Comparing the Competitive Ability of Old and New Wheat Cultivars against Rocket (*Eruca sativa*) in Iran

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ABSTRACT

During the 2003-2004 growing season, an experiment was conducted at the Plant Protection Research Institute in Karaj, Iran, to compare the competitive ability (CA) of eight wheat cultivars released during the last 50 years. Each cultivar (Tabasi, Roshan, Karaj2, Azadi, Niknejad, Mahdavi, Shiraz and Pishtaz) was grown in weed-free conditions or infested with rocket (*Eruca sativa*). The results indicated that grain yield competitive indices differed significantly between the cultivars. An old cultivar, Karaj2, showed a high ability to withstand competition (AWC), high competitive indices (CI) and low grain yield in the weed-free plots (3865 kg ha^{-1}). Cultivar Tabasi, a less competitive cultivar, had the lowest AWC and CI amongst the cultivars. There was a significant negative correlation between AWC and grain yield in the weed-free plots. Also, no significant correlation was observed between CI and AWC. The number of spikes m^{-2}, number of fertile tillers

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plant^{-1}, number of plants m^{-2}, and number of kernels spike^{-1} were the most influenced components of yield in weedy conditions. This study showed that local adaptation is important for the Karaj2 cultivar to prevent yield loss (tolerance) in weed-infested conditions, and more suppression ability in the presence of rocket.

Keywords: Competition, *Eruca sativa*, suppressive ability, tolerance, wheat.

چکیده

برایر ارزیابی توانایی رقابتی هشت رقم گندم پائیزه معرفی شده در ۵۰ سال اخیر، در برابر علف‌هرز منداب (*Eruca sativa*)، آزمایشی در سال زراعی ۸۳-۸۲ در مزرعه تحقیقاتی موسسه گیاهپزشکی کشور در کرج اجرا شد. هر رقم گندم در شرایط وجود و عدم وجود رقابت با علف‌هرز منداب کشت گردید. نتایج نشان داد که این ارقام از نظر عملکرد دانه در هر دو شرایط با یکدیگر اختلاف معنی‌داری دارند. همچنین توانایی رقابت ارقام نیز با یکدیگر متفاوت بود. کرج ۲ به عنوان یک رقم قدیمی، علی‌رغم داشتن عملکرد دانه پایین در شرایط عدم حضور علف‌هرز، به‌طور معنی‌داری موجب کاهش بیوماس و تولید بذر علف‌هرز منداب شد. در میان این ارقام، رقم طبسی به عنوان یک رقم ضعیف در رقابت با منداب، دارای کمترین مقدار AWC (توانایی تحمل یک رقم در برابر علف‌هرز) و CI (توانایی یک رقم در کاهش بیوماس و بذر علف‌هرز) در میان ارقام بود. نتایج تجزیه همبستگی نشان داد که بین میزان تحمل ارقام (شاخص AWC) و عملکرد دانه در شرایط عدم حضور علف‌هرز، همبستگی منفی معنی داری وجود دارد. همچنین هیچ همبستگی معنی داری بین دو شاخص AWC و CI دیده نشد. تاثیر پذیرترین اجزای عملکرد ارقام گندم در شرایط رقابت با منداب، به ترتیب تعداد سنبله در متر مربع، تعداد پنجه بارور در هر گیاه، تعداد بوته در متر مربع و تعداد دانه در هر سنبله بودند. به طور کلی نتایج این تحقیق نشان داد که رقم کرج۲ به دلیل سازگاری بهتر با شرایط منطقه کرج، توانایی بالایی در جلوگیری از کاهش عملکرد خود در شرایط رقابت با منداب، داشته (تحمل بالا) و از طرفی بیوماس و مقدار بذر علف‌هرز را نیز تاحد زیادی کاهش داد.

واژه‌های کلیدی: رقابت، منداب، گندم، توانایی رقابتی، تحمل.

INTRODUCTION

Weeds cause yield loss in cereal production systems, particularly where there is no herbicide application or a lack of weed control because of herbicide resistance (Powles *et al.*, 1997). Rocket (*Eruca sativa*) is a winter annual broad-leaf weed that is particularly troublesome in winter wheat fields of Iran (Khodabandeh, 1998). Under field conditions, rocket and wheat seeds germinate simultaneously. The weed grows rapidly with prostrate habit and establishes a deep and extensive root system.

In Iran, farmers use high levels of herbicides in cereal fields to control broad-leaf weeds. Extensive use of herbicides may result in contamination of underground and surface waters and also adjacent land areas. This has negative environmental impact and may lead to restrictions in herbicide application. Moreover, weed resistance has become a major problem, and has begun to force farmers towards integrated weed management, which involve a greater reliance on non-chemical control measures. The use of more competitive crops is one of the important components of integrated weed management, although selection for increased crop competitiveness is a difficult task (Korres and Froud-Williams, 2002). Therefore, one approach to alleviate weed competition in winter wheat would be to make use of more competitive cultivars (Balyan *et al.*, 1991). Two factors contribute to crop competitiveness against weeds: ability to withstand competition (AWC) i.e., the ability to maintain high yields in the presence of weeds, and weed suppressive ability (WSA), the ability of the crop to reduce weed biomass and seed production (Jannink *et al.*, 2000). WSA and AWC are often difficult to separate in field experiment data (Lemerle *et al.*, 2001). However, there are indications that varietal variation in WSA may be greater than that of AWC (Jordan, 1993). In addition, WSA may be considered the most agronomically desirable trait, since it controls weed populations for long-term periods, and therefore has greater implications for weed management programs. However, this will depend on its overall effectiveness, and its use by farmers in combination with other control methods (Lemerle *et al*., 2001, 1996).

Variation in the competitive ability (CA) of wheat cultivars has been reported (Lemerle *et al.*, 2001; Blackshow, 1994). Tepe *et al.* (2005) investigated the effect of weeds on different lentil (*Lens culinaris* L.) cultivars. Challaiah *et al.* (1986) also compared the CA of 10 winter wheat varieties against downy brome (*Bromus tectorum*). *D*ry matter production ranged from 1900 to 3249 kg ha^{-1} when competing against these different varieties at one site, compared with 1100–1970 kg ha^{-1} at another site. Corresponding yield losses among the wheat varieties ranged from 9 to 21% at one site and from 20 to 41% at the second site. The use of competitive cultivars in weed management practice requires an assessment of varietal responses to weed competition in terms of yield loss. Furthermore, varietal responses should be compared with the varietal yield differences in the absence of weeds.

The objectives of this study were (i) to evaluate yield and yield components of Iranian winter wheat cultivars which have been released in the past 50 years in competition with rocket; and (ii) determining the CA of the wheat cultivars and introducing more competitive cultivars in competition with rocket.

MATERIALS AND METHODS

The work was conducted at the Plant Protection Research Institute in Karaj, in 2003-2004 on a loamy clay soil. The experiment was established in a randomized complete block design with a factorial arrangement of treatments and four replications. Eight wheat cultivars were used (Table 1), each grown under weed-free and weed-infested conditions.

Taking into account seed viability and weight, the cultivars were each planted at their optimum density (Tollenaare, 1986), as proposed by the Iran Seed and Plant Improvement Institute. Rocket seeds were planted uniformly and concurrently with wheat cultivars and thinned to 80 plants m^{-2}. Each plot consisted of eight rows, 6m in length with 0.3m row spacing. The first irrigation was performed immediately after drilling. During the growth season, all weed species in weed-infested plots except rocket were hand weeded, as well as all emerging weeds in the weed free plots.

Table 1. Wheat cultivars, year of release, optimum plant density, optimum nitrogen fertilizer and 1000-grain weight used in this study.

Cultivars	Year of release	Optimum plant density (Seeds m^{-2})	Optimum nitrogen fertilizer (Kg ha^{-1})	1000-grain weight (g)
Tabasi	1956	250	-	51
Roshan	1958	250	110	53
Karaj2	1976	325	110	29
Azadi	1978	325	105	27
Niknejad	1995	425	120	37
Mahdavi	1995	375	130	41
Shiraz	2002	400	120	32
Pishtaz	2002	400	120	39

Wheat was harvested at economic maturity. All plant materials were weighed to calculate biomass. After threshing, grain weight was also determined. To measure yield components, twenty spikes were collected randomly from each plot at harvest to estimate kernels $spike^{-1}$, fertile and unfertile spikelets $spike^{-1}$ and spike length.

WSA of wheat cultivars was calculated using Equation 1 (Zand, 2000) which was obtained from Callaway and Francis (1993) with a few modifications:

$$CI = \left(\frac{V_i}{V_{mean}}\right) / \left(\frac{W_i}{W_{mean}}\right) \quad (1)$$

where V_i is the yield of cultivar *i* in the presence of weeds, V_{mean} is the mean yield of all cultivars in presence of weeds, W_i is the weed biomass related to cultivar *i* and W_{mean} is the mean weed biomass in the presence of all cultivars. To evaluate WSA of the cultivars in reducing rocket seed production, Equation 2 was applied:

$$CI_2 = \left(\frac{V_i}{V_{mean}}\right) / \left(\frac{S_i}{S_{mean}}\right) \quad (2)$$

where S_i is the weed seed yield related to cultivar *i* and S_{mean} is the mean weed seed in a mixed stand of all cultivars. It is worth mentioning that Eq. (2) has been obtained from combining Eq. (1) and the amount of rocket seed production, instead of rocket biomass production, and is presented here for the first time.

AWC of wheat cultivars against rocket was calculated from the following equation (Watson, 2002):

$$AWC = \left(\frac{V_i}{V_p}\right) \times 100 \quad (3)$$

where V_i is the yield of cultivar *i* in the presence of weeds, and V_p is the mean yield of cultivar *i* in weed-free conditions.

Correlation coefficients were calculated between yield and different yield components. Cluster analysis was performed to classify cultivars in terms of their competitive ability (CA) including the three indices AWC, CI and CI_2. The linkage method was Average Linkage (between groups) and dissimilarity metric was Squared Euclidean Distance. The effects of weeds on wheat cultivars and differences among cultivars were analyzed with the SAS statistical package (1998).

RESULTS AND DISCUSSION

Wheat grain yield and competitive ability

The analysis of variance (ANOVA) showed that there were significant interactions between wheat cultivars and weed infestation for wheat grain yield and biomass. The percent yield loss (AWC) was different between cultivars (Table 2); cultivars Roshan and Karaj2, showed the highest AWC, and cultivars Tabasi, Niknejad and Mahdavi had the lowest AWC. High AWC in cultivars Karaj2 and Roshan was accompanied by low grain yield in the weed-free plots (3241 and 3865 kg ha^{-1}, respectively). So, there was a significant negative correlation between weed tolerance ability and yield potential in the weed-free plots, which is consistent with the results from correlation analysis ($r=-0.817^{*}$) (Table 3). The negative relationship between AWC, as an indication of wheat CA, and the weed-free yield potential is of concern (Donald and Hamblin, 1976). In the UK, wheat varieties that produce the greatest grain yield in weed-free plots were the most severely affected by weed competition (De Lucas and Froud-Williams 1994). In contrast, in Australia no relationship was observed between weed-free yield and percent yield loss (Lemerle *et al.*, 2000; Gill and Coleman, 2000).

In the case of CI, our results also indicated significant differences between cultivars. Cultivar Shiraz had the highest CI (2.28) which could be attributed to its higher grain yield under weed-infested conditions (3155.8 kg ha^{-1}) and its ability to reduce rocket biomass (1351.4 kg ha^{-1}). Also, no positive relationship was found between grain yield under weed-free and weed-infested conditions ($r = -0.223$). Adversely, Australian data showed a strong positive correlation between weed-free and weed-infested grain yield (Cousens and Mokhtari 1998; Gill and Coleman, 2000). However, it seems possible to introduce a cultivar which is able to reduce weed biomass whilst keeping its grain yield high (Shiraz and Karaj2) (Table 2). Bussan *et al.*, (1997) also found this. Cultivar Pishtaz, a less competitive genotype, showed high yield, both under weed-free and weed-infested conditions. Cultivar Tabasi had the lowest CI amongst the cultivars. This was due to its high weed biomass and very low grain yield (2012.8) in the presence of rocket (Table 2). Gill and Coleman (1999) also reported a strong association between yield reduction in wheat and *L. rigidum* biomass in southern Australia.

Rocket seed production was highest when it was grown with cultivars Karaj2 and Niknejad, respectively (i.e. CI_2). Although rocket seed production and biomass were reduced by old and modern cultivars, no significant correlation was found between CI and CI_2 (Table 3). For instance, cultivar Shiraz, which had a high CI, possessed a low CI_2. Also, no significant correlation was found between CI and AWC, but there was a significant correlation between AWC and CI2 (Table 3). Lemerle *et al.* (2001) stated that AWC and WSA might not necessarily be present in the same variety. Nevertheless, in the present study it was observed that weed tolerant cultivars Roshan and Karaj2 also had high CI_2.

Determination of Less and More Competitive Cultivars

Generally, an ideal crop cultivar should have high yield potential under both weed-free and weed-infested conditions, the ability to withstand weed growth, and weed growth suppressive ability (Bussan *et al.*, 1997). Using these criteria,, no ideal cultivar was identified in the present study. For instance, cultivar Karaj2 which showed high AWC and CI_2 showed a low CI and produced low grain yield in the weed-free plots (Table 2). Our results also showed a negative correlation between the weed-free grain yield and competitive indices (Table 3). Therefore, we may not be able to introduce a cultivar which has a high grain in the weed-free plots, whilst maintaining a high CA. However, it is possible to introduce relatively ideal cultivars using these criteria. Following this line of thought, cluster analysis grouped the wheat cultivars into 3 groups based on AWC, CIM and CI_2 (Fig. 1).

Table 2. Grain yield, wheat biomass, rocket biomass and seed production, AWC, CI and CI_2 of wheat cultivars under weed-free and weed infested.

Grain yield (kg ha^{-1})	Wheat biomass (kg ha^{-1})		Rocket production (kg ha^{-1})		AWC	CI	CI_2
Weed-infested	Weed-free	Weed-infested	Biomass	Seed			
2012.8d	15278 a	8472cd	4073.1a	919.66b	42.93c	0.46c	0.69cd
3152.2b	10417c	9028cd	2525.4c	864.44b	96.87a	1.22b	1.19ab
3288.6a	10972bc	11806a	2927bc	833.44b	85.07a	1.26b	1.5a
3124.2b	13194abc	10556abc	2344.3cd	1118.79ab	55.14bc	1.29b	0.92bcd
2330.3cd	16389a	9306bcd	1900.8cd	1412.61a	39.88c	1.24b	0.52d
2758.3bc	15625a	7639d	4044.7a	1035.25ab	44.76c	0.71bc	0.95cd
3155.8b	14167ab	9861abcd	1351.4d	888.88b	59.54bc	2.28a	1.10abc
3890.8a	15972a	11667ab	3633.3ab	819.94b	67.26b	1.04b	1.29ab

* Means within each column followed by the same letter are not significantly different according to Duncan's multiple range test at the 0.05 level.
AWC: Ability to withstand competition, CI & CI_2: Competitive indices.

Table 3. Correlation coefficients between competitive indices and the weed-free grain yield.

	Weed-free grain yield	AWC	CI	CI_2
d-free grain yield	1.000	-0.817*	-0.049	-0.435
		1.000	0.259	0.779*
			1.000	0.314
				1.000

* Significant at the 0.05 probability level.
AWC: Ability to withstand competition, CI & CI_2: Competitive indices.

Cultivars Tabasi, Niknejad and Mahdavi were grouped as less competitive cultivars (with high weed-free yield), Roshan and Karaj2 as more competitive cultivars (with low weed-free yield), and Shiraz, Pishtaz, and Azadi as an intermediate group (with high weed-free yield). In total, cultivars Tabasi and Karaj2 would be introduced as less and more competitive cultivars, respectively. With their high weed-free grain yield, cultivars Pishtaz and Shiraz could be introduced as more competitive cultivars because of their lower competitive indices.

Yield Components

Our results indicated that there were significant differences in the number of spikes m^{-2} and fertile tiller $plant^{-1}$ between weedy and weed-free conditions (Table 4). Even though other yield components, including number of plant m^{-2}, kernel $spike^{-1}$, 1000-grain weight, spike length, fertile and unfertile spikelets $spike^{-1}$ showed non-significant reduction in competition with rocket (Table 4). Blackshaw (1993) attributed wheat yield reduction under weed infestation to a reduction in kernel $spike^{-1}$. McLelland (2000) also reported that wheat tillering ability was reduced against *Alopecurus sp.*, *Polygonum aviculare, and Lolium rigidum*, however, 1000-

grain weight was not affected by weed competition. In current study, the effect of yield components when considered as a whole caused different losses in grain yield between cultivars. Our results agree with findings of Tepe *et al.* (2005) who studied lentil competition against weeds. They reported that the effect of weeds on the different lentil cultivars and their yield components was significant.

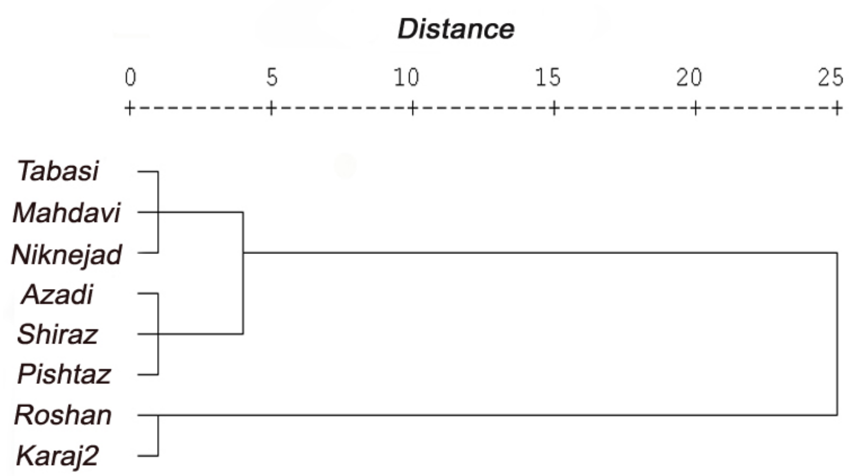

Figure 1. Cluster analysis of wheat cultivars based on three competitive indices (AWC, CI & CI_2).

Although the effect of rocket on wheat population density was not significant, the reduction (113.95 and 100.6 plants m^{-2} in the weed-free and weed-infested plots, respectively) could be attributed to inter-specific competition. The same result was obtained for kernels $spike^{-1}$ (Table 4). Jafarnejad and Rahimian (2003) also reported that wheat population density was reduced in competition with rocket. This is probably attributable to the prostrate growth habit of rocket, caused shading on the wheat and resulting in a reduction in plants m^{-2}.

Table 4. Yield components of wheat cultivars under weed-free and weed-infested conditions.

Yield components	**Weed-free**	**Weed-infested**
Plants/m^2	113.95a*	100.6a
Spikes/m^2	562.44a	443.16b
Kernels/spike	29.91a	27.53a
1000-grain weight (g)	47.69a	49.12a
Spike length (cm)	8.16a	8.09a
Fertile tillers/ plant	4.99a	4.44b
Fertile spikelets/ spike	13.25a	13a
Unfertile spikelets/spike	3.89a	4.02a

* Within each column, means followed by the same letter are not significantly different based on Duncan's multiple range test at the 0.05 level.

Significant reduction in spikes m^{-2} is mostly related to reductions in stand density and tillers $plant^{-1}$. Correlation analysis showed that there was a significant positive correlation between plants m^{-2} and spikes m^{-2} ($r=0.85^{**}$). As a result, grain yield reduction under weed-infested conditions was mostly related to losses incurred in primary yield components. Williams and Mohammad (1996) stated that *Circium arvense* caused yield loss by affecting wheat stand density and spikes m^{-2}.

There was a significant reduction in the number of tillers $plant^{-1}$ under weed-infested conditions compared with the weed-free plots (Table 4). This was mostly due to the capture of water, nutrients, and light by rocket. Due to the important role of tiller number in wheat yield increase, it would be advantageous to cultivate wheat cultivars which have high tillering ability under weed infestation.

Table 5 shows correlation coefficients between yield and yield components under weed-infested conditions. Although there were no positive correlations between yield and yield components, cultivars' grain yield was affected by yield components when considered as a whole.

Altogether, it is concluded that number of spikes m^{-2}, fertile tillers $plant^{-1}$, plant m^{-2}, and number of kernel $spike^{-1}$ are the most affected yield components in wheat under weed-infested conditions. So, these yield components could be used in breeding programs to increase wheat yield against rocket.

The results of the present study showed that rocket reduced growth, yield, and yield components of various wheat cultivars. Generally, cultivars Shiraz and Karaj2 were introduced as highly competitive cultivars against rocket. Cultivar Karaj2 was introduced in 1975 at Karaj, which shows the important role of local adaptation in CA of a cultivar. It also indicates the importance of the genotype×environment interaction on wheat CA. By sowing this cultivar we should be able to reduce herbicide dosage in wheat fields for the control of rocket. However, the effect of differing years and locations on the variability of results is extremely important and must be considered.

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Table 5. Correlation coefficients of yield and yield components of wheat cultivars in competition with rocket.

	Grain yield	Fertile tillers plant^{-1}	Unfertile tillers plant^{-1}	1000-grain weight	Plants m^{-2}	Spikes m^{-2}	Kernels spike^{-1}	Spike length	Fertile spikelets spike^{-1}	Unfertile spikelets spike^{-1}
Grain yield	1.000	0.413	0.270	0.039	-0.265	-0.005	0.316	0.475	0.524	0.266
Fertile tillers plant^{-1}		1.000	-0.294	0.496	-0.526	-0.048	-0.314	0.227	-0.242	-0.226
Unfertile tillers plant^{-1}			1.000	0.064	0.066	-0.030	0.159	0.253	0.343	0.122
1000-grain weight				1.000	-0.047	0.176	-0.853**	-0.056	-0.326	0.025
Plants m^{-2}					1.000	0.853**	-0.179	0.173	0.309	0.052
Spikes m^{-2}						1.000	-0.322	0.350	0.229	0.096
Kernels spike^{-1}							1.000	0.392	0.623	0.120
Spike length								1.000	0.803*	-0.050
Fertile spikelets spike^{-1}									1.000	0.138
Unfertile spikelets spike^{-1}										1.000

*, ** Significa nt at the 0.05 and 0.01 level of probability, respectively.

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