

Adaptation of spring-sown chickpea to the Mediterranean basin.

II. Factors influencing yield under drought

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ABSTRACT

Drought during the late vegetative and reproductive stages of development is the major constraint to the productivity of spring-sown chickpea in the rainfed farming systems of West Asia and North Africa. This paper examines the contribution of crop traits to yield under drought and determines the relative contributions of drought escape, yield potential and a drought response index (DRI) to such yield.

In years with mild drought (1986/87 and 1987/88), high biomass, high yield potential and high harvest index were highly correlated with grain yield. During the severe drought of 1988/89, early flowering and low straw yield, high harvest index, yield potential, pod and seed number and seed mass were correlated with rainfed grain yield.

Differences among chickpea cultivars in rainfed (drought) yield were partitioned into drought escape, yield potential and DRI. Drought escape accounted for 41% in 1986/87, 37% in 1987/88 and 69% in 1988/89; yield potential accounted for 47%, 37% and 1%, respectively; and DRI accounted for 4%, 17% and 17% of the variations, respectively. The three factors combined explained an average of 90% of the variability in grain yield. The DRI was used to quantify tolerance or susceptibility of a cultivar independently of drought escape (early flowering) and yield potential. Of the traits which were significantly associated with drought yield, high harvest index, large number of pod and high seed mass were associated with drought escape (early flowering), while deep root system, high leaf water potential at dawn and large number of seeds were associated with drought tolerance (DRI).

INTRODUCTION

In the Mediterranean areas of West Asia and North Africa (WANA), where rainfall is in winter, chickpea is normally sown in spring in areas with at least 400 mm annual average rainfall. From the late vegetative stage of growth until maturity, the crop experiences ever-increasing evaporative demand be-

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cause of high temperatures. Soil moisture reserve is rarely adequate to meet water requirement of the crop and considerable drought stress is experienced, which limits grain yield (Saxena et al., 1990).

The emphasis in spring chickpea improvement at ICARDA (International Center for Agricultural Research in the Dry Areas) is on the development of cultivars that give high and stable yields in the WANA region, where the crop depends on variable amounts of moisture stored in the soil profile and where terminal drought is a major production constraint. Presently, grain yield is the main selection criterion for drought resistance. Better adapted and higher yielding barley cultivars can be bred more efficiently and effectively if attributes that confer drought resistance are identified and used as selection criteria (Acevedo and Ceccarelli, 1989). In lentil, early growth vigour, establishment of high ground cover early in the season, light green colour during early vegetative growth and early flowering and maturity are attributes associated with high yield under drought (Silim et al., 1993). Similarly, in wheat (Fischer and Wood, 1979) and pearl millet (Bidinger et al., 1987a), early flowering was reported as an important trait for high yield under drought. Bidinger et al. (1987b) used a drought response index (DRI) to describe the response of individual cultivars of pearl millet to drought, independently of phenology and yield potential (non-stress yield), and determined attributes associated with DRI.

This paper examines the response of spring-sown chickpea cultivars of diverse origin to terminal drought, estimates the relative importance of drought escape, yield potential and DRI in adaptation to drought and determines traits that contribute to tolerance to drought independently of phenology (drought escape) and yield potential.

MATERIALS AND METHODS

Field experiments

The details of the field experiments on which the analyses of response to drought are based are described fully in the first paper (Silim and Saxena, 1993). In summary: the trials were conducted at Tel Hadya in northern Syria using 16, 17 and 20 chickpea cultivars of diverse origin in 1986/87, 1987/88 and 1988/89, respectively. The cultivars (lines) used in the study included landraces from WANA and the Indian sub-continent, and high-yielding cultivars bred at ICARDA and ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) in India. A line-source sprinkler irrigation system was used to create a soil moisture supply gradient. Areas closest to the sprinklers received the highest supplemental moisture supply and those far away none, these latter thus depending on residual moisture from rainfall stored in the soil. The grain yields from the rainfed area were the drought-

stress yields and those from areas closest to the line-source sprinkler, yield potential.

The yield response of chickpea cultivars to moisture supply and the traits associated with variations in grain yield were presented in the previous paper (Silim and Saxena, 1993).

Factors contributing to drought yield

The relationships between drought yield and yield components, phenology and yield potential were examined first. Similar correlations for the yield potential treatment were also examined to determine whether traits associated with high grain yield were similar under drought and non-stressed conditions. According to Bidinger et al. (1987b), grain yield under drought is a function of time to flowering, yield potential and drought response. If drought resistance is considered a consequence of advantages conferred by one or more physiological or morphological characteristics (Turner, 1982) and can be manipulated in the breeding program as an independent genetic trait (Blum, 1979; Quisenberry, 1982; Richards, 1982), drought resistance should be assessed independently of the effects of time of flowering and yield potential. Therefore, we have quantified the response of each cultivar to drought stress independently of drought escape (early flowering) and yield potential, using the drought response index (DRI) as reported by Bidinger et al. (1987b), based on multiple regression:

$$Y_0 = a - bF + cY_i \quad \text{and}$$

$$\text{Drought response index (Standard residual)} = \frac{Y_0 - \hat{Y}_0}{\text{Standard error of } \hat{Y}_0}$$

where Y_0 = yield under drought; \hat{Y}_0 = regression estimate of yield under drought; Y_i = yield potential; F = days to flowering.

The relative contributions of drought escape, yield potential and DRI were then determined. Finally, drought escape and DRI for each cultivar in each year were correlated with some of the traits measured, to determine whether they were related to either of the two.

RESULTS AND DISCUSSION

Climate

Weather at Tel Hadya during the period of study was described by Silim and Saxena (1993). Briefly, the seasons provided contrasts in temperature and rainfall and hence drought stress experienced by the crop. The 1986/87 season was a low-stress season favourable for crop growth; precipitation was 359 mm, slightly higher than the long-term average for Tel Hadya (330 mm), and the temperatures during the March–May period were lower than the long-

term average. The 1987/88 season again was favourable, precipitation was 504 mm, the wettest since 1940/41, with temperatures similar to or slightly lower than the long-term average. In contrast, drought was intense during the 1988/89 season; total precipitation was only 234 mm, with most received in the November–January period, and the rise in temperatures was fast, with temperatures in March–May period higher than the long-term average. This provided an opportunity to determine whether traits associated with grain yield were similar in all seasons or were environment dependent and only evident in particular seasons.

Grain yield under drought stress

Details of grain yield under drought for the period of study are given in Silim and Saxena (1993). In summary, the range in grain yield was 0.636–

TABLE 1

Ranges in phenology, grain yield and yield components of chickpea in the unirrigated and irrigated treatments at Tel Hadya, northern Syria for three seasons

	Unirrigated		Irrigated	
1986/87				
Days to flowering	53	-84	53	-84
Days to maturity	87	-101	97	-116
Grain yield (t/ha)	0.636-1.231***		1.285-2.504***	
Straw yield (t/ha)	0.650-1.783***		1.443-3.370***	
Biomass (t/ha)	1.323-2.523***		3.127-5.874***	
Harvest index	0.42 -0.60**		0.37 -0.56**	
Pods/m ²	389	-862**	638	-1933***
Seeds/m ²	451	-1262**	858	-3687***
100-seed mass (g)	17.4	-47.8***	13.7	-48.7***
1987/88				
Days to flowering	45	-59	45	-59
Days to maturity	75	-96	78	-98
Grain yield (t/ha)	0.803-1.364***		1.313-2.027***	
Straw yield (t/ha)	0.727-1.625***		1.079-2.756***	
Biomass (t/ha)	1.542-2.893***		2.316-4.578***	
Harvest index	0.33 -0.60***		0.39 -0.57**	
Pods/m ²	248	-697***	428	-950***
Seeds/m ²	268	-880***	503	-1160***
100-seed mass (g)	18.5	-48.3***	18.0	-43.3***
1988/89				
Days to flowering	44	-63	44	-63
Days to maturity	67	-85	84	-97
Grain yield (t/ha)	0 -0.658***		0.718-2.708***	
Straw yield (t/ha)	0.558-1.885**		1.869-5.795***	
Biomass (t/ha)	0.781-1.955***		3.777-6.513***	
Harvest index	0 -0.46*		0.11 -0.52***	

Significance: ** = $P < 0.01$; *** = $P < 0.001$.

1.231 t/ha in 1986/87; 0.803–1.364 t/ha in 1987/88; and 0–0.658 t/ha in 1988/89 (Table 1), and the respective mean grain yields for each year were 0.984 t/ha, 1.099 t/ha and 0.187 t/ha.

Factors influencing grain yield under drought stress

The correlations between drought yield and various crop traits varied with year (Table 2). Correlations between drought-stress grain yield and biomass were positive and significant only during the low-stress years, 1986/87 ($r=0.685^{***}$) and 1987/88 ($r=0.718^{***}$) and those between drought grain yield and harvest index were significant in all three years ($r=0.509^*$, 0.521^* and 0.950^{***} , respectively for 1986/87, 1987/88 and 1988/89), hence strongest in the high-stress season. The results for 1986/87 and 1987/88 are similar to those reported by Saxena et al. (1990) for chickpea and Silim and Saxena (1992) for faba bean, i.e. under favourable growing conditions, high biomass production is a major pre-requisite for attaining high grain yields, but this should be accompanied by a high harvest index. However, in a non-stress treatment, during the same period (1986/87 and 1987/88), the major trait associated with high grain yield was high biomass (Table 2). Probably in spring-sown chickpea, when thermal and moisture regimes are favourable, attainment of high grain yield is associated with high biomass production; and at low to intermediate levels of moisture and thermal stresses (as in the rainfed treatment in 1986/87 and 1987/88), both high biomass production

TABLE 2

Correlations between drought stress grain yield (D) and potential grain yield (I) and some plant traits of spring-sown chickpea at Tel Hadya, northern Syria for three seasons

Traits	1986/87	1987/88	1988/89
Days to flower: D	-0.173	0.431	-0.842 ^{***}
I	0.345	0.130	-0.656 ^{**}
Days to mature: D	0.085	-0.268	-0.562 ^{**}
I	0.449	0.195	0.432
Biomass: D	0.685 ^{**}	0.718 ^{***}	0.252
I	0.758 ^{***}	0.827 ^{***}	-0.302
Straw yield: D	0.029	0.245	-0.609 ^{***}
Harvest index: D	0.509 [*]	0.521 [*]	0.950 ^{***}
I	0.229	-0.022	0.810 ^{***}
Irrigated (potential) grain yield: D	0.688 ^{**}	0.593 ^{**}	0.546 ^{**}
Pods/m ² : D	-0.287	0.053	0.878 ^{***}
I	-0.356	-0.192	-0.450 [*]
Seeds/m ² :D	-0.369	-0.064	0.887 ^{***}
I	-0.402	-0.185	-0.381
100-seed mass (g): D	0.482 [*]	0.342	0.461 ^{***}
I	0.525 [*]	0.549 [*]	0.071

Significance: * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$.

and partitioning of a high proportion to the grain (high harvest index) become major factors contributing to high grain yield. At high levels of stress (1988/89), however, partitioning becomes the major factor contributing to high grain yield (Table 2). Correlations between drought grain yield and phenology (days to flowering and maturity) and between drought grain yield and straw yield were highly significant and negative, only during the 1988/89 season (Table 2). Similarly, several other yield components were significantly correlated with drought grain yield only in the 1988/89 season (Table 2). The traits which were significantly correlated with drought grain yield during the 1988/89 season were significantly correlated with harvest index (Table 3), which suggests that in 1988/89 grain yield was mainly sink determined. These results clearly show that traits that determine yield under low stress are different from those for severe drought. In all three years, drought grain yield was positively correlated with yield potential, confirming that drought yield is influenced by yield potential (Bidinger et al., 1987b).

The DRI was used for quantification of susceptibility and tolerance of a cultivar. The performance of a cultivar was characterized by the sign of DRI, a positive sign indicating that a cultivar is tolerant and a negative sign that it is susceptible (Bidinger et al., 1987b). A threshold value of DRI of 1.30 was, however, chosen as that which selects cultivars in the upper and lower 10% of the normal distribution of drought yields. A cultivar was considered non (zero) responsive to drought, if the absolute value in the drought treatment was smaller than ± 1.30 DRI and responsive (have real response) if the absolute value under drought exceeded ± 1.30 DRI (Bidinger et al., 1987b). The cultivar FLIP 83-2 was rated as tolerant and ICCL 82001 as susceptible in the 1986/87 season with low temperatures, ILC 1919 as tolerant and FLIP 85-4 and ICCL 82001 as susceptible in the 1987/88 season with high rainfall, and Annigeri as tolerant and ILC 1272 as susceptible in the extremely dry 1988/89 season (Table 4). Most of the cultivars rated as tolerant to drought had deep root systems and high pre-dawn leaf water potentials (Silim and Saxena, 1993). These results suggest that for areas with moderate levels of

TABLE 3

Correlations between harvest index (HI) and some of the traits during the 1988/89 season

Trait

Straw yield (kg/ha)	0.700***
Pods/m ²	0.921***
Seeds/m ²	0.917***
100-seed mass	0.434
Days to flowering	-0.816***
Days to maturity	-0.556***

Significance: * = $P < 0.05$; *** = $P < 0.001$.

TABLE 4

Drought response index (DRI) for spring-sown chickpea cultivars at Tel Hadya, northern Syria during the 1987–1989 period

Cultivar	1986/87	1987/88	1988/89
ILC 100	NT	NT	-0.853
ILC 262	NT	NT	0.526
ILC 464	0.186	-0.180	-0.884
ILC 624	NT	NT	-0.749
ILC 629	0.715	0.940	-0.869
ILC 1272	NT	NT	-1.411
ILC 1919	1.077	1.520	0.072
ILC 1929	NT	NT	-1.140
ILC 1930	0.225	0.057	-0.813
FLIP 82-73	1.097	0.760	-0.821
FLIP 83-2	1.302	0.703	0.805
FLIP 84-12	-0.666	-0.687	NT
FLIP 84-74	-0.774	0.572	NT
FLIP 84-78	-0.725	-0.155	NT
FLIP 84-80	1.116	-1.234	-0.255
FLIP 85-4	-0.018	-1.602	-0.964
FLIP 85-49	-0.911	-0.384	-0.925
K 850	NT	NT	-0.199
ICC 4958	-0.578	1.079	1.092
ICC 10448	0.255	0.556	0.430
ICC 10991	0.450	-0.809	0.670
ICCL 82001	-1.753	-1.504	0.040
Annigeri	NT	0.490	2.455

NT = not tested.

DRI > +1.30 = Cultivar is tolerant to drought.

DRI > -1.30 = Cultivar is susceptible to drought.

stress (moisture and temperature), cultivars such as ILC 1919 and FLIP 83-2 are better adapted; and under severe stress as in 1988/89, the well-adapted cultivar is Annigeri.

The relative contribution of drought escape (early flowering), yield potential (yield in the fully irrigated treatment) and drought susceptibility or tolerance (characterized by DRI) to measured yield under drought, were evaluated by multiple regression. The contribution of each was expressed as percentage of the sum of squares it accounted for (Table 5). Drought escape was a major contributor to drought yield, particularly in the dry year, and accounted for 41, 37 and 69% of the variations in 1986/87, 1987/88 and 1988/89, respectively; yield potential for 47, 37 and 1%, respectively; and DRI for 4, 17 and 17%, respectively. The three factors combined explained on average 90% of the variability in grain yield under drought. This method of analysis thus provides an effective estimator of major factors that determine yield under drought. Drought response index (DRI) was positively and

TABLE 5

Partitioning of sum of squares as percentage for drought yield (YNI) among time to flowering (FL), yield potential (YFI) and specific cultivar effect (DRI) in spring-sown chickpea

	1986/87	1987/88	1988/89
FL	41	37	69
YFI	47	37	1
DRI	4	17	17
Residual	8	9	13

TABLE 6

Correlations of yield and yield-related variables in drought stress treatment with time to flowering (drought escape = FL) and drought response index (DRI)

Correlate	Correlation coefficient	
	FL	DRI
1986/87		
Biomass	0.464	0.106
Straw yield	0.641**	-0.174
Harvest index	-0.631**	0.423
Grain yield	-0.173	0.587*
Pods/m ²	-0.096	0.257
Seeds/m ²	-0.100	0.314
Individual grain mass	0.203	-0.004
Days to mature	0.823***	0.244
1987/88		
Biomass	0.167	0.028
Straw yield	0.499*	-0.239
Harvest index	-0.709**	-0.559*
Grain yield	-0.431	0.561*
Pods/m ²	-0.351	0.378
Seeds/m ²	-0.328	0.328
Individual grain mass	0.147	-0.142
Days to mature	0.813***	-0.263
1988/89		
Biomass	-0.255	0.081
Straw yield	0.365	-0.215
Harvest index	-0.816***	0.650**
Grain yield	-0.842***	0.701***
Pods/m ²	-0.690***	0.660**
Seeds/m ²	-0.422	0.694***
Individual grain mass	-0.655**	-0.012
Days to mature	0.863***	-0.222
Greatest rooting depth	0.075	0.657**
Water potential at 77 DAS ^a	0.237	-0.482*
Water potential at 84 DAS	0.041	-0.626**

^aDAS = days after sowing.

Significance: * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

significantly correlated with drought grain yield (0.587* in 1986/87, 0.561* in 1987/88 and 0.701*** in 1988/89) (Table 6), but not time to flowering and yield potential, confirming that its relationship to grain yield under drought was independent of the latter two factors.

Identifying traits for drought escape and tolerance

Analysis of the data indicates that drought escape expressed in this study as time to flowering was a major contributor to differences in drought yield and despite the low relative contribution of DRI, a few cultivars (with $DRI > 1.30$) exhibited real drought tolerance (Tables 4 and 5). The traits that were significantly correlated with drought yield were correlated with time to flowering and to DRI to determine whether they were associated with drought escape or tolerance/susceptibility to drought (Table 6). Separating traits correlated to yield under drought into escape (early flowering) or tolerance, provided an indication of those traits that are most useful as selection criteria for either drought escape or tolerance. High values of harvest index were clearly associated with drought escape, particularly under severe terminal drought (1988/89); additional traits associated with drought escape were production of a large number of pods/m² and high individual grain mass. Application, therefore, of these traits as selection criteria will identify many of the same lines identified using early flowering. Under the severe drought of 1988/89, DRI was highly correlated with deep root systems, maintenance of high leaf water potentials and production of a large number of seeds/m² and not related to earliness (Table 6) and the former three, not the latter could be used as selection criteria for drought tolerance. Most of the cultivars identified as tolerant to drought using DRI had deep root systems (Silim and Saxena, 1993), which is consistent with the recommendations of Ludlow and Muchow (1988) for using that trait as a selection criterion for drought tolerance in sorghum and cowpea, and the correlation with high grain number is consistent with the report by Bidinger et al. (1987b) for terminal drought in pearl millet. The trait deep root system was exhibited under both drought and full irrigation and is, therefore, independent of moisture supply (Silim and Saxena, 1993). Maintaining high leaf water potential was most probably due to deep root systems that permitted continued water extraction. Similarly, production of large numbers of seeds was probably due to the ability of roots to extract water. Silim and Saxena (1993) earlier indicated that screening for deep root systems is laborious and suggested that a simple and indirect way to screen for deep root systems would be to select cultivars with high leaf water potential during reproductive growth. An additional trait to select would be production of high numbers of seeds under drought.

CONCLUSIONS

The results of the present investigation clearly show that under severe terminal drought, as in 1988/89, drought escape was the major contributor to high grain yield. Selection for early flowering is, therefore, an appropriate strategy if the intention is to breed for environments drier than the traditional chickpea growing areas of WANA. If, however, the intention is to develop chickpea cultivars for the traditional areas with mean annual rainfall of at least 400 mm, and where variability from year to year is high, then DRI is an appropriate tool because it identifies cultivars and traits associated with drought tolerance.

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