carboxylic acid synthase (ACS) plays an important role in transformation of ethylene (Apelbaum and Yang, 1981). Ethylene production in plants was increased with increased ACS activity (Rudus´ et al., 2013). Recently, some reports have shown that inhibition of ethylene action by 1-MCP had a more pronounced inhibitory effect on ethylene release in rice (Seneweera et al., 2003). Regulation of 1-MCP showed favorable results on reducing ACS activities of inferior spikelets (Zhang et al., 2014). However, little information is available with regard to the effects of 1-MCP on the difference in grain development between superior and inferior spikelets. More recent work has shown that application of ethylene inhibitors like AVG is more favorable on spikelts development in compact panicled rice cultivar (Panda et al., 2009). Whether ethylene action inhibitor, 1-MCP plays a role of spikelets development in lax-panicled rice is unknown until now.

The purpose of this study was to investigate changes in photosynthetic rate of flag leaf, grain filling rate, ACS activity and ethylene production and starch content in superior and inferior spikelets, grain yield and yield components after application of 1-MCP by using four genotypes differing in panicle types, and to determine whether 1-MCP plays a role in regulating function of flag leaf and development of superior and inferior spikelets in rice cultivars differing in panicle types.

2. Materials and methods

2.1. Plant materials and growth conditions

Field experiments were conducted at China National Rice Research Institute (39°4′49″ N, 119°56′11″ E), Zhejiang Province, China in 2012 and 2013 (Figs. 1 and 2). Four rice cultivars with large panicles differing in panicle types were used. They were two lax-panicled rice cultivars, Liangyoupeijiu (LYP9) and Guodao 6 (GD6); two compact-panicled rice cultivars, Yongyou 9 (YY9) and Yongyou 12 (YY12). LYP9 and GD6 have similar growth period ranged from 134 to 148 days from sowing to physiological maturity, while YY9 and YY12 share similar growth period ranged from 152 to 156 days. Seedlings were raised in field at a hill spacing of 17 cm × 30 cm with two seedlings per hill. Plots were separated by plastic film buried to a depth of 30 cm under the soil to prevent lateral seepage of water and fertilizers. Except drainage at end-tillering, the water level was maintained at 2–4 cm during the whole growth period. The dates of the rice plant growth are presented in Table 1.

A paired check plot design was used in this trial. The plots were 3.06 m × 4.6 m in size with 6 replications. The soil of the field was loam clay that contained organic matter at 4.7% and available

Table 1
Planting data in 2012 and 2013.

Year	Cultivar	Sowing mm/dd	Transplanting mm/dd	Max tillering mm/dd	Mid-booting mm/dd	Initial flowering mm/dd	Full heading mm/dd	Maturity mm/dd
2012	LYP9	05/23	06/18	07/25	08/15	08/22	08/25	10/08
	GD6	05/23	06/18	07/21	08/11	08/17	08/21	10/04
	YY9	05/23	06/18	07/30	08/25	09/03	09/08	11/03
	YY12	05/23	06/18	07/30	08/25	09/03	09/08	11/03
2013	LYP9	05/24	06/16	07/22	08/20	08/23	08/26	10/17
	GD6	05/24	06/16	07/18	08/15	08/19	08/22	10/15
	YY9	05/24	06/16	07/26	08/27	09/10	09/14	11/19
	YY12	05/24	06/16	07/26	08/27	09/10	09/14	11/19