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Yield and Yield Components Affected by Leaf Water Status in Field-grown Common Bean Genotypes under Two Contrasting Irrigation Regimes

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ABSTRACT: physiological response of common bean yield to leaf water status plays a key role to understanding the yield loss in limiting conditions. to investigate the responses of common bean genotypes (akhtar, mcd-4011, wa-4531-17, cos16, d81083, and-1007, wa-4502-1 and ks21486) and moisture regimes (i_1 and i_2: irrigation after 55 to 60 and 100 to 110 mm evaporation from class a pan, respectively), a split-plot experiment using randomized complete block (rcb) design with four replications was conducted. significant changes in leaf relative water content (rwc) and water potential (ψ_w) of genotypes induced by water deficit were 52.12% (ks21486) to 49.86% (akhtar), and -1.58 mpa (ks21486) to -2.46 mpa (d81083). during the growing season, rwc and ψ_w values of i_2 were significantly lower than those of i_1. the interrelationship of ψ_w and rwc revealed that wa-4531-17 and d81083 in non-stressed, and wa-4502-1, and-1007 and d81083 in water deficit stressed conditions had the lowest rwc reductions per unit decrease of leaf ψ_w. increased grain yields of wa-4502-1, wa-4531-17 and and-1007 were due to increased 1000 grains weight. the results of this experiment showed that the genotypes with suitable water content in their leaf tissues, wa-4502-1, wa-4531-17 and and-1007 produce relatively high grain yield under water limited conditions. d81083 produced low grain yield because of its minimum levels of grains and pods per plant (in spite of suitable leaf moisture content).

Key words: Relative water content, leaf water potential, grain yield, water deficit, *Phaseolus vulgaris* L.

INTRODUCTION

Common bean (Phaseolus vulgaris L.) is an important grain legume in the different parts of the world (Singh, 1999). Most of its production takes place in developing countries (Hillocks et al., 2006). This crop is a primary crop and least expensive source of calorie, protein, dietary fiber, minerals and vitamins for the population in these countries, although, its intake does not satisfy their mineral requirements (Welch and Graham, 1999; Guzman-Maldonado et al., 2000; Hillocks et al., 2006). It is the principal food and cash crop legume widely cultivated in the semi-tropics and tropics. In some areas, bean leaves are cooked and eaten like spinach as a vegetable and young leaves are used in salads. Common bean in combination with cereals and other carbohydrate rich foods provides near perfect nutrition to people of all ages and helps to lower cholesterol and cancer risks (Singh, 1999).

Water requirement as consumptive use of a crop is the quantity of water needed mainly to meet the demands of evapotranspiration, metabolic processes, normal growth and development, and its yield. Jiang et al. (2003) stated that the water requirement of any crop depends on the factors such as variety, growth stage, growth duration, growing season conditions and plant population as well as soil and climate factors and crop management practices. Deonisio et al. (2001) reported that wheat varieties differed in their response to irrigation periods. Halti et al. (2001) also stated that wheat grain yield significantly increased as irrigation levels increased. Schneider and Howell (2001) showed that reducing irrigation rates to 50% of the full crop requirement resulted in 5 to 14% yield reduction in wheat.

Drought is perhaps a worldwide problem, constraining global crop production and quality. Recent global climate change has made this situation more serious (Pan et al., 2002). Permanent or temporary water deficit connected with almost all aspects of biology, limits the performance of cultivated plants more than any other environmental factors (Shao et al., 2008). Shoot biomass accumulation is considered as an important trait in attaining high yield in grain legumes (Rosales-Serna et al., 2004). Drought during the reproductive stage reduces the harvest index (Shao et al., 2008). Moderate to high drought stress can reduce significantly biomass, number of pods and grains per plant, days to maturity, grain weight, grain yield and harvest index in common bean (Acosta-Gallegos and Adams, 1991; Ramirez-Vallejo and Kelly, 1998). A moderate drought stress reduced yield by 41% in P. vulgaris (Foster et al., 1995). However, severe drought stress reduced yield by 50% (Castellanos et al., 1996). The lack of water interferes with the normal metabolism of the plant during flowering, first stages of pod development and grain filling, as these are stages when drought causes the greatest yield reduction in common bean (Singh, 1995; Pimentel et al., 1999; Costa-Franca et al., 2000; Molina et al., 2001).

Leaf water status is intimately related to several leaf physiological characteristics, such as leaf turgor, stomatal conductance, transpiration, photosynthesis, respiration and growth (Kramer and Boyer, 1995). Schonfeld et al. (1988) showed that wheat cultivars having high RWC are more resistant against drought stress. Generally, it seems that preserving leaf turgor in most crops is one of the main mechanisms to retain metabolic activities (Gunasekera and Berkowitz, 1992). Stoyanov (2005) reported that by reaching soil water potential to -0.9 MPa and exerting drought stress for 14 days, osmotic potential and turgor pressure in first leaf of bean was strongly decreased. Markhart (1985) reported that the water potential of well-watered common bean cultivars was higher and not significantly different from each other, but Ψ_w of stressed plants decreased rapidly from control levels of -7 to -9 bars up to -18 bars usually within 7 days after the beginning of treatment. Ferrat and Lovatt (1999) subjected bean plant to drought stress by withholding water (terminal water). They found that stem RWC was significantly lower as compared with control plants.

Relative water content decreased 24.8% in Kenaf (Ogbonnaya et al., 1998), 5% in Phaseolus acutifolius and 10% in P. vulgaris (Ferrat and Lovatt, 1999) under drought stress as compared to control plants. Rozales-Serna et al. (2004) found that water deficit in common bean decreased grain yield and harvest index through reduced relative water content. The degree of decrease was different among cultivars.

Although, water potential measures the energetic status of water inside the leaf cells (Slatyer and Taylor, 1960), but the ability to maintain higher relative water content at leaves, postponed shoot dehydration in P. acutifolius compared to P. vulgaris under drought stress (Ferrat and Lovatt, 1999).

The purpose of this work has been to determine the effects of leaf water status parameters on yield and yield components of common bean genotypes under two different levels of moisture conditions.

MATERIALS AND METHODS

The experiment was carried out during 2009 at the Research farm of the Faculty of Agriculture, University of Tabriz, Iran. The trial was conducted using split-plot experiment based on RCB design with four replications. The irrigations (I1 and I2: Irrigation after 55 to 60 and 100 to 110 mm evaporation from class A pan, respectively) and genotypes (Akhtar, D81083 and AND-1007 with red seed colors, MCD-4011, COS16 and KS21486 with spotted seed colors, and WA-4531-17 and WA-4502-1 with white seed colors) were randomly arranged in main and sub-plots, respectively. Seeds were obtained from the National Bean Research Station of Khomain, Iran. Seeds were treated with 2 g kg^{-1} Mancozeb and were then planted by hand in 5 cm depth from the surface of the soil on 28^{th} May, 2009. Each plot was 15 m^2 and consisted of 5 rows of 5 m length with 50 cm distance between rows and 5 cm between plants in the row. All plots were normally irrigated after sowing until emergence of the second trifoliate leaf, but subsequent irrigations were carried out according to the treatments. After establishment of seedlings, plots were fertilized with 50 kg/ha^{-1} urea before irrigation treatments. Weeds were controlled by hand.

Relative water content (RWC) of leaves was determined between 11: 00 A.M. to 01: 00 P.M. mid-day by comparing the current hydration of leaf tissue to its maximum potential hydration according to the method of Weatherley (1950) at the beginning of each irrigation treatment:

$RWC = (FW-DW)/(TW-DW)\times 100$

Six leaf disc samples were randomly collected from three plants per plot and weighed to determine their fresh weight (FW). The leaf discs were rehydrated by distilled water for 18 to 20 h at 5°C in the darkness in order to obtain turgid weight (TW), followed by drying at 75°C for 48 h (to a constant weight). Dry weight (DW) of leaf discs was measured after this stage. Leaf water potential (Ψw) was measured at the beginning of each irrigation treatment between 11:00 A.M. to 01:00 P.M. midday using a pressure chamber according to Scholander et al. (1965).

At maturity, five plants were harvested from each plot to determine numbers of pod per plant, grain per pod, grain per plant and 1000 grains weight. Finally, in an area of 2 m^{-2} at each plot, harvested materials were divided into two parts: grains and remainders for determination of the harvest index.
SPSS version 16.0 software was used for data analysis, and means comparison based on Duncan's multiple range test ($p \leq 0.05$).The figures and the tables were drawn by version of Microsoft office 2007 software.

RESULTS

Crop water relations
Leaf relative water content (RWC)

In the studied genotypes, RWC of genotypes in the normal condition were between 90.33% (KS21486) and 76.22% (D81083), which means relative changes of 15.62% in the genotypes (Table 1). Under limited conditions, the changes were 52.12% (KS21486) to 49.86% (Akhtar) with a relative change of 4.34%. During the growing season, RWC was significantly higher in normal irrigation condition compared with water deficit (Figure 1a). RWC was the lowest 37 days after sowing (DAS) in I_2.

Leaf water potential (Ψ_w)

Significant difference was found among genotypes with respect to Ψ_w at both irrigation regimes. D81083 and KS21486 genotypes had the lowest and the highest Ψ_w at both irrigation treatments, respectively. Control plants had the highest Ψ_w with the lowest values at 35, 55, 88 and 100 DAS (Figure 1b). During the growing season, leaf Ψ_w at the plants grown under water deficit condition was less than that of plants irrigated normally. The lowest value in I_2 treatment was seen at 37 DAS (Figure 1b).

Relationship between leaf RWC and Ψ_w

The relationship between RWC and Ψ_w of the genotypes were described in terms of seed colors. In Akhtar, D81083 and AND-1007 genotypes with red seed color, leaf RWC and Ψ_w were higher in normal condition, but in limited irrigation, Ψ_w was low in D81083 compared with Akhtar and AND-1007, which were in the same range (Figure 2a). MCD-4011, COS16 and KS21486 with spotted seeds showed high and low leaf RWC under normal and stressed conditions, respectively (Figure 2b). Between 40 to 60% RWC, COS16 had almost lower Ψ_w compared with other two genotypes. In this group, the trend of variations in Ψ_w and RWC were the same at I_1 and I_2.

The third group (WA-4531-17 and WA-4502-1) with white seed coats showed different Ψ_w under normal and water deficit conditions. However, under stressed condition, Ψ_w in WA-4502-1 was low in the range of 40 to 45% leaf RWC compared with WA-4531-17 (Figure 2c).

In general, the result showed that under both irrigation levels, the differences between genotypes for Ψ_w value at low RWC were high, but in high RWC, low variations were observed among genotypes with respect to Ψ_w.

Yield and yield components

Analysis of variance revealed that number of pods per plant, number of grains per plant, 1000 grains weight and grain yield were significantly affected by irrigation and genotype, but number of grains per pod and biological yield were only affected by irrigation. There was no significant difference between irrigation regimes as well as, among genotypes with respect to harvest index. The irrigation and genotype interaction was not significant for yield and yield components (Table 2).

WA-4531-17 and WA-4502-1 with of 38.43 and 34.49 grains per plant as well as, 11.16 and 10.37 pods per plant respectively, produced the maximum amount of these traits. Among the genotypes, minimum levels of grains and pods per plant belonged to D81083 (12.99 and 4.33, respectively). Grains of WA-4502-1, AND-1007 and WA-4531-17 are much greater than the other genotypes under research: 436.72 to 418.47 g per 1000 grains compared with KS21486 with 324.01 g per 1000 grains, which was the lowest. While the grain yields of WA-4502-1, WA-4531-17, COS16 and Akhtar with AND-1007 were statistically in the same group, but WA-4502-1 with the production of 401.72 g grain m^{-2} had the highest grain yield. KS21486, MCD-4011 and D81083 produced much lower grain yield (279.13, 238.38 and 124.94 $g.m^{-2}$) than the others (Table 3).

The high grain yields of two white common bean genotypes, WA-4502-1 and WA-4531-17 may be contributed by high number of pods per plant, number of grains per plant and high 1000 grains weight of these genotypes (Table 3). Pods per plant, grains per pod, grains per plant, 1000 grains weight, biological yield and grain yield per unit area were decreased by water deficit (65, 8, 28, 16, 53 and 42%, respectively).

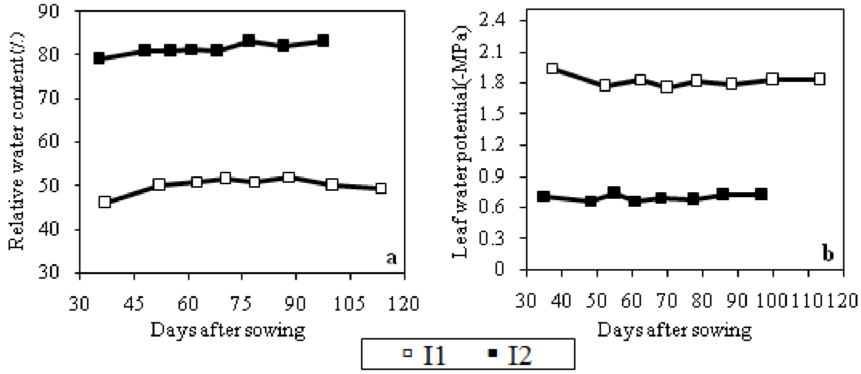

Figure 1. The means of leaf relative water content (a) and leaf water potential (b) during the growing season

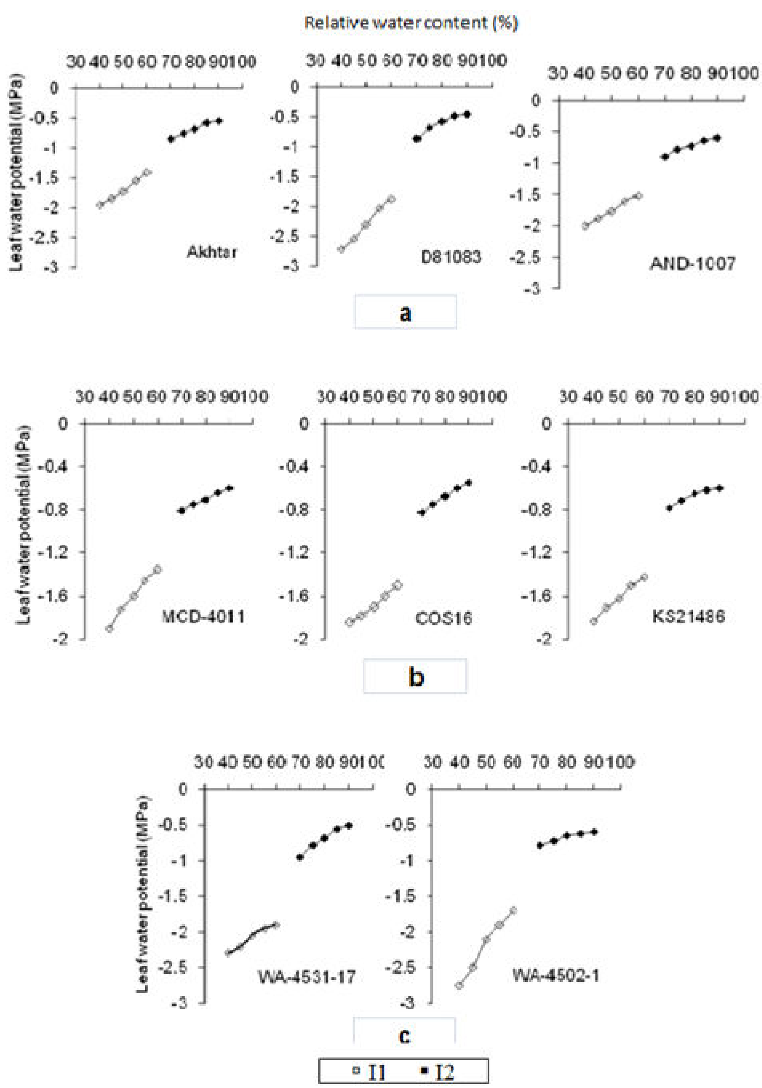

Figure 2. Relationship between RWC and Ψw of the studied genotypes: (a) Red seed genotypes (b) Spotted seed genotypes (c) White seed genotypes.

Table 1. Effect of irrigation regimes on leaf relative water content (%) and leaf Water potential (MPa) of common bean genotypes.

Genotypes	Treatment	RWC (%)	Ψ_w (MPa)
Akhtar	I_1	81.42	-0.69
	I_2	49.86*	-1.72*
MCD-4011	I_1	85.18	-0.67
	I_2	50.55*	-1.62*
WA-4531-17	I_1	86.14	-0.69
	I_2	51.26*	-1.95*
COS16	I_1	82.33	-0.68
	I_2	50.65*	-1.69*
D81083	I_1	76.22	-0.70
	I_2	51.36*	-2.46*
AND-1007	I_1	84.38	-0.68
	I_2	51.74*	-1.81*
WA-4502-1	I_1	89.62	-0.66
	I_2	50.43*	-2.04*
KS21486	I_1	90.33	-0.62
	I_2	52.12*	-1.58*

*: significantly different from control (I_1) at $p \leq 0.05$.

Table 2. Analysis of variance for various traits in the studied common bean genotype.

Source	df	Pods per plant	Grains per pod	Grains per plant	1000 grains weight	Grain yield	Biological yield	Harvest index
Rep.	3	38.132*	0.785	488.93**	8.92	74911.816	322697.771	20.284
Irrigation (I)	1	137.212**	1.535*	2311.20**	221.936**	345820.994**	2204240.68**	10.088
Ea	3	15.437	0.161	101.197	1.046	34844	214992.036	22.157
Genotype (G)	7	46.657**	0.166	580.238**	11.112**	69513.301*	316310.961	83.088
I*G	7	6.899	0.307	165.907	8.886	22331.417	61976.346	73.977
Eb	42	12.057	0.348	119.943	5.884	18678.195	157741.404	61.905
Total	64	---	---	---	---	---	---	---
CV (%)	---	11.97	57.08	18.21	11.97	0.58	15.47	0.69

*, **: Statistically significant at $p \leq 0.05$ and $p \leq 0.01$, respectively.

Table 3. Mean comparison of yield and yield components in the eight common bean genotypes.

genotypes	Pods per Plant	Grains per plant	1000 grains weight (g)	Grain yield (gm^{-2})
Akhtar	5.95 cd	23.33 bcd	400.12 bc	334.77 a
MCD-4011	5.53 cd	17.16 cd	418.47 ab	238.38 ab
WA-4531-17	11.16 a	38.43 a	385.56 c	381.06 a
COS16	7.49 cd	24.20 bcd	350.07 d	374.14 a
D81083	4.33 d	12.99 d	392.02 c	124.94 b
AND-1007	9.07 abc	25.58 c	426.37 ab	358.22 a
WA-4502-1	10.37 ab	34.49 ab	436.72 a	401.72 a
KS21486	9.82 cd	21.71 cd	324.01 e	279.13 ab

Different letters at each column for genotypes indicating significant difference at $p \leq 0.05$.

DISCUSSION

Our results showed that the response of various common bean genotypes to water deficit was different (Table 1). Pennypacker et al. (1990) and Gorai et al. (2010) reported that the leaf RWC significantly decreased in Medicago sativa as water stress intensified during the growing season. Similar results were reported by Martínez et al. (2007) in P. vulgaris. As shown in Figure 1, leaf RWC and Ψ_w increased up to 35 to 50 DAS under irrigation regimes especially in stressed plants, suggesting that irrigation in stressed treatment resulted in full recovery of plants. Markhart (1985) observed similar results in common bean. Maintenance of high RWC has been considered as drought-resistance rather than drought-escape mechanism. It is a consequence of adaptive characteristics in plants (Grashoff and Ververke, 1991). Any considerable changes in each of RWC and Ψ_w of leaves were not seen thereafter in Figure 1.

Inter-relation of leaf RWC and Ψ_w in drought condition plays a key role in stress tolerance of crop plants. The results of our experiment showed a clear but different relationship between these two parameters under irrigation regimes (Figure 2).

The results revealed that well-watered plants exhibited higher Ψ_w with a higher RWC. In contrast, the stressed plants showed the lower Ψ_w and percentage of RWCs. The same results were reported in Glycine max by Adejare and Umebese (2007).

Significant changes were not observed in RWC and Ψ_w of genotypes under normal condition, except spotted group and white WA-4502-1 genotypes which showed relatively high Ψ_w in low RWC (Figure 2). A possible explanation could be a low stomatal control allowing high transpiration rate. Costa-Franca et al. (2000) reported the differences among P. vulgaris cultivars in response to substrate water supply.

In the stressed plants, only D81083 and WA-4502-1 showed a low Ψ_w under low RWC (Figure 2). White WA-4531-17 had a low Ψ_w in the same RWC compared with Akhtar and AND-1007 (red genotypes) and spotted group. It seems that these genotypes could not maintain leaf turgor in stressed condition. This result confirms the findings of Kramer and Boyer (1995) and Costa-Franca (2000) in P. vulgaris.

It was reported that the maintenance of leaf water status or capacity of leaf turgor maintenance is a result of proper control via guard cells in any environmental conditions, supporting growth activities and enhance the ability of species in the stressful conditions (Leung and Giraudat, 1998; Steudle, 2000; Stoyanov, 2005). The effects of per unit decrease in leaf water potential due to environmental constraints were estimated quantitatively based on RWC changes in the genotypes (Figure 2). Substantially, there were large differences in their relationships between genotypes. Therefore, in non-stress treatment, the highest leaf RWC loss per unit decrease in Ψ_w was observed in KS21486 (13.3%), MCD-4011 (9.1%) and WA-4502-1 (8%) genotypes. It seems that in these genotypes, the leaf stomata were more open as reported in P. vulgaris by Costa-Franca (2000). The lowest decreases were seen in WA-4531-17 (4.50%) and D81083 (4.65%).

In the water deficit condition, the highest leaf RWC reduction per unit decrease in Ψ_w belonged to MCD-4011 (6.75%) and COS16 (5.75%) genotypes. WA-4502-1 (2%), AND-1007 (2.25%) and D81083 (2.50%) had the lowest leaf RWC decreases and as such, more tolerant species. Stoyanov (2005) found that the capacity to maintain high RWC in young bean leaves under drought could be due to their capacity to accumulate great quantities of proline and other osmotic active compounds.

According to the review of Kumar et al. (2006) in snap bean, the high yielding cultivars displayed a smaller reduction in leaf RWC but a greater reduction in leaf Ψ_w compared with low yielding under decreased soil water condition. They proposed that such differences in leaf water relations could be due to differences in osmotic adjustment and cell wall elasticity. Yield components in common bean are the number of pods per plant, grains per pod, grains per plant and 1000 grains weight. Grain yield was reduced (42%) in water deficit treatment by 65, 8, 28 and 16% reduction in each of the aforementioned yield components, respectively. Kumar et al. (2006) reported that responses of photosynthetic parameters and shoot extension to leaf water status related to soil water reduction. Drought stress significantly altered the internal water status with decreasing RWC, Ψ_w and osmotic potential in maize which consequently inhibited photosynthetic rate and reduced the final yield. Occurrence of drought especially, at tassel emergence stage had a deleterious impact on the plant productivity(Atteya, 2003). Szilagyi (2003) suggested that grain yield reduction in common bean cultivars under drought stress was mainly due to reduction in number of pods per plant.

All the genotypes used in this experiment showed significant variations in grain yield and some of the yield components. These results are comparable to the findings of Szilagyi (2003) in black bean and Castaneda et al. (2006) in dry bean. Although, number of pods per plant and grains per pod are two important components of common bean yield, but in our study the increased grain yields of WA-4502-1, WA-4531-17 and AND-1007 was due to increased 1000 grains weight. This result may draw attention to the low decrease in most important parameter in drought tolerance, RWC of leaf tissues. WA-4502-1 genotype proved to be the most productive under shortage of water supply (Figure 2). It seems that physiologically, closure of stomata more slowly is often able to maintain CO_2 uptake longer even during drought. It is well established that photosynthesis is relatively resistant to water shortage (Brestic et al., 1995). Costa-Franca (2000) in P. vulgaris and Adejare and Umebese (2007) in G. max reported the same results. Meanwhile, the lowest grain yield belongs to D81083 in which mean number of pods and grains per plant were not considerable (4.3 and 13, respectively), whereas sink strength (as a single-grain level) was higher because of low reduction in leaf RWC in each of the two conditions (Figure 2), and as such, noticeable 1000 grains weight was produced.

CONCLUSION

Common bean is one of the extremely sensitive crops to drought stress. The results of the present study highlights the fact that the reduced leaf RWC reduction percent or turgor maintenance is a factor of high importance in *P. vulgaris* genotypes especially, in the field conditions. The results of this experiment showed that the genotypes with suitable water content in their leaf tissues, WA-4502-1, WA-4531-17 and AND-1007 produce relatively high grain yield under water limited conditions. D81083 produced low grain yield because of its minimum levels of grains and pods per plant (in spite of suitable leaf moisture content).

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