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EVALUATION OF GENOTYPIC RESPONSE OF *KABULI* CHICKPEA (*CICER ARIETINUM* L.) CULTIVARS TO IRRIGATION REGIMES IN NORTHWEST OF IRAN

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Water deficiency is commonly the most important yield -restraining factor in semi-arid and Mediterranean environments. Chickpea (*Cicer arietinum* L.), which is one the main legume crops of the region, often experiences terminal drought. To investigate the response of chickpea genotypes to different irrigation levels, experiments were conducted in Maragheh, Northwest Iran. Three levels of irrigation including zero (rain-fed condition), full irrigation (enough water to fill the root zone profile) and two supplement irrigations (SIs) during flowering and grain filling stages were evaluated over 2013 growing season. Results revealed that plant height, canopy spread, primary and secondary branches, chlorophyll content, day to maturity, grain yield and yield components were significantly affected by irrigation regimes. However, there was no statistically significant difference between full irrigation and SI for number of pods per plant, number of seeds per pod, 100-grain weight, grain yield per unit area and grain filling rate. The seed yield of the genotypes when grown under the full irrigation condition increased at a rate of 58% over those in rain-fed condition. Investigation of grain yield and drought resistance indices revealed that FLIP 98-106C and Arman can be selected as the best tolerant genotypes to rain-fed condition. In general, under semi-arid conditions and where some limited water resources are available, SI could be an efficient management practice for alleviating the unfavourable effects of soil moisture stress on the yield of rain-fed chickpea during crucial reproductive growth stages.

Key words: drought; genotype; grain yield; kabuli; rain-fed conditions

Chickpea (*Cicer arietinum* L.) is one of the earliest grain legumes believed to have originated in rainfed areas of the Mediterranean basin (Kumar & Abbo 2001). Chickpea can be considered one of the most important food legumes in the world. Major chickpea producing countries include India, Pakistan and Iran (FAO 2008), where the crop is generally sown in spring (March–April) after the main rainy season, and when monthly rainfall decreases gradually till June. Chickpea is traditionally grown as a rain-fed crop on stored soil moisture and this makes terminal drought stress as a primary constraint to productivity (Serraj *et al*. 2004). It covers 15% of the cultivated area and contributes to 14% (7.9 million ton) of the world's pulse harvest of about 58 million tons (FAO 2008). Besides being an important source of human and animal food, chickpea also plays an important role in the maintenance of soil fertility, particularly in the dry, rain-fed areas (Katerji *et al*. 2001; Gaur *et al*. 2007). Most chickpea growing areas in Iran have cool and cold semi-arid climates with terminal drought stress (Ghassemi-Golezani *et al*. 2008). In west and northwest of Iran with cold wet winters (December–February) and hot dry summers (June–

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August), chickpea is traditionally sown in spring (March–April), which roughly corresponds with the end of the rainy season in the region. Consequently, water deficit during late vegetative and reproductive stages is a common yield-limiting factor (Soltani *et al*. 2001). However, the severity of water stress varies from year to year, depending on the amount and distribution of rainfall and also the rate of evapotranspiration. Terminal drought stress is normally accompanied by increasing temperature during the time of maturity, often to levels more than 30°C, which may affect pod filling (Khamssi *et al*. 2011). A scarcity of soil moisture in the rain-fed areas of Iran often arises during the most susceptible stages of chickpea growth, i.e. flowering and grain filling (Shamsi *et al*. 2010).

Irrigated agriculture is the primary user of diverted water globally, reaching a proportion that exceeds 70–80% of the total in the arid and semi-arid zones (Fereres & Soriano 2007). However, rain-fed agriculture accounts for about 80% of the world's farmland and two-thirds of global food production. Despite the higher risks and generally lower productivity compared with irrigated areas, rain-fed agriculture will continue to play a dominant role in providing food and livelihood for an increasing world population (Oweis & Hachum 2012). When water supplies are limited, the farmer's goal should be to maximise net income per unit water used (i.e. water productivity) rather than per land unit (Fan *et al*. 2005). Although chickpea is well adapted to semi-arid conditions and considering its winter cycle usually does not need irrigation, sometimes two or maximum three Supplemental Irrigations (SIs) are required. Supplemental irrigation could be introduced as an important strategy to increase water productivity in semi-arid regions. Supplemental irrigation may be defined as the providing of small quantities of water to rain-fed chickpea in order to promote and stabilise yield. SI is only applied when the rainfall fails to provide crucial moisture for normal plant growth especially during reproductive phase. Oweis and Hachum (2003) reported that application of SI in winter-sown food legumes in the Mediterranean environments could significantly improve grain yield and water productivity. Malhotra *et al*. (1997) found that supplemental irrigation (80–120 mm) could enhance the yields of winter-sown chickpea grown in the lowland Mediterranean drylands by 44.0%. The ratio of increase based on estimated annual net profit per hectare to estimated difference in annual costs between rain-fed systems and SI strategy is near to 200%, which is considerable (Oweis & Hachum 2006).

The present study was designed to determine the effect of different levels of water supply ranging from a zero to full irrigation on growth, yield and yield component of *Kabuli* chickpea genotypes. This study will provide information, which can be used in choosing suitable tolerant genotype and will be useful for farmers making decisions on irrigation in Mediterranean area.

MATERIALS AND METHODS

The present study was carried out on an Experimental Farm in Faculty of Agriculture at University of Maragheh in Northwest Iran during the 2013 spring season. Seven different Kabuli chickpea (*Cicer arietinum* L.) genotypes including five lines from the International Center for Agricultural Research in the Dry Areas (FLIP 03-71C, FLIP 03-64C, FLIP 98-106C, FLIP 00-40C and FLIP 99-66C) and two checks from Iran (Arman and Azad) were grown as materials. The field was located at 46°16' East longitude and 37°23' North latitude, at an altitude of 1485 metres from sea level; based on Koppen's classification, this region has a semi-arid and cold temperate climate with an annual precipitation of 375 mm, consisting of 73% rain and 27% snow. The soil type was a clay loam, pH of 6.85 and EC = 0.84 ds/m. Monthly meteorological data for the duration of the experiments are presented in Table 1. The experimental fields were ploughed once in early fall and harrowed twice to bring the soil to fine tilth one week before planting. The recommended dose of fertiliser (30 kg N and 75 kg P_2O_5/ha) was applied in the form of urea and triple superphosphate at the time of seed bed preparation. The experimental design was factorial on the bases of randomised complete block in three replicates. Factors were seven chickpea cultivars and three irrigation regimes including zero irrigation (rain-fed condition that received natural rainfall only), full irrigation (receiving natural rainfall plus enough irrigation to fill the root zone profile) and two supplemental irrigations (SI) during flowering and grain filling stages. The amount of irrigation water was calculated to restore water content in the root zone to field capacity. Depth of net irrigation water fraction was ~110 mm. Seeds were hand-sown on 17 March 2013 in 4 cm depth of soil. Treatment plot size was 4×3 m or 12 m^2 (with a harvested area 4 m^2). In each plot, seeds were sown into 16 rows, at 25 cm row-to-row spacing and 8 cm plant-to-plant spacing. Weeding was done manually. During the irrigations, plots were irrigated up to 70% of field capacity. All necessary cultural practices and plant protection measures were followed uniformly for all the plots during the entire period of experimentation. Planting days from sowing to 50% seedling emergence (DSE), days to initial flowering, days to maturity and reproductive period were determined as growth traits. Chlorophyll content was measured on ten leaves of five plants at each plot, using a portable chlorophyll meter (SPAD-502, Minolta, Japan) at full bloom stage (R2). Grain filling rate (GFR) was measured as methods described by Khamssi *et al*. (2011). At early flowering, 30 plants from the each genotype were marked. The day of tagging was referred to as 0 day and subsequent days as days after flowering (DAF). Then, five marked pods per plot were hand harvested five times at 6-day intervals and brought back to the laboratory. The pods were threshed and grains detached from the pods. Grains dry weight was determined after oven drying to constant weight at 75 ± 1°C. A linear regression model (two parts) was used in order to estimate and analyse grain filling parameters:

$$W = \{a + bt \; t < tm; \; a + btm \; t \geq tm\}$$

where W is grain weight, *a* the intercept, *b* the GFR, *t* the DAF and *tm* the end of grain filling period (mass maturity time). At maturity, when seed moisture content was 16–18%, the plants were cut off at ground level and dry weight of aboveground biomass was determined by oven drying for 5–7 days at 50°C.

Data were recorded on random sample of 10 plants from each plot for plant height [cm], canopy spread [cm], length of pod bearing branch [cm], primary branches and secondary branches per plant, pods per plant, seeds per pod, 100 seed weight [g], biological yield [kg/ha] and seed yield per plant [kg/ha]. Harvest Index was determined as the ratio of grain yield to biological yield. Some drought tolerance indices like as Stress Tolerance Index (STI; Fernández 1992), Stress Susceptibility Index (SSI; Fischer & Maurer 1978), Mean Productivity (MP; Rosielle & Hamblin 1981), Geometric Mean Productivity (GMP; Fernández 1992), Yield Stability Index (YSI; Bouslama & Schapaugh 1984), Yield Index (YI; Lin *et al*. 1986) and Stress Tolerance (TOL; Rosielle & Hamblin 1981) were used to identify high yielding and drought tolerant genotypes. The data were subjected to analysis of variance using MSTATC statistical package. Differences were compared by least significant difference test at alpha 0.05.

RESULTS AND DISCUSSION

For DSE, there was a significant difference between both irrigation regimes and genotypes. Comparison of the DSE between irrigation regimes revealed that a small amount of irrigation (30 mm) immediately after sowing increased emergence rate up to 70%. The highest rate of seedling emergence was recorded in lines FLIP 03-71C, FLIP 03-64C and FLIP 98-106C (Table 2). In rain-fed Mediterranean areas, a high rate of seedling emergence in spring crops, which leads to prompt plant establishment and early maturity to escape terminal heat and drought, tends to produce larger grain yields (Yau *et al*. 2011). In highland semi-arid zones, irrigation immediately after sowing can ensure early germination and greater use of spring rains improves crop yield (Tavakkoli & Oweis 2004).

The effects of irrigation regimes and genotype on plants height were significant (Table 2). Full and supplemental irrigation (SI) caused the highest plant height and plant grown under rain-fed condition had the lowest height (Table 2). A similar trend was observed for canopy spread. The results are consistent with those of Shamsi *et al*. (2010) who found SI could significantly increase chickpea plant height. Comparison of plant height between genotypes showed that the highest height was related to cv. Azad and line FLIP 98-106C. There was no significant difference between Arman and lines FLIP 00-40C and FLIP 99-66C. The shortest height was observed in line FLIP 03-71C. Hawtin and Singh (1984) suggested that variation in plants height depends on variety, latitude and date of planting. The significant main effect of irrigation regimes and significant irrigation × genotype interaction were obtained for number of primary branches (Table 2). SI could considerably increase (32%) the number of primary branches in comparison with rain-fed condition. The highest number of primary branches was recorded in FLIP 99-66C, Arman and FLIP 98-106C under full irrigated condition (Table 2). However, the effect of water supply during critical growth stages on number of secondary branches was more prominent than primary branches, so that SI increased the number of secondary about 128% over the rain-fed condition. The highest number of secondary branches was observed in FLIP 98-106C. This result is in agreement with the findings of Leport *et al*. (2006) who that showed in all early, mid and late stress treatments of secondary branches

T a b l e 1

Weather data for the chickpea grown seasons in 2013 at Maragheh station

Month	Mean air temperature [°C]	Total precipitation [mm]	Relative humidity [%]	Total evaporation [mm]
March	7.4	34.4	76	13
April	12.5	21.8	70	35
May	15.1	20.6	71	72
Jun	21.9	2.9	54	269
July	26.7	0	44	316

T a b l e 2

Effect of irrigation regimes on some morphophysiological traits of chickpea genotypes

Factor	DSE	PH	CS	NPB	NSB	CHL	DSF	DTM
Irrigation (IR)								
Zero	24.72^{a}	24.28^{b}	13.81^{b}	2.93^{c}	6.51^{b}	40.24^{b}	58.48^{b}	100.26^{c}
Supplement Irrigation	24.41^{a}	32.17^{a}	27.67^{a}	3.87^{b}	14.85^{a}	47.75^{ab}	63.13^{b}	124.05^{b}
Full	14.93^{b}	34.03^{a}	33.74^{a}	6.13^{a}	18.47^{a}	55.31^{a}	85.56^{a}	135.03^{a}
Genotype (G)								
FLIP 03-71C	24.52^{a}	24.63^{c}	24.98^{a}	3.88^{a}	12.19^{ab}	48.31^{ab}	63.08^{d}	111.27^{c}
FLIP 03-64C	22.41^{ab}	28.79^{bc}	24.19^{a}	3.96^{a}	10.66^{b}	46.22^{b}	65.51^{cd}	113.28^{c}
FLIP 98-106C	22.47^{ab}	34.65^{a}	27.16^{a}	5.21^{a}	17.28^{a}	50.48^{ab}	71.20^{bc}	118.66^{bc}
FLIP 00-40C	20.40^{bc}	30.53^{ab}	23.47^{a}	3.31^{a}	10.32^{b}	47.24^{ab}	73.84^{b}	119.90^{abc}
FLIP 99-66C	18.51^{c}	32.57^{ab}	25.25^{a}	4.74^{a}	12.84^{ab}	47.20^{ab}	69.32^{bcd}	117.10^{bc}
Arman	19.97^{bc}	32.14^{ab}	26.01^{a}	4.68^{a}	13.41^{ab}	45.82^{b}	83.31^{a}	127.89^{ab}
Azad	21.19^{b}	34.80^{a}	25.33^{a}	4.45^{a}	10.67^{b}	51.43^{a}	87.51^{a}	130.35^{a}
IR	++	++	++	++	++	++	++	++
G	++	+	NS	NS	++	+	++	++
IR × G	NS	NS	NS	+	NS	NS	NS	++

DSE – days from sowing to 50% seedling emergence, PH – plant height [cm], CS – canopy spread [cm], NPB – number of primary branches, NSB – number of secondary branches, CHL – chlorophyll content, DSF – days from sowing to flowering, DTM – days to maturity, IR – irrigation regimes and G – genotypes
Mean values of the same category followed by different letters are significant at $P \leq 0.05$ level; $^{++}$ significant on 0.01 level; $^{+}$ significant on 0.05 level; ^{NS} non-significant

were more affected than primary ones. The indirect consequences of water deficit include its adverse effects on plant phenology, phasic development, growth, carbon assimilation, assimilate partitioning and plant reproduction processes. Phytohormones function to coordinate plant growth and development and play critical roles in developmental process. For instance, indole-3-acetic acid (auxin) and gibberellins have been shown to play essential roles in the regulation of internodes elongation (Yang *et al*. 1996). It seems that water stress may affect plant growth characteristics through changes in levels of plant hormones. Hamayun *et al*. (2010) reported that the level of endogenous growth hormones in soybean plant was affected by drought stress, as the contents of plant growth promoting hormone (gibberellin) declined, while those of jasmonic acid and abscisic acid increased under drought.

Effects of irrigation regimes and genotype were significant on chlorophyll content. Result showed that under rain-fed condition terminal drought stress imposed and resulted in significant decrease in chlorophyll content by 37% over to full irrigation (Table 2). At full bloom stage, variety Azad showed higher chlorophyll content than the other varieties. The interactions between genotype and irrigation regimes were not significant. The results are in agreement with Mafakheri *et al*. (2010) who described a significant decrease of chlorophyll content caused by water deficit in three Kabuli chickpea cultivars. A decrease of total chlorophyll with drought stress implies a lowered capacity for light harvesting. Since the production of reactive oxygen species is mainly driven by excess energy absorption in the photosynthetic apparatus, this might be avoided by degrading the absorbing pigments (Herbinger *et al*. 2002).

Results showed that the number of days from sowing to flowering (DSF) was significantly affected by irrigation regimes and cultivar (Table 2). The range in DSF was 49–74 under rain-fed condition and 72–90 under full irrigated. It was clear that moisture supply during the growing period had a strong influence on phenology, with high temperatures and the amount of water in the soil during

T a b l e 3

Effect of irrigation regimes on yield, yield components and GFR of chickpea genotypes

Irrigation	PN	SN	100-GW	GY	BY	HI	GFR
Irrigation (IR)							
Zero	11.57^{b}	0.990^{b}	30.78^{b}	922^{c}	4,391^{b}	42.03^{b}	9.61^{b}
Supplement Irrigation	20.11^{a}	1.190^{b}	34.68^{a}	1,963^{ab}	7,697^{a}	45.25^{ab}	11.07^{a}
Full	23.44^{a}	1.010^{ab}	34.22^{a}	2,221^{a}	10,144^{a}	46.95^{a}	11.19^{a}
Genotype (G)							
FLIP 03-71C	14.86^{c}	1.098^{ab}	34.15^{a}	1,384^{d}	5,660^{b}	47.20^{a}	10.61^{ab}
FLIP 03-64C	16.88^{bc}	1.053^{b}	35.88^{a}	1,635^{bc}	6,506^{b}	49.03^{a}	9.84^{b}
FLIP 98-106C	20.39^{a}	1.104^{ab}	33.27^{ab}	1,867^{a}	10,733^{a}	37.04^{c}	11.03^{a}
FLIP 00-40C	16.67^{bc}	1.091^{ab}	34.70^{a}	1,585^{cd}	6,153^{b}	50.51^{a}	9.92^{b}
FLIP 99-66C	21.05^{a}	1.097^{ab}	29.16^{c}	1,727^{abc}	8,135^{ab}	42.96^{ab}	10.68^{ab}
Arman	20.61^{a}	1.132^{a}	31.05^{bc}	1,881^{a}	9,027^{ab}	43.09^{ab}	10.98^{a}
Azad	18.35^{b}	1.100^{ab}	35.42^{a}	1,817^{ab}	8,695^{ab}	43.32^{ab}	11.37^{a}
IR	++	++	++	++	++	++	++
G	+	+	++	++	++	++	+
IR × G	NS	+	NS	NS	NS	+	NS

PN – pod number, SN – seed number, 100-GW – 100-grain weight [g], GY– grain yield [kg/ha], BY – biological yield [kg/ha], HI – harvest index [%], GFR – grain filling rate [mg/day], IR – irrigation regimes and G – genotypes
Mean values of the same category followed by different letters are significant at $P \leq 0.05$ level

T a b l e 4

Mean comparison of drought tolerance indices among chickpea genotypes

Genotype	SSI	MP	TOL	STI	GMP	YI	YSI
FLIP 03-71C	0.833[c]	1,419.17[b]	952.64[c]	0.391[b]	1,331.00[ab]	1.022[ab]	0.513[a]
FLIP 03-64C	1.135[ab]	1,605.07[ab]	1,595.35[ab]	0.398[b]	1,392.40[ab]	0.875[bc]	0.337[bc]
FLIP 98-106C	0.894[bc]	1,795.28[a]	1,314.39[abc]	0.561[a]	1,662.28[a]	1.233[a]	0.472[ab]
FLIP 00-40C	0.891[bc]	1,395.90[b]	1,063.00[bc]	0.342[b]	1,278.14[b]	0.936[b]	0.479[ab]
FLIP 99-66C	1.010[abc]	1,470.44[ab]	1,257.60[abc]	0.360[b]	1,325.96[ab]	0.912[b]	0.412[abc]
Arman	1.151[a]	1,705.04[ab]	1,716.00[a]	0.452[ab]	1,472.32[ab]	0.918[b]	0.320[c]
Azad	0.904[abc]	1,613.54[ab]	1,190.00[abc]	0.469[ab]	1,498.19[ab]	1.104[b]	0.472[abc]

SSI– stress susceptibility index, MP– mean productivity, TOL – stress tolerance, STI – stress tolerance index, GMP– geometric mean productivity, YI– yield index, YSI– yield stability index
Mean values of the same category followed by different letters are significant at $P \leq 0.05$ level

the last months of spring time to flowering greatly reduced. Similarly, time to maturity was extended by high moisture supply and reduced by drought. Irrigation extended reproductive growth. Lines from ICARDA flowered first, followed by Iranian check cultivars (Arman and Azad).

The yield response of chickpea genotypes to irrigation regimes is given in Table 3. The effects of irrigation and genotype on number of pods, seed number per pod, 100-grain weight, grain yield, biological yield and harvest index were significant, while interaction of irrigation × genotypes was only significant for seed number per pod and harvest index. All yield components significantly decreased by terminal drought stress (rain-fed condition). SI could increase the number of pods per plant by 73% over the rain-fed condition. However, there was no difference between full irrigation and SI conditions. A similar status was observed for 100-grain weight, grain yield and biological yield. Although Arman and FLIP 98-106C had the highest number of pod and number of seeds per pod, these had the lowest 100-grain weight (Table 3). The highest number of seeds per pod was obtained by full irrigation. Water application at flowering and pod filling stage increased the number of seeds per pod by 21% over rain-fed condition. Biological yield of FLIP 98-106C and Arman was significantly higher than those of the other cultivars. However, the lowest harvest index was recorded for FLIP 98-106C. The supplementary irrigation positively influenced grain yield in all seven genotypes and showed an increase from 76 to 153%. These results confirm those obtained in Mediterranean environments (Shamsi *et al*. 2010; Oweis & Hachum 2012).

Investigation of the GFR showed that SI could increase GFR by 15%, compared with the plants grown under the rain-fed condition. The highest GFR was recorded in FLIP 98-106C, Arman and Azad. The rate of grain filling is linear for a relatively long period of time from around pod forming to near physiological maturity. Providing good management during the period can help to provide a high GFR and, in some cases, may extend the grain filling period a few days thereby increasing yields. Availability of water for crop growth is the largest single controllable factor during this period. Sadeghipour (2008) reported that environmental stresses such as water shortages, especially during grain filling, cause reductions in photosynthesis and remobilisation of stored materials, rate and duration of grain filling and grain weight. Water stress generally accelerates leaf senescence and shortens grain filling duration as shown for chickpea (Chowdhury *et al*. 2002).

Previous field studies have shown that in a Mediterranean-type environment, water deficits develop near the onset of podding (Turner 2003), induce faster and shorter seed filling (Mafakheri *et al*. 2010), reduce pod and seed number, and reduce seed yield and seed size (Leport *et al*. 2006; Khamssi *et al*. 2011). The performance of spring-sown chickpea depends on the amount of moisture stored in the soil profile and the capacity of the root system to extract it. The cultivars with deep root systems can extract water at the greatest depths both under drought and irrigated conditions (Turner 2003; Oweis & Hachum 2012).

Stress intensity calculation based on equation (*SI*) = 1 − (yield under rain-fed condition/yield under full irrigated environment) suggested that plants grown under rain-fed condition experienced a drought stress intensity with 0.58. Mean comparisons of drought resistance indices are shown in Table 4. On the basis of seed yield under rain-fed condition (Y_s), line FLIP 98-106C gave a higher yield than the best check; Arman and FLIP 99-66C showed the lowest. However, Arman and FLIP 98-106C gave the highest yields and FLIP 03-71C the lowest in full irrigated environment (Y_p). The highest mean productivity (MP), mean productivity (MP), STI and GMP were recorded for line FLIP 98-106C. The highest value of tolerance index (TOL) and STI was observed for cv. Arman, which resulted from high Y_p. Conversely, the lowest values were recorded in line FLIP 03-71C. However, line FLIP 03-71C showed the highest value of YSI and the lowest value was related to Arman. YSI evaluates the yield under stress of a genotype relative to its non-stress yield, and should be an indicator for drought tolerant genetic materials. Therefore, the genotypes with high YSI are expected to have few yield losses under stress environments. The highest value of YI was observed for line FLIP 98-106C. YI ranks genotypes only on basis of their yield under stress. In general, FLIP 98-106C and Arman could be introduced as suitable genotypes for semi-arid conditions.

CONCLUSIONS

Nowadays, irrigation is the largest single consumer on the planet. In semi-arid areas, competition for water from other sectors will force irrigation to operate under the condition of water scarcity. Chickpea production under rain-fed conditions is low and subject to substantial year-to-year fluctuation due to erratic rainfall and its poor distribution. In the region, it seems that chickpea grain yield and water productivity can be greatly increased by supplemental irrigation, which is applied at flowering and/or grain filling stage to reduce the water shortage stress. The major traits of adaptation for spring season legumes in low rainfall Mediterranean-type environments are early flowering and seed set before the onset of terminal drought. In addition, limited supplemental irrigation in the most susceptible periods will secure yield. The present study revealed that yield of chickpea could be substantially enhanced and stabilised with minimal irrigation, together with higher yield potential. The most impressive implication from this study is the saving in irrigation water with little loss in yield. However, where irrigation water is available, early germination and emergence can be ensured by applying a small irrigation immediately after sowing. Among the investigated genotypes, FLIP 98-106C and Arman showed the best performance under SI conditions.

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