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Effect of Mixed Cropping of an Early- and a Middle-ripening Wheat Cultivar on Mitigation of Competition during Post-anthesis Moisture Stress

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ABSTRACT

A two-year field experiment was carried out in semi-arid region of southern Iran (Shiraz), during 2007-2008 and 2009-2010 growing seasons using various mixtures of an early- (cv Falat) and a middle-ripening (cv Shiraz) winter wheat cultivar to evaluate the beneficial effects of inducing temporal growth heterogeneity on reduction of intra-specific competition during post-anthesis moisture stress conditions. Treatments were composed of five combination ratios of the two cultivars (1:0; 2:1; 1:1; 1:2, 0:1), and two levels of post-anthesis moisture conditions i.e. equal to Field Capacity and 50% ***FC.*** **The results showed that the equal ratio (1:1 mixed cropping of early and middle-ripening cultivars) was superior in grain yield components as well as post-anthesis water use efficiency (PWUE) among the mixture treatments. It appeared that mixed cropping of early- and middle-ripening cultivars had the potential for altering the intensified competition under deficient moisture conditions and may improve** ***PWUE.*** **Additional research for determining the best choices of cultivars, mixing ratios, sowing date, phenological differences, input requirements, and management practices for each regional environment are essential to achieve the maximum benefits.**

Keywords: Cultivar mixture, Intra-specific competition, Post anthesis water use efficiency, Semi-arid regions.

INTRODUCTION

Competition, one of the most important factors affecting crop yield (Hauggaard-Nielsen and Jensen, 2001; Dhima *et al.*, 2007; Jahansooz *et al.*, 2007), is exacerbated by increased limitations in resource availability. Greater similarity in the temporal or spatial patterns of input utilization results in increased competition (Jahansooz *et al.*, 2007; Zhang *et al.*, 2008). In this situation, the more competitor plant would take the greater proportion of inputs. With the presence of unwanted (e.g. weed) species in the canopy, any attempt to change the competition trend toward benefiting the favored species, e.g. by optimizing use of inputs, may be a good approach to maintain or enhance crop yield in an intensive cropping system. However, when the major portion of competition in the canopy refers to competition among crop individuals themselves, the only option to limit yield reduction might be trying to reduce general intra-specific competition going on in the canopy; since there are favored plants on both sides. In fact, in such situations, the quantity of competition is more important than its quality.

In general, various kinds of mixed cropping systems can reduce competition

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and increase yield, mainly by inducing variation in temporal or spatial patterns of crop growth which, in turn, changes the crop resources utilization. Cultivar mixture is an alternative to monoculture for crop production (Smithson and Lenne, 1996; Lopez and Mundt, 2000; Wolfe, 2000; Newton and Guy, 2009) which may simultaneously include the advantages of both mixed cropping and monoculture. In other words, it is expected that cropping the best mixture of cultivars, in addition to reducing competition among individuals, may reduce field practices and costs in comparison to other common mixed cropping systems. Except for the mixing practice at sowing time, mixed cultivars can plant or harvest similar to monoculture by only one-time usage of a common planter or harvester; or even in most cases, carry out other farm practices e.g. irrigation and fertilization exactly the same as monocultures. There are some evidences indicating the effective role of cultivar mixtures in reducing diseases and increasing seed yield in cereals (Finckh *et al.*, 2000; Mundt, 2002; Smithson and Lenne, 1996; Lopez and Mundt, 2000; Newton and Guy, 2009; Sharma and Ghosh, 2000; Cowger and Weisz, 2008). Determination of the best cultivars for mixture formation is a basic aspect of such studies. Lopez and Mundt (2000) evaluated the ability of a prediction method to predict the mean of complex mixtures and select the best cultivars for mixed cropping of wheat. Among many factors affecting selection decisions, more attention might be paid to some cultivars properties that can be managed to manipulate heterogeneity patterns towards achieving mixed cropping goals. In a case study with consideration of temporal heterogeneity in varieties growth stages, Sharma and Ghosh (2000) evaluated the performance of early- and long-duration rice cultivars mixture and reported a higher productivity and stability of yield in mixture cultivation.

A considerable part of southern Iran has a semi-arid climate with a Mediterranean pattern of precipitation (Sadeghi *et al.*, 2002; Karimi *et al.,* 2002). In such climates, evapotranspiration in the winter months is low due to low radiation and temperatures. However, towards the end of the growing season (i.e. June and July), it increases rapidly as the result of increased temperature and radiation. At the same time, declined amounts of rainfall mark a post-anthesis water shortage in the critical period when the crop faces terminal drought stress (Sadeghi *et al.*, 2002; Asseng *et al.*, 2008). Emam *et al.* (2007) evaluated ten winter wheat genotypes and reported a significant reduction in seed yield and yield components related to post-anthesis drought stress.

In the present study, the option of mixture cropping of an early- and a middle-ripening wheat cultivar was examined with the aim of reducing the adverse effects of post-anthesis moisture stress. This evaluation was made by providing combinations of cultivars in the mixture. It appears that there are at least two main probable mechanisms by which the yield would increase due to reduction in competition: (i) occurrence of a temporal variety in the growing patterns of different cultivars with an intensifying trend after flowering, coinciding with post-anthesis moisture stress; (ii) existence of an even short period of time gap between the maturity of early- and the middle-ripening cultivar. This may provide an opportunity which probably results in reduced competition in the most critical growth period (post-anthesis grain filling stage). It is similar to less plant density in the late season, without any yield reduction related to low plant densities.

MATERIALS AND METHODS

Field Trial

Two field experiments were conducted during winter cropping seasons (December 2007 to June 2008; and December 2009 to June 2010) at the agricultural research field of the Faculty of Agriculture, Shiraz University, Shiraz, Iran (29°50´ N latitude and 52°46´ E longitude at an altitude of 1,810 masl). The soil was silty-clay with 0.87% OM, 0.46% OC, and pH of 7.7. The total amount of precipitation during the 2007-2008 and 2009-2010 seasons were 127 and 174.5 mm, respectively, and were totally in the form of rainfall before wheat flowering stage.

The factorial experiment consisted of moisture and mixture treatments which were laid out in a randomized complete block design with four replicates. The treatments included two moisture levels (well-irrigated and deficit-irrigation) and five mixture ratios of two local and widely planted winter wheat (*Triticum aestivum* L.) cultivars, namely, Falat and Shiraz, as early- and middle-ripening, respectively. Mixture treatments were five levels of combination ratios of Shiraz:Falat, forming a replacement series: 1:0, 2:1, 1:1, 1:2, and 0:1. Seed laboratory tests indicated that there were no significant differences between 1000-grain weights of the two cultivars, and their germination percentages (data not shown). Therefore, the seeds were mixed by weight ratios. At the sowing time, the blends were made for each plot separately to ensure the maintenance of the planned mixture ratios within the plot and achieving more uniformity in sowing. The seed mixtures were hand sown.

Standard fertilizers treatments (150 kg N per ha as urea, and 20 kg P per ha as ammonium phosphate, also as another source of N) were applied. No fungicide, herbicide or plant growth regulator was used. Plant density was adjusted to 450 plants per m^2 with row spacing of 20 cm. The experimental site consisted of 40 plots of 4×4 m^2 each, separated by 1 m buffers.

Moisture Treatments

Moisture treatments consisted of: (i) well irrigated (WI) throughout the season, in which the amount of water applied at each irrigation was enough to bring the soil available water content to field capacity (FC) at root depth; and (ii) deficit-irrigation (DI), in which water was supplied similar to *WI* until anthesis and, afterwards, moisture was supplied up to 50% *FC*. The post-anthesis irrigation interval was 10 days. Soil water content was measured gravimetrically before and after each irrigation for every 30 cm layer (down to 90 cm). Measured mean field capacity, mean permanent wilting point (PWP) and the mean bulk density of the three depths were 27.3%, 16.9%, and 1.66 g cm^{-3}, respectively. The first irrigation for the stress treatment started during the period between flowerings of the two cultivars as the actual moisture stress usually begins in the region at this time.

Ripening Tests

Maturity of the cultivars was monitored by field observations and regular measurements of grain water content in monoculture plots following the soft dough stage. Grain water contents of 35 and 14% were defined as physiological and harvest maturity, respectively (Emam, 2007).

Yield and Yield Components Measurements

Observations in the monoculture plots during this study indicated that there was a highly significant difference in spike compactness, i.e. the spikelets were more densely arranged in Falat compared to Shiraz cultivar (Figure 1). Since this difference was quite visible, it was easy to separate these two cultivars. Spike compactness was calculated as follows:

Spike compactness= Number of spikelets per spike/Spike length (cm) (1)

Although the cultivars had different maturity dates, since the early cultivar, Falat, was resistant to shattering, the final harvest was done when the middle-ripening cultivar was ripened. The final harvest area for each

Figure 1. Spikes of Falat and Shiraz cultivars, which are different in spike compactness.

plot was 1 m^2 composed of four 0.5×0.5 m quadrates. Finally, the grain yield of each cultivar was determined by weighing the samples, and then total grain yield of the mixture was calculated by the summation of the two related values.

Analysis of Competition

The plant relative yield (PRY) and relative yield total (RYT) indices were used to evaluate the relative competitiveness of the cultivars and patterns of resource utilization. *RYT* was calculated using the following equations (Duke, 1985; Ghosh *et al*., 2009):

PRY_{AB}= Total grain weight of A grown in mixture with B/Total grain weight of A grown in monoculture; (2)

PRY_{BA}= Total grain weight of B grown in mixture with A/Total grain weight of B grown in monoculture; (3)

$$RYT= (PRY_{AB}/2)+(PRY_{BA}/2) \quad (4)$$

Where, *PRY* is the plant relative yield, *A* and *B* are different species (in this study, different cultivars) of mixture, *AB*: Marks conditions in which cultivar *A* is grown in a mixture with cultivar *B* and *BA*: Inverse of *AB* condition.

Estimating Post-anthesis Water Use Efficiency

As described above, the main focus of evaluating crop water demand was on the post-anthesis period. Therefore, only post-flowering related data were taken into account for evaluating crop evapotranspiration (ET_c). Using grain yield and post-anthesis values of ET_c, an index as "post-anthesis water use efficiency (PWUE)" was introduced and evaluated. *PWUE* was calculated as follows:

$$PWUE= GY/PET_c \quad (5)$$

Where, *PWUE* is the post-anthesis water use efficiency (kg ha^{-1} mm^{-1}), *GY* the grain yield (kg ha^{-1}), and PET_c is the post-anthesis actual evapotranspiration (mm). PET_c was estimated in the same way as ET_c by Gao *et al.* (2009) using water balance:

$$PET_c= P_P+I_P+U_P–R_P–D_P–\Delta S_P \quad (6)$$

Where, $_P$ subscripts of all variables refer to post-anthesis period; *P* is the effective precipitation (mm), *I* the irrigation quota (mm), *U* the upward capillary flow (mm), *R* the runoff (mm), *D* the deep percolation from root zone (mm), determined by using hydraulic conductivity, as reported by Sepaskhah and Ilampour (1995), and *ΔS* the change of water stored in the 0-90 cm soil layer (mm). Post-anthesis related values of the upward flow, the runoff, and effective precipitation were negligible for the two seasons (there was no precipitation after flowering).

Statistical Analysis

Analyses of variance (ANOVA) were carried out for grain yield, yield components and physiological traits by using the SPSS software version 12.0 (SPSS Inc., 2003).

Treatment means were compared using either the least significant difference (LSD) or Tukey's test.

RESULTS AND DISCUSSION

Patterns of Growth and Development in the Canopy

According to our observations (Figure 1), there was a significant difference between the spike compactness of Falat and Shiraz cultivars. This difference was stable in both well irrigated and deficit irrigation conditions and also the same in both seasons (Table 1). Therefore, it could be used as a reliable comparative property for the recognition of these two cultivars in mixtures. Using spike compactness as a differentiating factor might be considered as a morphological tool for distinguishing mixed cropped cultivars.

Falat cultivar started stem elongation 7 and 4 days earlier than Shiraz cultivar in 2007-2008 and 2009-2010, respectively (Table 2). Such a temporal difference between the two cultivars was maintained, with a cumulative trend, towards the end of the growing season (Figure 2). Duration of growth season for Falat and Shiraz cultivars in the first year was 23 and 15 days more than the second year, respectively. However, some growth or developmental stages were longer during the second season compared with the first; for instance, the total duration of stem elongation and booting (Figure 2, the interval between points 2 and 3) or the period from ear emergence to flowering (Figure 2, point 3 to 4) was shorter in 2009-2010. Despite such important variations that resulted from different weather conditions during the two seasons (mostly higher temperatures for the second season, data not shown), the whole designed heterogeneous growth pattern within the canopy occurred and remained in accompaniment with the purpose of the study.

Table 1. Spike compactness of early- (Falat) and middle-ripening (Shiraz) cultivars (number of spikelets per cm of spike length).

Moisture treatment	Spikelet compactness	
	2007-2008	
	Falat	Shiraz
Well irrigation	2.18 a, A*	1.81 b, A
Deficit irrigation	2.16 a, A	1.75 b, A

*The small and capital letters are for horizontal and vertical comparisons only within a season, respectively. Meanwhile, the effect of year was not significant (LSD, P≤ 0.05).

Grain Yield and Competition Analyses

Individual Grain Yield and Plant Relative Yield (PRY) of Cultivars

The *PRY* (Table 3) revealed the intra-cultivar competitiveness of Falat plants within the mixtures compared to monoculture, which confirmed the general order of 1:2> 1:1> 2:1 (Shiraz:Falat) for Falat grain yields. Meanwhile, the *PRY* of Falat evidenced an almost dominant trend in which the grain yield of this cultivar did not match the potential amounts expected on the basis of the proportion sown in both seasons; as the values of PRY_{Falat} in the 2:1, 1:1, and 1:2 mixtures of Shiraz:Falat were mostly less than 0.33, 0.50 and 0.66, respectively, and also mean values were less than 0.5 (Table 3). On the other hand, the moisture stress reduced the mean PRY_{Falat} in the second season, indicating that under the moisture conditions with water contents equal to 50% *FC*, Falat benefited more in monoculture than within the various mixtures. Accordingly, exclusive evaluation of the early ripening cultivar Falat revealed its tendency to yield higher in monocultures, particularly when a moisture stress occurred. Such component behaviors may potentially lead to reduced benefits of mixtures when other components would not compensate the loss.

Table 2. Main growth stages of early (Falat) and middle-ripening (Shiraz) cultivars.

Stage	Days after sowing			
	2007-2008		2009-2010	
	Falat	Shiraz	Falat	Shiraz
Sowing	0 (0) [a]	0 (0)	0 (0)	0 (0)
Emergence	33 (33)	33 (33)	24 (24)	24 (24)
Early stem elongation	133 (100)	140 (107)	84 (60)	88 (64)
Ear emergence	141 (8)	149 (9)	118 (34)	126 (38)
Flowering	147 (6)	156 (7)	132 (14)	140 (14)
Physiological maturity	192 (45)	205 (49)	165 (33)	187 (47)
Harvest (ripening)	199 (7)	210 (5)	176 (11)	195 (8)
(Over ripening)	210 (11)	–	–	–

[a] Numbers in parentheses show the number of days for previous stage (duration of last stage). Over ripening occurred only in 2007-2008 season for early-ripening cultivar Falat in which seed water content at harvest time was 6%.

Similar to Falat cultivar, the effect of moisture stress on grain yield of the middle-ripening Shiraz cultivar was significant (P< 0.05) only in the second season. Meanwhile, the effect of mixture treatment on the grain yield of Shiraz was significant (P< 0.01). However, despite the early ripening cultivar, the effect of year on Shiraz grain yield was significant (P< 0.01).

In the light of *PRY*, the relative yield of Shiraz showed a different pattern in the mixtures compared with Falat. The mean

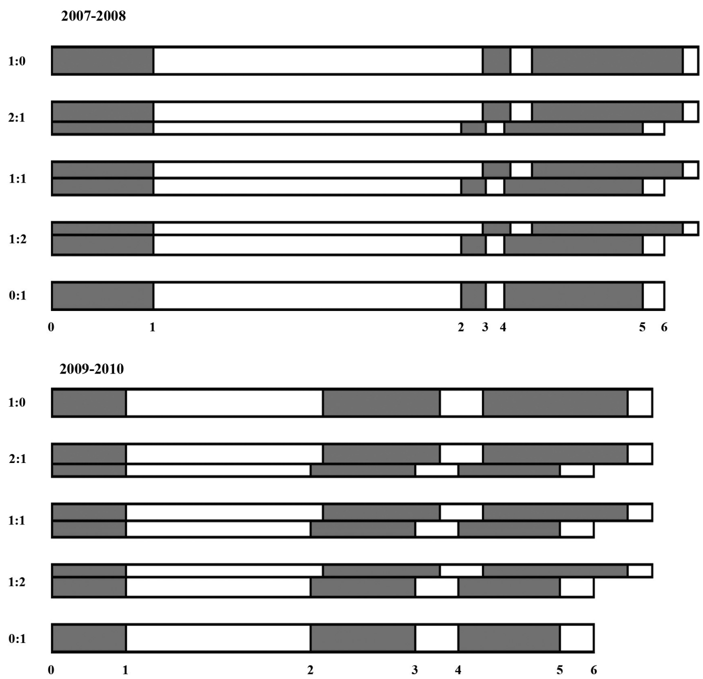

Figure 2. Synchronized growth stages of early and middle-ripening winter wheat cultivars Falat and Shiraz within the mixtures. The ratio of single or paired bars indicates the ratio of Shiraz:Falat in the canopy, which also has been represented by the thickness of bars. Numbers 0 to 6 indicate the sowing date, emergence, early stem elongation, ear emergence, flowering, physiological maturity, and ripening, respectively.

Table 3. Grain yield of early and middle-ripening winter wheat cultivars, plant relative yield, relative yield total, total yield, post-anthesis crop evapotranspiration, and post-anthesis water use efficiency.

Year	Moisture treatments	Mixed ratios of Shiraz:Falat	Grain yield Shiraz (kg ha^{-1})	Grain yield Falat (kg ha^{-1})	PRY_{Shiraz}	PRY_{Falat}	*RYT*	Total yield (kg ha^{-1})	PET_c (mm)	*PWUE* (kg ha^{-1} mm^{-1})
2007-2008	Well irrigated	1:0	5584.63 a,a	–	–	–	–	5584.63 ab,a	354.91 a,a	16.13 ab,a
		2:1	3537.68 b,a	1711.28 c,a	0.63	0.27	0.90	5248.97 ab,a	375.78 a,a	14.88 ab,a
		1:1	3072.26 bc,a,a	2961.35 b,a,a	0.55	0.47	1.02	6033.61 ab,a	390.77 a,a	15.47 ab,b
		1:2	2195.66 c,a	2800.42 bc,a	0.39	0.44	0.83	4996.08 b,a	410.39 a,a	12.15 b,b
		0:1	–	6354.61 a,a	–	–	–	6354.61 a,a	383.35 a,a	16.78 a,b
		Mean	3597.56 -,a	3456.91 -,a	0.53	0.39	0.92	5643.58 -,a	383.04 -,a	15.08 -,b
	Deficit irrigation	1:0	3891.81 a,a	–	–	–	–	3891.81 b,a	223.95 a,b	17.48 b,a
		2:1	3629.59 a,a	1539.9 c,a	0.93	0.26	1.19	5169.5 ab,a	248.81 a,b	20.83 ab,a
		1:1	2964.86 ab,a,a	2459.73 b,a,a	0.76	0.41	1.17	5424.6 ab,a	186.58 a,b	29.21 ab,a
		1:2	1919.22 b,a	2896.27 b,a	0.49	0.49	0.98	4815.5 ab,a	231.13 a,b	21.07 ab,a
		0:1	–	5959.17 a,a	–	–	–	5959.17 a,a	182.66 a,b	36.40 a,a
		Mean	3101.37 -,a	3213.77 -,a	0.73	0.39	1.11	5052.12 -,b	214.63 -,b	25.00 -,a
		Mixture	s*	s*	–	–	–	s*	ns	s*
2009-2010	Well irrigated	1:0	4304.96 a,a	–	–	–	–	4304.96 a,a	323.77 a,a	13.45 a,b
		2:1	3036.79 b,a	2049.96 c,a	0.71	0.36	1.06	5086.76 a,a	287.81 a,a	18.40 a,b
		1:1	2334.33 bc,b,a	3094.34 bc,a,a	0.54	0.54	1.08	5428.67 a,a	301.00 a,a	18.03 a,a
		1:2	1425.80 c,a	3777.86 b,a	0.33	0.66	0.99	5203.67 a,a	271.42 a,a	19.14 a,b
		0:1	–	5715.44 a,a	–	–	–	5715.44 a,a	294.54 a,a	19.46 a,a
		Mean	2775.47 -,a	3659.40 -,a	0.53	0.52	1.05	5147.90 -,a	295.71 -,a	17.69 -,b
	Deficit irrigation	1:0	3441.17 a,a	–	–	–	–	3441.17 c,a	169.42 a,b	20.39 b,a
		2:1	2528.79 b,a	1569.73 d,a	0.73	0.30	1.04	4098.52 bc,a	150.92 a,b	27.24 ab,a
		1:1	1995.22 c,b,a	2438.60 c,a,a	0.58	0.47	1.05	4433.82 ab,a	172.94 a,b	23.76 ab,a
		1:2	1371.97 d,a	3458.91 b,a	0.40	0.67	1.07	4830.88 ab,a	185.25 a,b	26.08 ab,a
		0:1	–	5179.41 a,a	–	–	–	5179.41 a,a	169.90 a,b	32.25 a,a
		Mean	2334.29 -,b	3161.66 -,b	0.57	0.48	1.05	4396.76 -,b	169.69 -,b	26.54 -,a
		Mixture	s*	s*	–	–	–	s*	ns	s
Year	–	–	s*	ns	–	–	–	s*	s*	ns

PRY: Plant relative yield; RYT: Relative yield total; PETc: Post-anthesis crop evapotranspiration, PWUE: Post-anthesis water use efficiency. Since the effect of year for most of indices is significant, every comparison should involve only the values of one year. The left letter refers to comparison among different mixtures of each irrigation treatment when the right one refers to comparison of irrigation treatments in the same mixtures (P< 0.05). Meanwhile, the middle letter for grain yield of separated cultivars within the ratios 1:1 refers to comparison of grain yields of two cultivars in the same irrigation treatments. For main effects, s, s*, and ns mean significant at (P< 0.05), significant at (P< 0.01), and non-significant, respectively. Dashes means that related comparisons are not applicable.

PRY_{Shiraz} in all moisture treatments in both seasons was more than 0.50, which was also reflected by the generally higher values of 2:1, 1:1 and 1:2 ratios than the basic quantities of 0.66, 0.50, and 0.33, respectively (Table 3). Moreover, under the deficit irrigation, *PRY* of Shiraz was higher than under the well irrigated conditions, which demonstrated that regardless of the total yield or the yield of the other cultivar in the mixture, Shiraz cultivar in moisture conditions of 50% *FC* had benefited more in mixtures compared with the monoculture.

Comparison of monoculture of the two cultivars (Table 3) indicated a similar trend in both seasons, and the grain yields of Shiraz and Falat were almost similar in the well irrigated treatment, while under deficit irrigation the Falat cultivar out-yielded Shiraz. It appears that the early ripening Falat cultivar had tolerated the moisture stress more efficiently. This could be related to a shorter growing period, having less simultaneity with post-anthesis moisture stress. It appeared that for the agro-climatic conditions of this investigation, the early cultivar (Falat) was superior to a middle-ripening cultivar (Shiraz). Previous studies have also evaluated the comparative behavior of wheat cultivars in mixtures (Dubin and Wolfe, 1994) and showed the various responses of components which would totally determine the yield and stability of mixtures.

Total Grain Yield and Relative Yield Total (RYT)

In both seasons, the mixture treatments reduced the total grain yield significantly ($P< 0.01$, Table 3). Monocultures of the early ripening Falat cultivar showed the highest total grain yields in all treatments, while that of Shiraz in monocultures ranked the lowest level in 3 out of 4 situations (Table 3). The results do not seem in agreement with the generally expected trend in which the potential yield of early ripening cultivars would be less than the middle-ripening ones due to a shorter duration of growing season. However, it may not necessarily be the case for every given pair of early- and middle-ripening cultivars, since other recognized or unknown properties of cultivars may change the expected trend, as occurred in the present study. Indeed, the ultimate culm height of Falat cultivar was less than Shiraz and this could be related to higher yield in this cultivar. Also, the moisture stress affected the total grain yield significantly during both seasons, as the mean total grain yields were 10.48 and 14.59% higher in the well irrigated treatments of 2007-2008 and 2009-2010, respectively. This result was found to be in accordance with the findings reported by Plaut *et al.* (2004), Emam *et al.* (2007), and Ercoli *et al.* (2008). However, in both seasons, there were no differences between irrigation treatments of a mixture (Table 3). Overall, the mixtures ranked in between the extreme monocultures, with no significant differences with the highest total yield in the replacement series. However, while the ratios 1:2 and 2:1 of Shiraz:Falat showed significant deviations from the highest yields under, respectively, well irrigated treatment of 2007-2008 and deficit irrigation of 2009-2010, the only mix which always remained in the statistically highest yielding group was the ratio 1:1. This revealed its comparative benefit and stability in producing grain yield. Gallandt *et al.* (2001) reported an overall grain yield advantage of 1.5% in mixed cropping of equal proportion of winter wheat cultivars compared with monocultures. Also, Newton and Guy (2009) reported the benefits of uneven patchy cultivar mixtures in the grain yield of winter barley.

The competition index, i.e. Relative Yield Total (RYT), was on average greater than the basic quantity of 1.0 for all irrigation-seasons, which showed the overall less intra-specific competition within the mixtures compared with the monocultures. In both seasons, *RYT* of moisture stress conditions was either equal or greater than the well irrigated treatments. This indicated more reductions in competition within the mixtures, which led to still more advantages of mixed cropping under moisture stress conditions. As it was true for the total grain yield, the mixed ratios of 1:1 often showed the greatest *RYT*, confirming the lowest competition among blends. Moreover, differences between *RYT* of deficit and well irrigated mixtures changed with various seasons and seemed to be greater in the first growing season. Dubin and Wolfe (1994) reported different degrees of stability for mixtures of wheat cultivars over a diverse range of environments. Such variations seem to be related to the complex processes underlying crop interactions (Kiær *et al.*, 2009) over different environments or seasons.

Spikes m^{-2} and 1,000 Grain Weight

The highest number of spikes m^{-2} was obtained from the combination ratio 1:1 in well irrigated conditions of both seasons (Table 4). Deficit irrigated treatments of 0:1

Table 4. 1000 grain weight and number of spikes per m^2 of early- and middle-ripening winter wheat cultivars in mixture and moisture treatments.

Moisture treatments	Mixed ratios of Shiraz:Falat	Cultivars	2007-2008		2009-2010	
			1000 grain weight (g)	Number of spikes per m^2	1000 grain weight (g)	Number of spikes per m^2
Well irrigated	1:0	Falat	–	466.75 b,a	–	448.00 c,a
		Shiraz	33.78 a,a		27.21 abc,a	
	2:1	Falat	31.77 a,a	422.00 c,a	29.00 abc,a	519.25 ab,a
		Shiraz	32.08 a,a		26.72 bc,a	
	1:1	Falat	31.94 a,a	533.00 a,a	30.56 ab,a	587.50 a,a
		Shiraz	31.84 a,a		26.81 bc,a	
	1:2	Falat	31.86 a,a	471.50 b,a	30.62 ab,a	391.25 c,a
		Shiraz	30.98 a,a		25.99 c,a	
	0:1	Falat	33.69 a,a	373.50 d,a	31.27 a,a	458.00 bc,a
		Shiraz	–		–	
	Mean	Falat	32.31 a,a	453.35 -,a	30.36 a,a	480.80 -,a
		Shiraz	32.17 a,a		26.68 b,a	
Deficit irrigation	1:0	Falat	–	436.00 b,b	–	432.25 cd,a
		Shiraz	30.68 a,a		24.62 b,a	
	2:1	Falat	28.94 a,a	409.50 b,b	31.54 a,a	533.50 b,a
		Shiraz	29.08 a,a		24.23 b,a	
	1:1	Falat	30.29 a,a	543.50 a,a	30.38 a,a	607.75 a,a
		Shiraz	30.61 a,b		24.86 b,a	
	1:2	Falat	29.50 a,a	432.00 b,b	29.50 a,a	378.25 d,a
		Shiraz	28.33 a,a		23.13 b,a	
	0:1	Falat	30.56 a,a	338.00 c,a	32.45 a,a	470.25 c,a
		Shiraz	–		–	
	Mean	Falat	29.82 a,b	431.80 -,b	30.96 a,a	484.40 -,a
		Shiraz	29.67 a,b		24.21 b,b	
Moisture			s*	s*	ns	ns
Mixture			ns	s*	ns	s*
Cultivars			ns	s*	s*	s*
Year			–	–	s*	s*

Since the effect of year on these characters was significant, every comparison should include only the values of one year. The left letter refers to comparison of the same or different cultivars within each irrigation treatment when the right one shows differences between two irrigation treatments of similar mixtures for a cultivar. For means, the left letter shows the differences between cultivars in each irrigation treatment and the second one refers to comparison between different irrigation treatments of a cultivar ($P< 0.05$). For main effects, s*, and ns represent significant at ($P< 0.01$), and non-significant, respectively. Number of spikes per m2 shows the total number of spikes in each mixture treatment.

and 1:2 showed the lowest values during 2007-2008 and 2009-2010, respectively. Hence, the monocultures of either early or middle-ripening cultivars would have a more severe intra-specific competition, compared with mixed cropping of equal ratios from early tillering to, probably, heading, when the final numbers of spikes were determined (see Figure 2, the stage begins between points 1 and 2 and terminates approximately at point 3). Variations in spikes m^{-2} among different mixtures and monocultures may have been caused by various patterns of light perception in the canopy. As mentioned before, in both seasons, stem elongation of Falat cultivar initiated earlier than Shiraz. Although final plant heights of cultivars were almost similar (data not shown), they differed until pre-heading of the middle-ripening cultivar, Shiraz. Such trend in different mixtures would lead to dissimilarity in quantities and qualities of light absorbed by various layers of the canopy which also may affect the survival of fertile spikes (Sparkes, *et al.*, 2006). In addition, under-ground relationships (e.g. competition for nitrogen) should be considered (Emam, 2007).

Weight of 1,000 grains is determined during post-anthesis period (Figure 2, points 4 to 5). As shown in Table 4, moisture stress had a highly significant effect on 1,000 grain weight of both cultivars in 2007-2008. This result confirms the findings of others who showed the effects of post-anthesis moisture stress on mean grain weight (Elhani *et al.*, 2007; Emam *et al.*, 2007; Plaut *et al.,* 2004). Indeed, cultivars had similar 1,000 grain weight, either in monoculture or mixed cropping treatments in the first season. However, the trend was reversed in the second growing season such that cultivars were different significantly ($P< 0.01$) in both irrigation treatments. In the second season, early ripened Falat cultivar showed a greater amount of 1,000 grain weight, compared to Shiraz. Mean values of 1,000 grain weight indicated that, in this season, Falat cultivar was not suffering from post-anthesis moisture stress, while the middle-ripening Shiraz cultivar was affected significantly (Table 4). Furthermore, the maximum and minimum 1,000 grain weights in both moisture conditions of the second season were observed in monocultures of Falat and Shiraz in the mixed ratio of 1:2, respectively ($P< 0.05$). It seems that the early ripening Falat cultivar had avoided post-anthesis moisture stress during 2009-2010 by a shorter phase of grain filling. Likewise, other grain yield components including number of spikelets $spike^{-1}$ and number of grains $spike^{-1}$ that were evaluated (data not shown) showed relatively subtle and inconsistent trends. Overall, it can be concluded that the responses of yield components to diverse conditions and treatments included a relatively wide range, which provides potentially suitable determinants for analyzing trends through cultivar mixtures.

Post-anthesis Evapotranspiration (PET_c) and Post-anthesis Water Use Efficiency (PWUE)

The moisture stress reduced the post-anthesis evapotranspiration (PET_c) significantly by 44 and 43% in the first and second seasons, respectively (Table 3). However, the mixture had no significant effect on PET_c neither within irrigation treatments nor seasons. This might be, at least to some extent, due to evaporative portion of PET_c, which could act as a buffer against variations among the mixtures, i.e. while blends and/or cultivars could have had different transpiration rates, the conditions for evaporation were almost similar.

The effects of irrigation treatments and mixtures were significant on the post-anthesis water use efficiency (PWUE) in both seasons (Table 3). Deficit irrigated treatment showed significantly higher values of *PWUE* compared with well irrigated conditions, reflecting considerable efficiency in water use under 50% of *FC*. Regardless of the well irrigated treatments of 2007-2008, monocultures of Falat and Shiraz had generally the extreme values of maximum and minimum *PWUE*, respectively. This clearly showed higher post-anthesis water use efficiency of Falat cultivar. Furthermore, since the effect of year on *PWUE* was not significant (Table 3), an additional analysis of variance was carried out (Tukey, P< 0.05) using related data of both growing seasons (data not shown). The results showed that over the two seasons, the effect of various blends on *PWUE* was not significant under well irrigated condition, while under moisture stress it was significant and mixtures fell into two statistically different groups: (a) the ratios (Shiraz:Falat) of 0:1, 1:1, and 2:1 with higher *PWUE*; and (b) 1:1, 2:1, 1:2, and 1:0 with low *PWUE*. Also, when the effect of irrigation was neglected, i.e. mean data of both seasons including all moisture conditions were used, the combinations 0:1 and 1:1 fell into the first set and other ratios fell together in a significantly lower set. This revealed that the equal combination ratios of Shiraz and Falat had led to enhanced water use efficiency during the critical post-anthesis period.

CONCLUSIONS

Results indicated that either components or mixtures responded variously to heterogeneous growth patterns at different moisture conditions. Such diversities may provide a potential opportunity to manipulate the intensive mono-species canopies towards more efficient and maintainable cropping systems, particularly in drought prone regions.

Various growth and ripening patterns, as occurred in this study, may alleviate intra-species competition mainly by two mechanisms: (i) temporal heterogeneity in the growth stages of cultivars; and (ii) terminal low densities provided during the grain filling of middle-ripening cultivar. In this study, the equal ratio (1:1 mixed cropping of early- and middle-ripening cultivars) showed the most advantages in grain yield components and sustainable post-anthesis water use efficiency among the mixtures and equaled those of monoculture of early ripening cultivar, which was the most efficient control. Non-equal mixtures also indicated some considerable, but unstable, benefits. Although competition indices showed generally lower competition within studied mixtures, the observations revealed that, probably, there would be even higher agronomic performance if a lower and a higher yielding cultivar were employed as an early and a middle-ripening cultivar, respectively. Such trends are the case commonly for most of even yielding pairs in actual conditions. Further experiments should test the combination of an early ripening cultivar which may have less grain yield potential but higher water use efficiency suitable for high drought risk conditions, and a common potentially higher yielding middle-ripening cultivar.

Overall, it seems that occurrence of heterogeneous patterns of growth and/or ripening within the canopy of winter wheat, provided by mixed cropping of early and middle-ripening cultivars, has the potential of altering the moisture stress patterns in intensive cropping systems of semi-arid regions. However, it is essential to determine the best choices of cultivars (i.e. mostly by screening), number of components, mixing ratios, sowing date, phenological differences, input requirements, and management practices for each regional environment to achieve the maximum benefits.

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تاثیر کشت مخلوط یک رقم زودرس و یک رقم میان رس گندم زمستانه بر کاهش رقابت در شرایط تنش رطوبتی پس از گلدهی

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چکیده

در سال های زراعی ۸۷-۱۳۸۶ و ۸۹-۱۳۸۸ پژوهشی مزرعه ای به منظور ارزیابی سودمندی ایجاد ناهمگونی زمانی رشد بر کاهش رقابت درون گونه ای در شرایط تنش رطوبتی پس از گلدهی، با استفاده از مخلوط های مختلف یک رقم زودرس (فلات) و یک رقم میان رس (شیراز) گندم زمستانه در منطقه نیمه خشک جنوب ایران انجام شد. تیمارها شامل پنج نسبت ترکیبی ارقام (۱:۰، ۱:۲، ۱:۱، ۲:۱، ۱:۰)، و دو سطح تیمار رطوبتی پس از گلدهی (برابر با ظرفیت مزرعه ای و ۵۰٪ ظرفیت مزرعه ای) بودند. نتایج نشان داد که در میان تیمارهای کشت مخلوط، نسبت برابر (کشت مخلوط ۱:۱ ارقام زودرس و میان رس) دارای بیشترین عملکرد دانه و کارآیی مصرف آب در دوره پس از گلدهی (PAWUE) بود. به نظر می رسد که کشت مخلوط ارقام زودرس و میان رس دارای قابلیت تغییر شدت رقابت در شرایط کم آبیاری بوده و بتواند کارآیی مصرف آب را در دوره پس از گلدهی افزایش دهد. در این زمینه پژوهش های تکمیلی برای تعیین بهترین گزینه های ارقام، نسبت های ترکیبی، تاریخ کاشت، و نهاده ها قابل توصیه می باشد.