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Competitive Performance of Hybrid Rice with Barnyardgrass

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ABSTRACT

Barnyardgrass had relatively higher growth vigor at the earlier growth stage than inbred rice did, showing the 2 fold higher α-amylase activity during the periods of germination and large leaf area expansion with high net photosynthetic rate at the earlier autotrophic stage, but it performed weak growth at the late growth stage. However, the hybrid rice Shanyou 63 had significantly higher α-amylase activity and net photosynthetic rate than that of barnyardgrass, exhibiting heterosis for two physiological traits during the germination (6~12 days) and autotrophic phase, respectively. Accordingly, hybrid rice, Shanyou 63, exhibited heterotic effect at the early growing stage when were presented with barnyardgrass. Shanyou 63 exhibited stronger tillering ability, faster leaf area expansion and higher net photosynthetic rate than those of barnyardgrass.

Keywords : α-amylase activity, hybrid rice, heterosis, interspecific competition, barnyardgrass.

It has been considered that heterosis is a complicate genetic phenomenon which can be manifested in quantitative trait and be expressed in vigor of the vegetative organs and the grain yield based on the resistance to disease and the tolerance to stress conditions of salinity, alkalinity, NH_4^+ as nitrogen source, waterlogging and drought etc.. Substantial evidences are available to indicate that hybrid rice is characterized by greater homeostasis by offering flexible alternative genetic pathways. However, no previous studies have been conducted to elucidate the heterotic performance for the competitiveness with noxious weeds and its ecophysiological process in rice. It is important to detect the relationship of their competitiveness between hybrid rice and barnyardgrass since weed control has become as one of the serious problems.

The indiscriminate use of herbicides during a short span of last decades has resulted to various problems including the emergences of resistant weeds to herbicides, the shift of weed population similar to crops, and the increasement of the environmental pollution, etc.. It has been attempted to depress the weeds by increasing competitive strength of crop itself or by using bioherbicide, which has been considered as parts of integrated weed management under the consideration of sustainable agricultural development (Kropff et al., 1993). Thus, it will be a new challenge for crop scientists to breed and to foster an ideal crop population to exert its competitive influence on weeds.

The objectives of this study were (a) to determine the effects of various densities of barnyardgrass which has been considered as the most problem weed in paddy field, especially in direct-seeded rice culture (Kim, 1993), and (b) to compare these effects with inbred rice cultivars so as to understand the competitive advantage and its physiological mechanism in hybrid rice.

MATERIALS AND METHODS

Barnyardgrass (*Echinochloa oryzicola*), one hybrid rice, Shanyou 63, has been currently used as an indica type in China, as well as Minhui 63 (R line) as its fertile male parent, and Milyang 23, an elite inbred rice, obtained from indica/japonica cross, were used in this experiment in Taegu, Korea.

At 2.5-leaf stage, two plants of rice entry were transplanted in the pots (0.1 m^2 surface area per pot) containing about 5 kg commercial soil. Eight different barnyardgrass densities of 0, 1, 2, 4, 8, 12, 16, and 18 plants/pot were treated under the same density of rice, 2 plants/pot and rice-free weed at the same density were planted as control. Additive design (Rado et al., 1984) and randomized complete arrangement were employed in this competitive experiment with 6 replications. Some plants that failed to survive were immediately replanted with plants similar in size as the failing ones. Two grams of fertilizer ($N:P_2O_5:K_2$= 16:16:16) were applied to a pot as the basal dressing prior to transplanting. One gram of fertilizer was applied as the top dressing at the active tillering stage. The number of tillers per plant and plant height were measured with the interval of 5 days during the main growth stages of rice and weed.

Determination of α-amylase activity

α-amylase activity in both rice cultivars and barnyardgrass were also measured at the germinating

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stage, following a procedure described by Takao et al. (1970) to correlate seed germinating speed with its effect on crop-weed competitive system.

Determination of chlorophyll content and net photosynthetic rate

Net photosynthetic rate and chlorophyll content of leaves in each entry were determined at the active tillering stage by using the half-leaf method and spectrophotometer approach as presented in the previous reports (Lin et al., 1996).

Determination of leaf area, biomass and yield components

Three replications were used to determine leaf area/pot, biomass of shoot and root of each rice genotype and barnyardgrass at the maximum tillering stage and heading stage. Total biomass, grain yield, and yield components were investigated with three replications.

Statistical analysis

All data obtained from this study were subjected to variance analyses with SAS program to determine the competitive relationships between barnyardgrass and rice cultivars on dry matter weight and their yields. The hybrid cultivars were compared with the inbred rice cultivars. In addtion, some aspects in the growth habits of hybrid and inbred rice were analysed under the conditions of different barnyardgrass densities.

RESULTS AND DISCUSSION

α-Amylase activity

The characteristics of initial growth at the heterotrophic stage of weed and crops have been considered as one of important factors in competitiveness with each other. Hybrid and inbred rice cultivars showed much lower α-amylase activity than that of barnyardgrass at the very onset of imbibition (Fig. 1). During the germination progress, the enzyme activity of the barnyardgrass, *E. oryzicola*, was remarkedly decreased from at the beginning of incubation to 6th day after incubation and then maintained until the late germination period, 12th day after incubation. α-amylase activity of barnyardgrass species, *E. crus-galli*, was also gradually decreased from at the beginning of germination to 6th day after germination and then was maintained till 12th day after incubation, showing similar tendency with α-amylase activity of *E. oryzicola*, although its activity was slightly higher in *E. oryzicola* than that of *E. crus-galli*. α-amylase

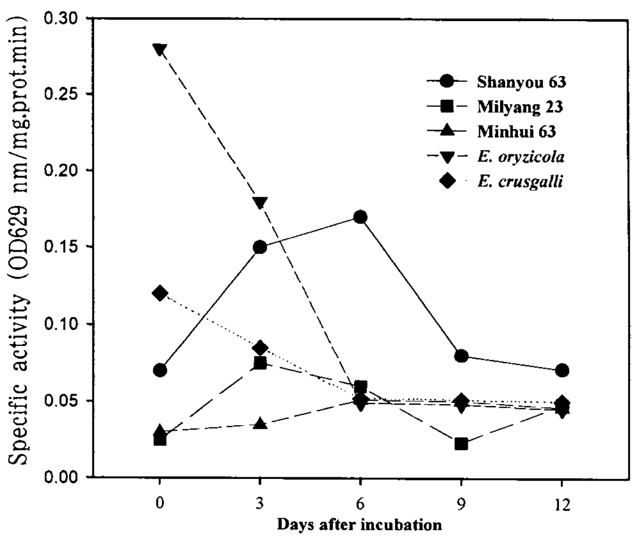

Fig. 1. Specific α-amylase activities of rice cultivars and barnyardgrass during germination stage.

activities of all rice genotypes were very low at the beginning of germination compared with the barnyardgrass species. α-amylase activity of hybrid rice, Shanyou 63, was progressively increased and peaked at 6 day after imbibition, remarkedly decreased to 9th day after imbibition and then slightly decreased to 12th day after incubation. However, α-amylase activity of hybrid rice, Shanyou 63, was appeared to be much higher than those of inbred rice cultivars throughout the all germinating peroid (0~12 d). It might be assumed that what Shanyou 63 had higher α-amylase activity compared to those of inbred lines was the heterotic effect.

α-amylase activity of barnyardgrass was approximately 4-fold higher than that of hybrid rice Shanyou 63 at the beginning of germination and maintained its higher activity till 3th day after imbibition. It has generally been known that higher α-amylase activity could accelerated the hydrolysis of starch in seeds to provide the energy and assimilates for the initial growth, especially at the heterotrophic stage (Takao et al., 1970). Therefore, it can be inferred that barnyardgrass will perform its growth advantage in the germinating stage comparing with the inbred rice cultivars, especially in direct-seeded rice system. If α-amylase activity affects to promote the germination particularly at the initial germinating stage, it would be expected that hybrid rice Shanyou 63 could have better competitiveness on the interferences between rice and barnyardgrass at the early growing stage, especially in direct-seeded rice system.

Table 1. Net photosynthetic rate and chlorophyll content in leaves of rice cultivars and barnyardgrass used in monoculture with same density per pot.

Genotype	Density (Plants/pot)	Chlorophyll content (mg/g fresh weight)	Net photosynthetic rate ($mg/cm^2/hr$)
Shanyou 63	2	1.66	16.30
Milyang 23	2	1.44	14.81
Minhui 63	2	1.30	13.31
E. oryzicola	2	1.15	15.78
$LSD_{0.05}$		0.12	1.34

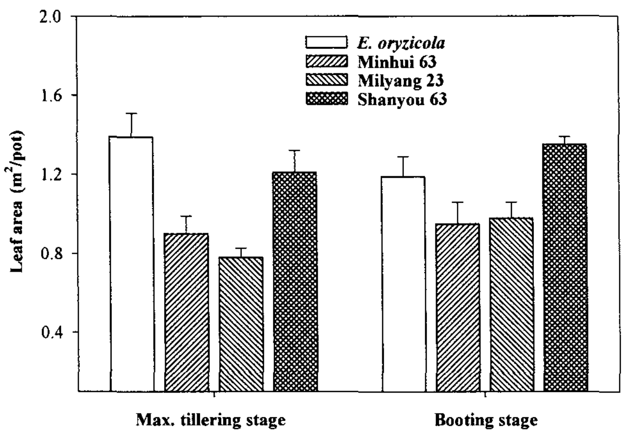

Fig. 2. Leaf areas in each entry at maximum tillering and booting and stage in mixtures.

Photosynthetic rate and chlorophyll content

In order to understand comparative characteristics in the growth habits between hybrid rice and barnyardgrass, particularly at the autotrophic stage, net photosynthetic rate in single leaf *in situ* and chlorophyll content in both rice cultivars and barnyardgrass were determined at the active tillering stage under monoculture with same plant density (Table 1). Net photosynthetic rate and chlorophyll content of leaves in hybrid rice, Shanyou 63, were significantly higher than those of inbred rice cultivars. Although barnyardgrass had significantly higher net photosynthetic rate than inbred rice cultivars and barnyardgrass, although the net photosynthetic rate of barnyardgrass, *E. oryzicola* was similar to that of Shanyou 63, hybrid rice. The inbred rice cultivars, Milyang 23 and Minhui 63 had significantly lower net photosynthetic rate compared to those of Shanyou 63 and barnyardgrass. It might be expected that what the barnyardgrass had higher photosynthetic rate was because the barnyardgrass had an effective C_4 photosynthetic pathway (Rado et al., 1984). In contrast with the net photosynthetic rate, barnyardgrass had significantly lower chlorophyll content than did all rice cultivars.

It has been generally known that the dry matter production of plant would be related to net photosynthetic rate, but also to plant leaf areas, including the duration of photosynthesis. At the booting stage, barnyardgrass had significantly larger leaf areas per pot than those of rice cultivars, except for the hybrid rice, Shanyou 63, showing the larger leaf area per pot compared to that of barnyardgrass. The leaf area of the hybrid rice was larger than those of inbred rice cultivars (Fig. 2). This implied that the barnyardgrass had the growth vigor at both maximum tillering and booting stages. It therefore suggested that depressing the earlier growth of barnyardgrass through doing earlier field management would better be an important key to weed control.

Leaf area, biomass and yield components

Comparing the competitiveness between barnyardgrass and rice cultivars on investigating the growth responses and yield in whole growth period, plant height of rice cultivars including hybrid rice was not significantly affected by the increase of the weed densities (Table 2). However, the yield components such as tiller number and spiklet number were significantly reduced with increasing the densities of barnyardgrass from 1 to 18 plants per pot. Percentage of filled grain and 1,000 grain weight were not significantly affected by the increase of barnyardgrass densities. The grain yield of each rice cultivars responded in similar nonlinear fashions to increased densities of barnyardgrass as shown in Fig. 3. A model $y=a+b \exp(-0.333\chi^2)$ derived from figure 3 could be used to predict rice yield loss under interference of barnyardgrass.

It was indicated that there was a theoretical lower asymptote in terms of the effect of the weed density on the grain yield of each rice genotype. In comparison inbred rice with the hybrid rice, Shanyou 63 showed a higher asymptote when they were mixed with higher densities of barnyardgrass. It was implied that the hybrid rice had stronger interspecific competitive advantage compared to the inbred rice cultivars. Its reason is probably because hybrid rice could have stronger tillering ability to produce more productive tillers per pot under the interference of

Table 2. Performance of main traits in each rice cultivars under the interference of barnyardgrass with different densities.

Cultivar	Traits	Weed densities (Plants/pot) 0	1	2	4	8	12	16	18	$LSD_{0.05(0.01)}$	Mean heterosis X_1	H_1	H_2
S 63	PH	98.0	98.0	98.0	97.0	97.0	95.0	94.0	94.0	4.20 (5.75)	65.9	12.7	13.6
	PT	69.3	31.0	30.0	29.7	19.7	14.7	14.6	14.2	3.20 (5.20)	31.7	21.5	42.8
	TS	8571.2	7431.8	3418.2	3154.3	2276.0	1659.7	1711.1	1610.7	121.00(152.00)	3729.1	84.5	68.5
	SP	123.7	120.1	113.9	106.2	115.5	112.9	116.7	113.3	11.20 (15.20)	115.3	65.9	26.1
	FP	85.6	84.0	83.0	84.1	82.7	78.9	70.5	70.0	10.10 (21.10)	79.9	9.9	5.7
	GW	27.6	27.6	27.2	27.1	26.5	25.2	25.3	25.1	0.57 (1.00)	26.5	0.4	14.2
M 63	PH	87.5	87.5	87.0	85.0	85.0	83.0	83.0	83.0	4.21 (5.71)	85.1		
	PT	67.0	40.1	31.7	25.3	20.7	9.3	7.3	7.0	2.30 (4.70)	26.1		
	TS	5792.2	3274.6	2308.9	2015.8	1490.0	526.2	386.1	372.9	85.30(111.60)	2020.8		
	SP	86.5	81.7	72.9	79.6	72.1	56.6	52.9	53.3	8.70 (11.30)	69.5		
	FP	78.2	78.5	79.3	79.0	81.2	64.0	60.7	60.4	5.10 (11.70)	72.7		
	GW	27.2	27.3	27.1	27.5	26.8	25.3	25.1	25.2	0.07 (1.20)	26.4		
M 23	PH	86.0	86.0	86.0	86.0	85.0	83.0	82.0	81.0	3.70 (5.51)	84.4		
	PT	59.5	37.3	23.0	18.7	14.9	8.3	8.0	7.7	4.33 (10.70)	22.2		
	TS	6267.8	4164.9	2289.4	1747.2	1420.0	779.0	534.8	502.2	91.30(121.70)	2213.2		
	SP	105.3	111.6	99.5	93.6	95.3	93.5	66.9	65.5	7.30 (15.33)	75.6		
	FP	80.9	79.7	79.5	77.2	75.4	71.4	70.7	70.3	4.67 (15.33)	75.6		
	GW	24.8	24.8	23.5	23.2	22.8	22.5	22.3	22.0	0.67 (1.67)	23.2		

* H_1: Heterobeltiosis(%)=[$F_1(X_i)$-Minhui63(X_i)/Minjui63], H_2: Standard hetorosis(%)=[$F_1(X_1)$-Milyang23(X_1)/Milyang23], X_1: Mean of each traits in all densities of barnyardgrass, PH: Plant height(cm), PT: Productive tillers/pot, TS: Total spikelets/pot, SP: Spikelets/panicle, FP: Percentage of filled grains(%), GW: 1000-grain weight(g), S63: Shanyou 63, M63: Minhui 63, M23: Milyang 23.

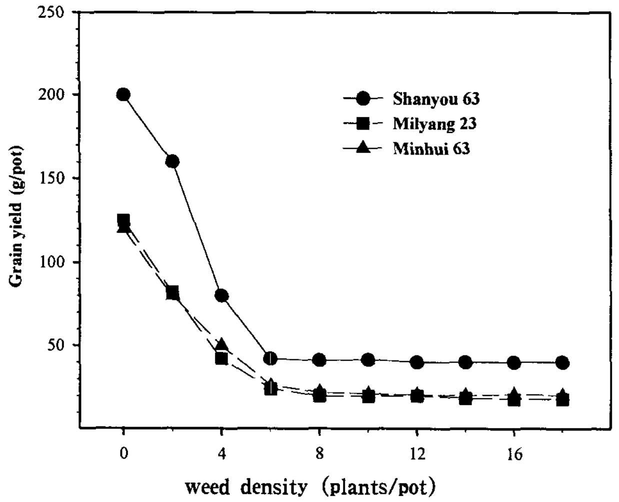

Fig. 3. The growth curve of grain yield(y_i) in hybrid rice and inbred rice under the interference of barnyardgrass with different densities of weed(x).

y_1(Shanyou 63)=$41.87+166.48e^{-0.333}\chi^{2}$($R^2$=0.9754)
y_2(Milyang 23)=$16.1942+103.5969e^{-0.333}\chi^{2}$($R^2$=0.9783)
y_3(Minhui 63)=$19.0743+94.2164e^{-0.333}\chi^{2}$($R^2$=0.9248)

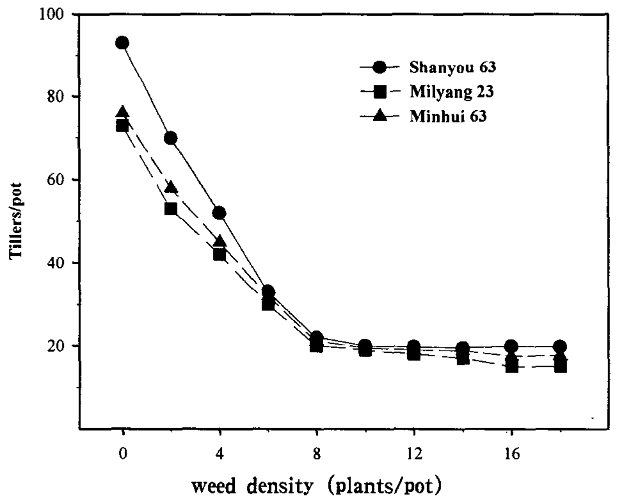

Fig. 4. The growth pattern of tillers(T_i) of hybrid and inbred rice under competition of barnyardgrass with different densities of weed(χ).

T_1(Shanyou 63)=$16.9998+74.5563e^{-0.333}\chi$ (R^2=0.9943)
T_2(Milyang 23)=$19.6996+50.7497e^{-0.333}\chi$ (R^2=0.9894)
T_3(Minhui 63)=$14.2303+50.6703e^{-0.333}\chi$ (R^2=0.9574)

barnyardgrass with the increase of its density.

The results of regressive fitting by the aid of computer indicated that a nonlinear equation y=a+b exp($-0.333\chi^2$) derived from Fig. 4 gave a better quantitative description of the relationship between rice tillering and the weed density. It showed that a theoretical lower asymptote would be existed in each rice genotypes. Hybrid rice displayed a higher asymptote, indicating heterosis for this trait responding to the competition of the weed, which in turn led to more productive tillers (PT) per pot (Table 2) with the largest direct effect on grain yield in hybrid rice as reported in the previous research (Lin et al., 1996). These results might imply that the use of nonlinear model to predict rice yield loss could be a better form compared to that which has been supported by Zimdahl (1980).

It could be concluded that yield components of each genotypes were decreased with increasing the barnyardgrass densities from 1 to 18 plants/pot in most cases, except for hybrid rice, Shanyou 63, which showed no significant differences with various weed densities due to its stronger homeostasis. Therefore, heterosis was pronounced and expressed as the mean value in all densities of barnyardgrass with the exception of heterobeltiosis in the mean value of 1000 grain weight (Table 2). The extent of heterosis for total spikelets per pot was the highest, attributed to higher extent of heterosis in productive tillers per pot with a desirable spikelets per panicle, supported by large leaf areas and high net photosynthetic rate in single leaf with higher chlorophyll content (Lin et al., 1998). The results obtained suggested that heterotic effect on yield performance in rice would be related not only to the genetic properties of rice hybrid, but also to the ability of competitiveness with noxious weeds.

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