Evaluation of Some Characteristics Affecting Competitiveness of Eight Iranian Wheat Cultivars with Rocket Weed

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ABSTRACT
Crops that better tolerate weed competition or preempt resources from weeds may reduce dependence on herbicides and benefit an integrated weed management program. A field trial was conducted to determine the morphophysiological characteristics affecting tolerance and weed suppressive ability of some winter wheat cultivars in competition with Rocket. The experimental treatments consisted of eight wheat cultivars; kept under weed free and weed infested conditions in a randomized complete block design with a factorial arrangement. The results indicated that

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cultivars with greater harvest index (HI) or ability to prevent HI losses in competition with Rocket could balance yield losses and consequently increase their tolerance. Height increase in more competitive cultivars in competition with Rocket, was important in the competitive ability (CA) of these cultivars (as both tolerance and suppressive ability). Those cultivars with higher CA, were taller or had greater rate of stem elongation. Enhancement rate of stem elongation caused an earlier closure of canopy in more competitive cultivars, and consequently through shading on weed, suppressed the Rocket growth. In conclusion, more competitive cultivars possessed a set of characteristics that contribute to their strong competitive ability including high leaf area and vertical leaf area distribution, taller and greater rate of stem elongation, and high early vigor (viability and speed of germination).

**Keywords:** wheat, competitiveness, *Eruca sativa*, morphophysiological characteristics.

**INTRODUCTION**

Rocket (*Eruca sativa* Mill.) is a winter annual broadleaf weed that is particularly troublesome in winter wheat fields of Iran (Khodabandeh, 1998). The rocket seed germinates along with wheat, grows rapidly, and establishes a deep and extensive root system, and its growth habit is prostrate. In Iran, farmers use large amount of herbicides to control the broadleaf weeds in cereals fields (Baghestani *et al*., 2007). The availability of selective herbicides during the last 30 years has enabled farmers to grow high yielding wheat varieties bred and producing optimal yields in weed free conditions. However, the increasing use of herbicides may lead to leaching to ground and surface waters and to adjacent natural areas. Thus, both public and political pressures have increased the emphasis on cultural weed control (e.g. the use of competitive cultivars) methods for prevention of weed problems (Olesen *et al*., 2004).
Several researchers have examined different morphological and physiological traits of wheat cultivars and their competitiveness with weeds (Blackshow, 1994; Fischer et al., 2001). In the experiments, characteristics commonly identified to make crops more competitive include rapid germination and root development, higher biomass at tillering, early vigor (e.g. speed of germination), hight gain and flag leaf area, vertical leaf area distribution and greater harvest index (Christensen, 1995; Lindquist and Mortensen, 1998; Ogg and Seefeldt, 1999; Lemerle et al., 2001; Weiner et al., 2001; Watson et al., 2002).

In the present experiment, the morphophysiological traits associated with competitive ability of eight wheat cultivars, which are commonly used on wheat agroecosystems in most areas, were studied, in competition with rocket. The morphological traits of more competitive cultivars would enable them to capture resources, or utilize resources more efficiently in comparison to a poorly competitive cultivar. Hence, these traits may be used in breeding programs to release new cultivars with better competitive ability, and consequently reducing herbicide use in wheat production.

MATERIALS AND METHODS
A field trail was conducted to determine the morphophysiological characteristics affecting competitive ability of eight winter wheat cultivars (Table 1) in competition with Rocket weed in Karaj, TE (35° 59' N, 57° 6' E; 1020 masl) during 2003-2004 growing season on a loam clay soil. Two weedy checks (weed free and weed infested) were used with eight wheat cultivars in a factorial experiment in randomized complete block design with four replicates. Each plot consisted of eight rows, of 6m in length and 0.3m row spacing.
In autumn, one plowing operation followed by two disking and land leveling were performed to prepare the seedbed for planting. Ammonium phosphate and urea were applied at rates of 150 and 100 kg ha\(^{-1}\), respectively, based on local soil analysis recommendations. Top dress urea was applied at tillering and heading stages at rate of 50 kg/ha each. All weeds except rocket were hand removed during the growing season.

To permit wheat showing its yield potential including competitive ability against weed, each cultivar was planted according to its own optimum density (Table 1). This method is strongly recommended by Tollenaar et al. (1994) when comparing different cultivars released in different area so each cultivar was able to show its preferences on another. According to the seed viability, grain weight, and optimum plant density (seeds m\(^{-2}\)) proposed by Iran Seed and Plant Improvement Institute, KA, each cultivar was then planted at the actual plant density (Table 1). Rocket seeds were planted uniformly and thinned to 80 plants m\(^{-2}\).

<table>
<thead>
<tr>
<th>Maturity group</th>
<th>Actual plant density (g m(^{-2}))</th>
<th>Seed 1000-weight (g)</th>
<th>Optimum nitrogen fertilizer (kg ha(^{-1}))</th>
<th>Optimum plant density (Seed m(^{-2}))</th>
<th>Release year</th>
<th>Cultivars</th>
</tr>
</thead>
<tbody>
<tr>
<td>early</td>
<td>13</td>
<td>51</td>
<td>-</td>
<td>250</td>
<td>1956</td>
<td>Tabasi</td>
</tr>
<tr>
<td>early</td>
<td>13</td>
<td>53</td>
<td>110</td>
<td>250</td>
<td>1958</td>
<td>Roshan</td>
</tr>
<tr>
<td>semi-late</td>
<td>10</td>
<td>29</td>
<td>110</td>
<td>325</td>
<td>1976</td>
<td>Karaj2</td>
</tr>
<tr>
<td>early</td>
<td>10</td>
<td>27</td>
<td>105</td>
<td>325</td>
<td>1980</td>
<td>Azadi</td>
</tr>
<tr>
<td>semi-early</td>
<td>17</td>
<td>37</td>
<td>120</td>
<td>425</td>
<td>1995</td>
<td>Niknejad</td>
</tr>
<tr>
<td>semi-early</td>
<td>16</td>
<td>41</td>
<td>130</td>
<td>375</td>
<td>1995</td>
<td>Mahdavi</td>
</tr>
<tr>
<td>late</td>
<td>13</td>
<td>32</td>
<td>120</td>
<td>400</td>
<td>2000</td>
<td>Shiraz</td>
</tr>
<tr>
<td>late</td>
<td>16</td>
<td>39</td>
<td>120</td>
<td>400</td>
<td>2002</td>
<td>Pishtaz</td>
</tr>
</tbody>
</table>
For estimating leaf area index (LAI) and rate of stem elongation, five 0.18m² destructive samples (after omitting border effects) were taken from each plot at two week intervals starting 20 March. Leaf area was measured with a leaf area meter (LI-3100A, LiCor Inc., Lincoln, Nebraska, USA). Plant height was measured as distance between root crown and the first fully expanded leaf. Quadratic polynomial functions were fit to leaf area index and plant height data to describe the relationship between each trait and time. Rate of stem elongation was then calculated as the slope of quadratic increase in plant height. All graphs were plotted on a thermal time scale. The base temperature used for estimation of the growing days was 4°C. At canopy closure (approximately Zadoks 61-68), a destructive sample was taken for measuring vertical leaf area distribution. Plants which were harvested from a 0.18m² plot were separated into 20cm layers leaf area of each layer was measured. At harvest, four outer rows of each plot and 50cm from each end of the plots were left as borders and the middle 1m of the 4 center rows were harvested and separated into weed and wheat stands, Wheat grain yield, plant height, and weed biomass were measured. Harvest index (HI) was calculated as the proportion of grain yield to biological yield.

Speed of germination on wheat cultivars were calculated from the Maguire equation as follow (Maguire, 1962):

\[
\text{Speed of germination} = \left( \frac{X_1}{Y_1} \right) + \left( \frac{X_2 - X_1}{Y_2} \right) + \ldots + \left( \frac{X_n - (X_{n-1})}{Y_n} \right) \tag{1}
\]

where \(X_n\) is percentage of germinated seeds at count \(n\), and \(Y_n\) is days from planting to count \(n\). The frequency of the germination counted to estimate the speed of germination was every subsequent day.
Lodging percent for all cultivars in competition with rocket was recorded using a scoring system from 1 to 9. Score 1, when there was no sign of lodging, 5 when half of plot was lodged and 9 when the whole plot was fallen. Lodging estimation was performed by Zadoks 90. Since the variances within the groups were equal here, this trait was not analyzed via ANOVA. Therefore the results are presented without statistical analysis.

The assumptions of the variance analysis were tested by insuring whether residuals were homogenous (using Bartlett test), with normal distribution about a mean of zero. In addition, data were tested for normality using the Anderson-Darling statistic as generated by the PROC UNIVARIATE procedure by SAS (Ver. 8.02, SAS Institute Inc., Cary, NC). The assumptions of variance were adequately met, and there were no need for data transformation. Means were separated using Duncan multiple range test set at 0.05. In conditions where weed and wheat cultivar interaction existed as a trait, data were presented separately by the weed condition (weedy and weed free).

RESULTS AND DISCUSSION
Grain Yield, Harvest Index and Competitive Ability
Generally, an ideal cultivar in crop-weed competition will have high yield potential in both weedy and weed-free situations, will tolerate weeds and significantly suppress their growth (through reducing weed biomass). In the previous work (Deihimfard et al., 2006), the authors concluded that Tabasi and Karaj2 were less and more competitive cultivars, respectively (according to the two indices calculated for the cultivars, namely CI and AWC). In fact, based on different earlier studies, it was concluded that Tabasi is not a good competitor for Rocket; however, Karaj2 has strong competitiveness against rocket. Although Pishbaz and Shiraz cultivars have high yield under weed-free conditions, due to their lower competitive indices comparing to
Karaj2, they did not introduce as more competitive cultivars (Deihimfard et al., 2006). Variation in the competitive ability (CA) of wheat cultivars has been reported (Blackshow 1994; Lemerle et al., 2001). Tepe et al. (2005) investigated the effects of weeds on different lentil (Lens culinaris L.) cultivars and concluded that there were differences among CA of cultivars.

HI in both less and more competitive cultivars was similar (Table 3). The highest HI belonged to tolerant cultivar of Roshan which its HI in weedy conditions was greater than that in weed-free. Therefore, it can be concluded that those cultivars, which can increase their HI or prevent losses in competition with Rocket, could balance their yield losses and increase tolerance. Results of correlation analysis is an indicator of high relatively relationship between HI and competitive ability (data not shown). Lindquist and Mortensen (1998) also, stated that in crop tolerance, dry matter partitioning into different organs is more important than total cumulative dry matter. Altieri and Liebman (1988) also reported that enhancing HI in competition with weeds is the main reason of tolerance to weeds.

**Final Height and Rate of Stem Elongation**

The results indicated that the effect of Rocket on wheat height was the same among cultivars. In addition, there were significant differences among cultivars ($P<0.0001$), in this respect (Figure 1). In other words, the interaction between weed and wheat cultivar was not significant in case of plant height, but data are presented separately based on weed conditions to highlight the importance of this trait making a cultivar more competitive cultivar against weeds. For example, tolerant cultivars (Karaj2 & Roshan) had the highest height, and the lowest height belonged to Mahdavi (as a less competitive cultivar). Height of Karaj2 and Roshan under weed competition increased from 78cm and 94cm in pure plots to 99cm in infested plots, respectively (Figure 1).
Increase in height was one of the important aspects of competitive ability (CA) of the mentioned cultivars. Berkowitz (1988) stated that weed-crop competition in earlier growth stages could increase the height of crop cultivars. This is probably due to change in the light quality within canopy (reduction in R/FR ratio) and subsequent cell size increase, which is related to mechanisms of shade avoiding (Rohrig & Stunzel, 2001). Consequently, growth and biomass production of Rocket was reduced due to shading and hence yield losses of Karaj2 and Roshan was prevented. Although Tabasi cultivar (as a less competitive) was taller, but its less competitive ability was mostly related to a large reduction in HI and leaf area in competition with Rocket (Table 3 & Figure 4). As a result, height could not affect CA solely, but in companion with other traits such as LAI; many studies suggest that the importance of varietal height to crop CA may also be linked to other factors such as early crop vigour, leaf characteristics, or shading ability (Verschwele, 1994; Huel & Hucl, 1996; Lemerle et al., 1996; Ogg & Seefeldt, 1999; Seavers & Wright, 1999). Traore et al. (2003) also, stated that development of tall sorghum hybrid with more LAI would be useful for integrated weed management.
Figure 1. Mean comparisons of height among wheat cultivars in weedy and weed-free conditions.

Figure 2. Rate of stem elongation of wheat cultivars through growing season in...
Table 2. Results of ANOVA for some wheat traits.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>MS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Grain yield</td>
</tr>
<tr>
<td>block</td>
<td>3</td>
<td>306434.06</td>
</tr>
<tr>
<td>cultivar</td>
<td>7</td>
<td>2683454.8**</td>
</tr>
<tr>
<td>weed</td>
<td>1</td>
<td>63851416.06**</td>
</tr>
<tr>
<td>cultivar × weed</td>
<td>7</td>
<td>4421493.7**</td>
</tr>
<tr>
<td>error</td>
<td>49</td>
<td>332512.4</td>
</tr>
<tr>
<td>C.V. %</td>
<td>-</td>
<td>14.30</td>
</tr>
</tbody>
</table>

** Significant at the 0.01 probability level.

Table 3. Mean comparisons of grain yield and harvest index in weedy and weed-free treatments.

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Weedy Grains yield (kg ha⁻¹)</th>
<th>Harvest index</th>
<th>Weedy Grains yield (kg ha⁻¹)</th>
<th>Harvest index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tabasi</td>
<td>2012d</td>
<td>0.25a</td>
<td>4767b</td>
<td>0.31c</td>
</tr>
<tr>
<td>Roshan</td>
<td>3152b</td>
<td>0.36a</td>
<td>3241c</td>
<td>0.31c</td>
</tr>
<tr>
<td>Karaj2</td>
<td>3288a</td>
<td>0.27a</td>
<td>3865c</td>
<td>0.31c</td>
</tr>
<tr>
<td>Azadi</td>
<td>3124b</td>
<td>0.29a</td>
<td>5841ab</td>
<td>0.44a</td>
</tr>
<tr>
<td>Niknejad</td>
<td>2330cd</td>
<td>0.27a</td>
<td>5928ab</td>
<td>0.36bc</td>
</tr>
<tr>
<td>Mahdavi</td>
<td>2758bc</td>
<td>0.36a</td>
<td>6294a</td>
<td>0.40ab</td>
</tr>
<tr>
<td>Shiraz</td>
<td>3155b</td>
<td>0.31a</td>
<td>5446ab</td>
<td>0.38abc</td>
</tr>
<tr>
<td>Pishnazar</td>
<td>3890a</td>
<td>0.33a</td>
<td>5786ab</td>
<td>0.36bc</td>
</tr>
</tbody>
</table>

Means within a column followed by the same letters are not significantly different according to Duncan’s multiple range test at P < 0.05.
Figure 2 indicates rate of stem elongation of wheat cultivars in competition with Rocket. These cultivars which were taller (e.g. Roshan & Karaj2), also had higher rate of stem elongation during growth stages. Results of correlation analysis also verify strong relationship between final height and rate of stem elongation (data not shown). Therefore, the cultivars, which had higher CA (as tolerance), were either taller or had higher rate of stem elongation. Greater rate of stem elongation resulted in an earlier closure of the more competitive cultivars canopy and therefore, led to reduction in growth of Rocket, due to shading. Ogg and Seefeldt (1999) also, in their study of traits affecting CA of wheat cultivars against *Aegilops cylindrica* mentioned that height gain is one of the most important traits that affect CA enhancement in infested conditions. Therefore, it is recommended that we use rate of stem elongation in the breeding programs for enhancing CA.

**Seed Viability and Speed of Germination**

Seed viability (seed's ability to germinate and grow) and speed of germination are two components of early vigor. Early vigor is the expression of relatively high growth rate and high rate of emergence. An ability to achieve an early large size early will be expected to confer later crop CA (Bastiaans *et al*., 1997; Seavers & Wright, 1999). The results of seeds viability (Table 4) showed that there were no differences among cultivars in the first count (four days after planting) and final count (eight days after planting). It is observed that all of the wheat cultivars had high seed viability and so this trait had no effect on CA of cultivars in competition with Rocket. Nevertheless, speed of germination differed significantly among cultivars (Table 4). Tolerant cultivars (e.g. Roshan and Karaj2) had greater speed of germination than less competitive cultivars (e.g. Niknejad & Mahdavi). Tabasi as a less competitive cultivar had high speed of germination. Therefore, low CA of Tabasi is mostly related to its
other growth traits such as lower leaf area index and rate of stem elongation, biomass at tillering and etc. Early high vigor and early rapid growth of the cultivars with high speed of germination resulted in a fast coverage of soil and therefore reduction in light penetration into the canopy and consequent increase in CA of these cultivars against weeds (Rebetzke & Richards, 1999). Also, Pavlichenco and Harringtone (1934, 1935) pointed to photosynthesis area expansion and uniform and fast germination as the most important traits affect CA,

Flag Leaf Area and Lodging Percent

The results indicated that flag leaf area was not significantly different between weedy and weed-free conditions (Table 2). However, differences were observed among cultivars (Table 4). The more competitive cultivars (Rosjan & Karaj2) had highest flag leaf area, and the lowest belonged to Pishtaz and Niknejad. With regard to the rate of flag leaf in canopy photosynthesis and its role of transportation of 50% of the total carbohydrate into grain, it could be concluded that probably more competitive cultivars in competition with Rocket due to greater flag leaf area compensated for the lost carbohydrate in competition and prevented yield losses due to the competition. Watson et al. (2002) also stated that the size of flag leaf was positively correlated to CA of barley cultivars.

Lodging index was not different between weedy and weed free conditions. Therefore, Rocket did not have any effect on lodging of cultivars and lodging was mostly related to other characteristics. Tabasi, Roshan and Karaj2, which were taller among other cultivars, also had the highest lodging index. So, although possessing higher height can result in more CA (tolerance and suppression), but care should be taken that very tall plant as a trait affecting CA at breeding programs, can increase lodging index and consequently reduce grain yield in competition (Mohler, 2001).
Table 4. Results of seeds viability, speed of germination, flag leaf area, and lodging index

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Seed viability (%)</th>
<th>Speed of germination (relative germination day⁻¹)</th>
<th>Flag leaf area (cm²)</th>
<th>Lodging index (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>First count</td>
<td>Final count</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tabasi</td>
<td>98</td>
<td>98</td>
<td>0.85a</td>
<td>118a</td>
</tr>
<tr>
<td>Roshan</td>
<td>99</td>
<td>99</td>
<td>0.86a</td>
<td>134.88a</td>
</tr>
<tr>
<td>Karaj2</td>
<td>93</td>
<td>93</td>
<td>0.67b</td>
<td>125.43a</td>
</tr>
<tr>
<td>Azadi</td>
<td>91</td>
<td>91</td>
<td>0.62bc</td>
<td>122.83a</td>
</tr>
<tr>
<td>Niknejad</td>
<td>92.5</td>
<td>92.5</td>
<td>0.42d</td>
<td>103.73ab</td>
</tr>
<tr>
<td>Mahdavi</td>
<td>95</td>
<td>95.5</td>
<td>0.63bc</td>
<td>106.42ab</td>
</tr>
<tr>
<td>Shiraz</td>
<td>97.5</td>
<td>97.5</td>
<td>0.63bc</td>
<td>127.10a</td>
</tr>
<tr>
<td>Pishtaz</td>
<td>97</td>
<td>97</td>
<td>0.59c</td>
<td>77.39b</td>
</tr>
</tbody>
</table>

Means within a column followed by the same letters are not significantly different according to Duncan’s multiple range test at P < 0.05.

**Vertical Leaf Area Distribution**

Since vertical leaf area distribution is an indicator of light distribution and penetration into crop canopy, cultivars which can concentrate greater leaf area at top of the canopy, can result in more CA. Figure 3 indicates vertical leaf area distribution of less and more competitive cultivars in weedy and weed-free conditions. In all cultivars, leaf area of each layer was reduced in weedy plots compared to pure plots. In Tabasi, there were no differences among layers in competition with Rocket and leaf area distribution was almost similar among layers. In contrast, leaf area distribution in more competitive cultivar (Karaj2) was similar in weedy and weed-free plots. Also, in upper layers (80-100 cm) leaf area was greater in more competitive cultivar. Giving attention to Rocket height (maximum 70 cm), greater leaf area in the upper layers in
more competitive cultivars in comparison with that of less competitive caused more shading on Rocket and a consequent prevention of light interception and Rocket growth. Cavero et al. (1999) and, Lindquist and Mortensen (1998) reported that vertical leaf area distribution is the most effective trait on competitiveness, especially when crop and weeds have different heights.

**Figure 3.** Vertical leaf area distribution of less (Tabasi) and more (Karaj2) competitive cultivars in weedy and weed-free conditions
Phenological Stages of Cultivars
Comparison of phenological stages in Zadoks scale (Zadoks et al., 1974) of wheat cultivars in weedy conditions showed that there are differences in growth and development stages of cultivars. Mahdavi and Niknejad (as less competitive cultivars) had shorter life cycle than other cultivars (nearly 2 or 3 weeks). Nevertheless, with regard to growth cycle of Rocket that was shorter than that of wheat cultivars at grain filling stage of Rocket, wheat field was green except for Mahdavi and Niknejad. It seems that wheat phenology could not be probably considered an important trait affecting CA. On the contrary, Fischer et al. (2001) reported early maturity of rice is a desired characteristic for the rice-Brachiaria spp. competition.

Leaf Area Index (LAI)
Rocket reduced leaf area of all cultivars and this reduction was not similar among cultivars during the growing season. The highest reduction belonged to Tabasi cultivar (Figure 4A). LAI of Karaj2 in weedy condition was nearly similar to that of pure plot during the growing season (Figure 4B). That cultivar, which can refrain from leaf area losses in competition (i.e. Karaj2), will be able to have greater photosynthesis and consequently more dry matter production. Also, by preventing leaf area losses and shading on weed, the consequent reduction in weed biomass would be resulted (biomass of Rocket in competition with Karaj2 was mostly reduced in comparison with less competitive cultivars, data not shown). Fischer et al. (2001) reported that leaf area is an important trait affecting CA of cultivars. Traore et al. (2003) also, stated that development of tall sorghum hybrid with high LAI would benefit their CA.
Conclusions

Highly competitive varieties often have a set of characteristics that contribute to CA. In many experiments, the greater competitiveness of a more cultivar could be attributed to rapid emergence and canopy closure, extensive branching and dense foliage, and maintenance of a closed canopy for a greater portion of season. The results of the present study revealed that several characteristic are related to high CA of wheat cultivars including high leaf area, vertical leaf area distribution, higher height, greater rate of stem elongation, and early vigor (viability and speed of germination). Also, it was concluded that breeding in modern varieties (e.g. Pishtaz, Mahdavi & Shiraz) has reduced plant height and tillering ability and increased harvest index; thus, it is difficult to separate out the effects of these traits when comparing old (Roshan, Karaj2 & Niknejad) with modern varieties. The use of higher height due to its usefulness in breeding for crop CA, should be noticed because taller plants are often associated with lower yields due to reduction in harvest index and increased susceptibility to lodging. However, if two current varieties have similar yield potential.
in infested conditions but differ in height, the taller varieties could be recommended to farmers for their weedy fields (e.g. Karaj2 in comparison with Shiraz).

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REFERENCES


