

Competitiveness of Rice (*Oryza sativa* L.) Cultivars against Barnyardgrass (*Echinochloa crus-galli* (L.) P. Beauv.) in Lowland Rice Fields

H. Aminpanah¹, A. Sorooshzadeh^{1,*}, E. Zand² and A. Moumeni³

¹Department of Agronomy, College of Agriculture, Tarbiat Modares University, Tehran, Iran

²Department of Weed Research, Iranian Plant Protection Research Institute, Tehran, Iran

³Rice Research Institute in Mazandaran, Km8 Babol Rd., Amol, Mazandaran, Iran

*Corresponding author, Email: soroosh@modares.ac.ir

Abstract

The main objective of this research was to compare the competitive ability of rice cultivars and lines against barnyardgrass. A field experiment was conducted at Rice Research Station in Tonekabon, Iran. The layout of the experiment was a factorial design with four randomized complete blocks. Seven rice cultivars and three lines were transplanted with and without barnyardgrass. Each cultivar or line was transplanted at its own optimum density, while the density of barnyardgrass was 20 plants per square meter. Results showed that for all rice cultivars or lines, yield and yield components were significantly reduced by barnyardgrass competition. Moreover, there was a significant difference among rice cultivars and lines in the relative yield loss under weedy condition, competitive index (CI) and ability to withstand competition (AWC). Line 843 had the minimum relative yield loss (18%), highest CI and AWC, while Khazar cultivar had maximum relative yield loss (50.65%), lowest CI and AWC. Therefore, this experiment demonstrated that the Line 843 was more competitive against barnyardgrass than the other cultivars and lines.

Keywords: barnyardgrass, competitive ability, rice, yield loss

Introduction

Weeds are the greatest constraint to yield in rice production, resulting in yield losses up to 25% (Lindquist and Kroff, 1996). Barnyardgrass (BYG) is the most frequently reported troublesome weed for rice production all over the world (Holm et al., 1977). It is a very aggressive invader, difficult to control, and causes major losses in rice production (Lopez-Martinez et al., 1999). Van Devender et al. (1997) reported that 20 BYG plants in one m² can decrease rice yield by 80%. Moreover, Heavy infestations may remove 60-80% of the nitrogen from the soil (Holm et al., 1977), as well as considerable amounts of other macronutrients (Maun and Barrett, 1986).

Increasing cost of herbicide inputs in intensive crop production systems and incidence of herbicide resistance in weeds have renewed interest in exploiting crop competitiveness to reduced herbicide

use. Weed-competitive ability (WC) of a crop includes two components: The first one is 'weed-suppressive ability' (WSA), or the crop's ability to suppress weeds, also referred to as 'weed suppression'. The second one is 'weed tolerance' (WT), or the ability of crop to maintain its yield with weed interference (Jannink et al., 2000). The difference among rice cultivars in the ability to compete with weeds has been reported since several decades ago. Tall, droopy-leafed and vigorous traditional cultivars were reported to be more weed-competitive but lower in yield potential than short-stature, erect modern ones (Jennings and Aquino, 1968; Jennings and Jesus, 1968; Jennings and Herrera, 1968; Kawano et al., 1974). Although a negative correlation between weed competitiveness and yield, have been reported by several researchers (Jennings and Aquino, 1968; Jennings and Jesus, 1968; Jennings and Herrera, 1968; Kawano et al., 1974), some researchers which worked on tropical

rice (Garritty et al., 1992; Fischer et al., 1997; Johnson et al., 1998; Fofana and Rauber 2000; Ni et al., 2000, Fischer et al., 2001; Anwar et al., 2010; Aminpanah and Javadi, 2011), barley (Watson et al., 2006), soybean (Rezvani et al., 2013), and wheat (Cousens and Mokhtari, 1998) have suggested that competitive cultivars could be developed without substantially lowering yields.

It has been reported that using rice cultivars with the stronger weed-suppressive ability is an effective method to reduce herbicide rates and may decrease dependence on herbicides in weed control (Fischer et al., 2001; Gibson et al., 2001). Therefore, the main objectives of this research were (i) to determine the effect of weed competition on yield of rice cultivars and advanced breeding lines (ii) to identify more and less competitive rice cultivar or line.

Materials and Methods

Field experiment was conducted at Rice Research Station in Tonekabon (36° 54' N, 40° 50' E; 20 m above sea level), north of Iran. Soil properties of the experimental field were 2.2% organic matter content, 37% clay, 44% silt, 19% sand, 6.8 pH, 29.9 cation exchange capacity (CEC) (meg 100 g). The layout of experiment was a factorial design with four randomized complete blocks. Rice seeds were disinfected with thiophanate-methyl 70 WP (20 g L⁻¹ H₂O) and subsequently were sown in the nursery. Cultivars and lines seedlings were manually transplanted in plots sized 18 m² (3 m by 6 m). Seven rice cultivars and three lines were transplanted with and without barnyardgrass. Each cultivar or line was transplanted at its own optimum density (Table 1), while the density of barnyardgrass was 20 plants per square meter. Recommended rates of nitrogen (Table 1), phosphorous (100 kg ha⁻¹) and Potassium (150 kg ha⁻¹) were applied. One-third amount of nitrogen and whole phosphorous and Potassium were applied as a basal dose at transplanting stage. The Remaining two-thirds of nitrogen were utilized in two split doses; 30 days after transplanting and panicle initiation stage. The permanent flood water level was maintained at 10 cm during rice growing period. During the growing season, all weed species except transplanted barnyardgrass were hand weeded.

At maturity, yield (14% moisture) and yield components were determined from 5 square meters per plot following methods described by Dingkuhn et al. (1998). Relative yield loss (RYL) in weedy plots was calculated as the following equation:

$$\text{Relative yield loss (\%)} = 100[(\text{weed-free yield} - \text{weedy yield})/\text{weed-free yield}]$$

For measuring rice biological yield and harvest index (HI), a 1 m² sample from each plot was randomly chosen, clipped at the ground level, threshed, dried at 70°C for three days and weighed. Rice biological yield was expressed as the dry weight of above-ground plant per hectare. Harvest index was the proportion (percentage) of filled grain to the whole above-ground biomass sample in weight.

Barnyardgrass biomass in each plot was determined by collecting the aboveground portion of barnyardgrass from 5 m² (the same sampling area as yield) in each weedy plot at maturity stage, oven dried at 70°C for three days and weighed. It was expressed as the dry weight of above-ground barnyardgrass per m².

In order to evaluating the competitive ability of rice cultivars and lines, competitive index was calculated using the following equation described by Challaiah et al. (1986):

$$CI = \left(\frac{Y_{wp}}{Y_{mean}} \right) / \left(\frac{W_i}{W_{mean}} \right)$$

Where Y_{wp} is the yield from the weedy plot, Y_{mean} is the mean yield from the weedy plot, W_i is barnyardgrass biomass in interference with rice cultivar and W_{mean} is mean biomass of barnyardgrass in interference with all rice cultivars. Also, ability to withstand competition of rice cultivars was calculated by following equation (Watson et al., 2002):

$$AWC = 100(Y_{WP} / Y_{WFP})$$

Where Y_{WP} is the yield from the weedy plot and Y_{WFP} is the yield from the weed-free plot.

Table 1 Released year, optimum density and recommended nitrogen fertilizer application of rice cultivars.

No.	Cultivar or line	Released year	Optimum density (m ²)	Nitrogen application rate (kg ha ⁻¹)
1	Line 843	-	16	200
2	Shiroodi	2006	16	200
3	Line 830	-	16	200
4	Sepidrood	1981	16	200
5	Fajr	2001	16	200
6	Line 841	-	16	200
7	Nemat	1995	16	200
8	Dorfak	2001	16	200
9	Deylamani	traditional	20	100
10	Khazar	1983	16	200

Statistical analysis was conducted using SAS program (SAS Inst., 1990) to make sure that weed suppression ability was significantly different between cultivars. Means were compared using fisher's protected LSD test at $\alpha=0.05$. Moreover, simple correlation analysis was used to draw inferences on the relationship between the recorded agronomic traits of rice and weed biomass, competitive index and ability to withstand competition.

Results and Discussion

Rice Yield and Competitive Ability

Analysis of variance showed that the interaction effect of rice cultivar and barnyardgrass density were significant for all traits (Table 2). Means comparison detected that there was a significant difference among rice cultivars and lines under both weed-free (Table 3) and weedy conditions (Table 4). Under weed-free conditions, Shiroodi, Nemat and Line 830 had the highest grain yield, while under weedy conditions, Shiroodi and Line 843 had the highest grain yield. Moreover, rice grain yield was significantly reduced under weedy conditions, i.e. 5208 kg ha⁻¹ under weed-free conditions and 3399 kg ha⁻¹ under weedy conditions, (Table 5). Rice yield loss under weedy conditions was reported by other researchers (Holm et al., 1977; Heafele et al., 2004; Zhao, et al.,

2006b). Under weedy conditions, the relative yield loss was significantly different between rice cultivars and lines (from 18% for Line 843 to 50.6 % for khazar). So, cultivars reaction was different to weed competition. Line 843 and Shiroodi cultivar had the greatest ability to withstand competition (82 and 75.5), respectively. In contrast, Khazar had the lowest (49.5) one (Table 6). Moreover, competitive index (CI) was significantly different between cultivars and lines (table 6). Line 843 had the highest CI (2.43) because of the higher yield under weedy conditions (4549 kg ha⁻¹) and lower barnyardgrass biomass (1209 kg ha⁻¹). In contrast, Khazar cultivar had the lowest competitive index (0.32) because of the low grain yield (2173.5 kg ha⁻¹) under competition with barnyardgrass and also higher weed biomass (4367 kg ha⁻¹).

These results confirmed that there was a significant difference between rice cultivars for the competitive ability against barnyardgrass. Similar results were reported by researchers in upland rice cultivar (Callaway 1992; Garrity et al., 1992; Dingkuhn et al., 1997; Fofana and Rauber, 2000; Caton et al., 2003; Gealy et al., 2003; Zhao et al., 2006b), lowland rice cultivars (Fischer et al., 1997; Toung et al., 2000), barley (*Hordeum vulgare* L.) (Watson et al., 2006), Soybean [*Glycine max* (L.) Merr.] (Jannink et al., 2000) and wheat (*Triticum aestivum* L.) (Blackshaw 1994; Lemerle et al.,

Table 2 Analysis of variance for comparison between rice cultivar and barnyardgrass density on rice yield, biological yield, fertile tiller number, grain number, 1000-grain weight and harvest index.

S.O.V	Df	Y	BY	FT (m ²)	GN	ThGW	HI
Block	3	47477.7 ^{ns}	99051.5 ^{ns}	46.4 ^{ns}	170.5 ^{ns}	0.89 ^{ns}	13.8 ^{ns}
Cultivar	9	4858889.6 ^{**}	13214576.5 ^{**}	13745.8 ^{**}	1441.9 ^{**}	23.8 ^{**}	67.2 ^{**}
Weed	1	65426105.1 ^{**}	216679445 ^{**}	11328.8 ^{**}	2726.1 ^{**}	10.2 ^{**}	99.1 ^{**}
Weed×cultivar	9	490191.5 ^{**}	1028825.7 ^{**}	519.6 ^{**}	151.7 [*]	0.6 ^{ns}	15.6 ^{**}
error	57	99052.7	1069736.7	75.7	63.7	1.42	4.7
CV (%)	-	7.31	11.6	3.6	7.94	4.31	4.4

*, ** and ns indicate significance at P < 0.05, 0.01 and not significant, respectively.

Table 3 Mean comparison of yield, fertile tiller number, grain number, 1000-grain weight, biological yield and harvest index under weed-free conditions.

Cultivar	Yield (kg ha ⁻¹)	Fertile tiller (No m ⁻²)	Grain number (No panicle ⁻¹)	1000-grain weight (g)	Harvest index	Biological yield (kg ha ⁻¹)
Line 843	5552.3 b	248 c	98.25 b	28.2 bc	52.5 abc	8732.8 de
Shiroodi	6121.3 a	320 a	116.25 a	27.95 bc	54 a	11989.5 a
Line 830	5778.8 ab	225 d	127 a	29.6 b	52.7 abc	11495.5 ab
Sepidrood	4753.3 dc	270 b	95 b	27.77 c	53.5 ab	9621.3 cd
Fajr	5452.5 b	273 b	93.75 b	27.12 dc	50.5 abc	10383.8 bc
Line 841	4906.8 c	241 c	124.75 a	26 d	49.7 c	10802.8 abc
Nemat	6163.8 a	277 b	104.25 b	31.8 a	51.5 abc	12105 a
Dorfak	5438.8 b	242 c	101.75 b	28.17 bc	52.2 abc	11188.3 ab
Deylamani	3498.8 e	231 d	80.25 c	27.8 c	45 d	5813.3 e
Khazar	4417.3 d	173.25 e	122.25 a	25.87 d	50.3 bc	8732.8 de

Terms with one or more common lowercase letter(s) in the same column were not significantly different at P < 0.05.

Table 4 Mean comparison of the yield, relative yield loss, fertile tiller number, grain number, 1000-grain weight (ThGW) and biological yield (BY) under weedy conditions.

Cultivar	Yield (kg ha ⁻¹)	Relative yield loss (%)	Fertile tiller (No m ⁻²)	Grain number (No panicle ⁻¹)	1000-grain weight (g)	Harvest index	Biological yield (kg ha ⁻¹)
Line 843	4549 a	18 e	260 a	97 b	28.7 b	54 a	9079 a
Shiroodi	4621 a	24 de	262 a	99 b	27.7 bc	54.3 a	9449 a
Line 830	3763 b	35 bc	213 d	116 a	28.8 b	52 ab	7719 b
Sepidrood	3116 cd	34 bc	246 b	87 b	27.3 bcd	46.3 ed	6568 cd
Fajr	3142 cd	42 b	261 a	89.25 b	26.2 d	49.8 bc	6612 cd
Line 841	2936 d	40 b	232 c	91.5 b	24.3 e	47.5 cd	7173 bc
Nemat	3760 b	39 bc	259 a	91.25 b	30.7 a	48.3 cd	7870 b
Dorfak	3501 bc	36 bc	233 c	92.25 b	27.9 bc	50 bc	7493 bc
Deylamani	2432 e	30 cd	186 e	71.5 c	26.4 cd	44 e	5813 ed
Khazar	2173 e	50.6 a	129 f	111 a	27.2 bcd	43.8 e	5074 e

Terms with one or more common lowercase letter(s) in the same column were not significantly different at P < 0.05.

1996; Lemerle et al., 2001). Difference of competitive index and ability to withstand competition in rice was linked to plant height

(Garrity et al., 1992), number of tillers (Fischer et al., 1997), early tiller production (Johnson et al., 1998), early height growth (Caton et al., 2003),

early crop biomass (Ni et al., 2000), leaf area index (Karimmojeni et al., 2010; Dingkuhn et al., 1997), canopy ground cover (Audebert et al., 1999), Specific Leaf Area (Audebert et al., 1999) and early vigor (Zhao et al., 2006 a). Correlation analysis (Table 7) showed that there was a significant negative correlation between rice yield and barnyardgrass biomass under weedy

conditions. Zhao et al. (2006b) in upland rice cultivars and Gibson et al. (2003) in lowland rice cultivar reported that there was a negative correlation between rice yield and weed biomass under weedy conditions. Also, it was observed that cultivars with the high ability to withstand competition had the high ability for weed suppression.

Table 5 Mean comparison of grain yield and yield components of rice cultivars and lines under weed-free and weedy conditions.

Trait	Weedy condition	Weed-free condition
Grain yield (kg ha ⁻¹)	5208.3 a	3399.6 b
Fertile tiller (No m ⁻²)	251.9 a	228.1 b
Grain number (No panicle ⁻¹)	106.3 a	94.6 b
1000-grain weight	28.3 a	27.3 b

Terms with one or more common lowercase letter(s) in the same column were not significantly different at $P < 0.05$.

Table 6 Mean comparison of competitive index, ability to withstand competition and barnyardgrass biomass.

Cultivar	Competitive index	Ability to withstand competition	Barnyardgrass biomass (kg ha ⁻¹)
Line 843	2.43 a	82 a	1209 d
Shiroodi	1.57 b	75.5 ab	1832 cd
Line 830	1.26 bc	65 cd	1822 cd
Sepidrood	1.15 bc	65.5 cd	1742 cd
Fajr	1.12 bc	57.75 d	1801 cd
Line 841	0.95 c	60.25 d	1892 cd
Nemat	0.92 c	61.25 d	2560 b
Dorfak	0.8 cd	64.25 cd	2722 b
Deylamani	0.73 cd	70 bc	2139 bc
Khazar	0.32 d	49.5 e	4367 a

Terms with one or more common lowercase letter(s) in the same column were not significantly different at $P < 0.05$.

Table 7 Correlation coefficient between yield and yield component, biological yield, HI, barnyardgrass biomass, CI and AWC under weedy conditions.

Trait	Y	FT	GN	ThGW	BY	HI	BYG.B	CI	AWC
Y	1								
FT	0.73**	1							
GN	0.15 ^{ns}	-0.23 ^{ns}	1						
ThGW	0.43**	0.31*	0.08 ^{ns}	1					
BY	0.93**	0.70**	0.1 ^{ns}	0.39*	1				
HI	0.68**	0.54**	0.26 ^{ns}	0.23 ^{ns}	0.55**	1			
BYG.B	-0.44**	-0.64**	0.19 ^{ns}	-0.1 ^{ns}	-0.40**	-0.54**	1		
CI	0.74**	0.50**	0.02 ^{ns}	0.16 ^{ns}	0.73**	0.63**	-0.49**	1	
AWC	0.70**	0.56**	0.04 ^{ns}	0.22 ^{ns}	0.59**	0.40**	-0.74**	0.64**	1

*, ** and ns indicate significance at $P < 0.05$, 0.01 and not significant, respectively.

Yield Components

Fertile tiller number per square meter

Means comparison for the fertile tiller number showed statistically significant differences among cultivars under both weedy and weed-free conditions. Under weed-free conditions, Shiroodi and Khazar cultivars had the highest and lowest fertile tiller number per square meter (320 and 173.25), respectively. In contrast, under weedy conditions, Shiroodi, Fajr and Nemat had the highest fertile tiller number per square meter (262, 261 and 259, respectively) and khazar had the lowest (129.5) one (Table 4). Reduction in the fertile tiller number per square meter under weedy conditions was reported by other researchers (Yang, 1995; Heafele et al., 2004; Zhao et al., 2006b).

Filled grain number per panicle

Under weed-free and weedy conditions, a significant difference was observed among rice cultivars and lines for grain number per panicle. The highest grain number per panicle was related to Khazar (122.25) and the lowest one was for Deylamani (80.25) under weed-free conditions (Table 3). In contrast, Lin 830 and Khazar had the highest grain number per panicle (116.25 and 111 grain, respectively) and Deylamani had the lowest (71) one under weedy conditions. This was according to yang (1995). Also, Fischer et al. (1997) found a significant interaction between genotype and weed in upland and lowland rice cultivars for the grain number per panicle. In contrast, Gibson et al. (2003) reported that there was no significant interaction between genotype and weed in lowland rice cultivars for the grain number per panicle. Zhao et al. (2006b) also declared the percentage of grain loss per panicle was different under weedy conditions.

1000-Grain weight

There was a significant difference among rice cultivars and lines under both weedy and weed-free conditions for 1000-grain weight. Under weed-free conditions, Nemat and Khazar had the highest and lowest (31.8 and 25.87 gram, respectively) 1000-grain weight. But, under weedy conditions, Nemat with 30.7 gram and line 842 with 24.3 gram had the highest and lowest 1000-grain weight, respectively

(Table 4). Yang (1995) reported that under weedy conditions, 1000-grain weight significantly reduced in rice cultivars. In contrast, some researchers (Heafele et al., 2004; Zhao et al., 2006b) demonstrated weeds had no significant effect on 1000-grain weight.

Rice yield is the function of the fertile tiller number per square meter, grain number per panicle and 1000-grain weight. Each factor affects on yield components, can affect on yield. However, cultivars' tiller number is a genetic trait, but environmental and agronomic factors can severely impose it. Plant density is one of the main factors which affect on tillering rate (wu et al., 1998). Increasing total density (rice plant number per m² + barnyardgrass plant number per m²) reduces space for each rice plant which in turn reduces tillering rate in rice plant and finally cause a reduction in rice yield. Nutrient limitation, especially nitrogen is the other main factor for reducing the tiller number under weedy conditions. Barnyardgrass is a C4 plant and comparison to rice (C3) plant; it had higher nitrogen use efficiency (Ampong-Nyarko and De Detta, 1991). It was reported that heavy infestation of barnyardgrass may remove 60-80 % of the nitrogen from the soil (Holm et al., 1977) as well as considerable amounts of other macro-nutrients (Maun and Barrett, 1986). Moreover, fertilizer applications can favor the weed over rice (Holm et al., 1977). Nitrogen deficiency can cause a reduction in tillering rate and grain number per panicle, resulted in a reduction in rice yield. In addition, nutrient limitation can increase infertile tillers per plant and unfilled grain number per panicle. It was reported, under weedy conditions, barnyardgrass was always a little taller than the rice plants irrespective of rice cultivar (Yamasue, 2001), resulted in a reduction in rice plant photosynthesis, especially in the grain filling period. In cereals such as rice, photosynthesis in the grain filling period has an important role on yield and the contribution of pre-anthesis accumulated reserves to grain weight ranged from 9.1 to 42.2% (Ntanos and Koutroubas, 2002). So, the reduction of rice photosynthesis in the grain filling period due to weed competition increases unfilled grain number per panicle, so this decreases the grain number per panicle and finally rice grain yield. Moreover, photosynthesis reduction in this

period can decrease 1000-grain weight. Holm et al. (1977) inferred that barnyardgrass can reduce rice tillering by 50 % and also can reduce the number of panicle, height, weight of grains and the number of grains per panicle; rice yield may be reduced by 2000 to 4000 kg ha⁻¹. In upland rice, Zhao et al. (2006b) concluded yield loss in competition with barnyardgrass was due to a reduction in rice biomass, fertile tiller number and panicle size while the harvest index, filled grain ratio and 1000-grain weight did not affect under weed competition.

Harvest index

There was a significant difference in rice HI under both weedy and weed-free conditions. Under weed-free conditions, Shiroodi and Deylamani had the highest and lowest harvest index, respectively (Table 3). Under weedy conditions, Shiroodi and Fajr had the highest and lowest harvest index, respectively (Table 4). Shiroodi is a dwarf cultivar so, it's HI be more than Deylamani. The reduction in HI due to weed competition indicates that under interference conditions, grain yield reduced more than biological yield. This finding was similar to those reported by other researchers (Heafele et al., 2004; Zhao et al., 2006b).

Biological yield

Under weedy and weed-free conditions, there was a significant difference in rice biological yield. Under weed-free conditions, Khazar had the lowest and Nemat had the highest biological yield,

although, there was no significant difference between biological yield of Nemat with Shiroodi, Dorfak and Line 830, Line 841 and Line 843 (Table 3). Rice biological yield significantly decreased with weed competition. Under weedy conditions, Khazar had the lowest biological yield and Shiroodi, and Line 843 had the highest one (Table 4). Zhao et al. (2006b) reported similar result.

Correlation analysis showed that there was a positive significant correlation ($r=0.93$) between biological yield and grain yield. Weed biomass decreased with increasing the competitive ability of rice cultivar, It was found that the cultivar which had the higher competitive ability also had higher biological yield and lower weed biomass (Zhao et al., 2006b).

Cultivars with Strong and Weak Competitiveness

Strong competitive cultivars are those which have high yield under weedy and weed-free conditions and also lower weed biomass. To determine these cultivars, cluster analysis in approximately Euclidian tolerance, separated the cultivars to 4 groups (Figure 1): First, Khazar cultivar had high yield potential under weed-free conditions, but low CI and AWC. Second, Line 843 had high yield potential under weed-free conditions, CI and AWC. Third, Shiroodi cultivar had high yield potential under weed-free conditions, and low CI but high AWC, and forth, other lines, and cultivars had low CI and AWC (Figure 1).

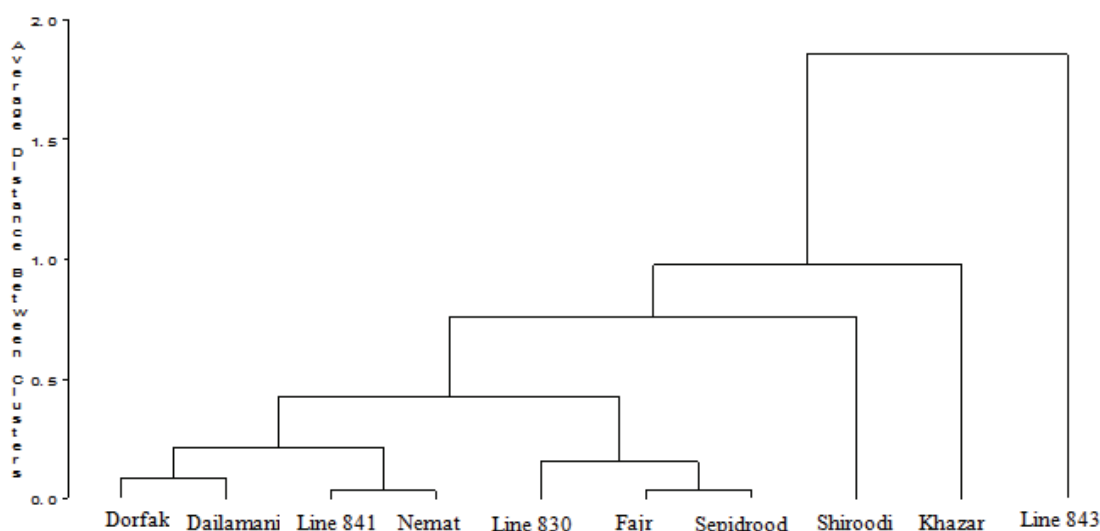


Figure 1 Cluster analysis of rice cultivars and lines basis on competitive ability.

Therefore, with considering cultivars grain yield under weedy and weed-free conditions, competitive index and ability to withstand competition, it was cleared that Line 843 had a high ability to produce high yield under weed-free conditions and also had low yield loss under weedy conditions, but Khazar cultivar was a weak competitive cultivar against barnyardgrass.

Conclusions

This experiment indicated that in all rice cultivars and lines, yield and yield components were significantly reduced by barnyardgrass competition. Moreover, there was a significant difference among rice cultivars and lines in the relative yield loss under weedy condition, competitive index (CI) and ability to withstand competition (AWC). Line 843 had the minimum relative yield loss (18%), highest CI and AWC, while Khazar cultivar had maximum relative yield loss (50.65%), lowest CI and AWC. Therefore, this experiment demonstrated that the Line 843 was more competitive against barnyardgrass than cv. Khazar.

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Manuscript received 05 December 2013, accepted 28 January 2014