RESEARCH ARTICLE

Exploring genetic variation based on drought-induced phenotypic alterations during reproductive stages in Desi and Kabuli types of chickpea

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Global warming and enhanced drought are predicted in the future; hence, identification of appropriate varieties adapted to the assumed changes is imperative. This study investigated the effects of water scarcity in reproductive stages as well as distinct responses to drought stress across sixty elite genotypes of Desi and Kabuli types of chickpeas. The estimated genotypic effects were detected significant at both limited and full irrigation conditions for GY, GN, GW, and SDM; however, these genotypic effects had smaller values than environmental effects except in GW. The SDM and GW in water-limited conditions showed a significant positive relationship with those of full irrigated at both chickpea types. GMP index provided the most positive correlations with GY for both Kabuli and Desi types either under limited or full-irrigated conditions. The biggest direct effect on GY was represented by SDM for Kabuli at both conditions as well as Desi chickpeas in limited water conditions, while GN was the most ones in full-irrigated Desi chickpeas. The ideal genotypes, 25 and 321, as Kabuli and Desi chickpeas, respectively, were detected with high stable and high GY. The present study facilitates the understanding of the genetic basis of phenotypic responses of Kabuli and Desi chickpeas, also helps to accelerate chickpea breeding for more adaptation to the terminal drought stress.

Key Words: *Cicer arietinum*; Path analysis; Genotypic effects; Yield stability

INTRODUCTION

Chickpea is a self-pollinated diploid plant and its cultivated species (*Cicer arietinum* L.) has been divided into two major distinct types. Chickpeas with black or brown grain coat and purple-colored flowers are categorized in Desi type and with cream or beige grain coats and white flowers are named Kabuli. Desi type has a smaller grain size as well as thicker grain coat compared to Kabuli type. Despite vast morphological differences, each type possesses unique characteristics, which can be introgressed from one type to another. For instance, the resistance to Fusarium wilt, more frequent in Desi, has been transferred to Kabuli type and the resistance to Ascochyta blight from Kabuli to Desi [1].

As a cool-season grain legume, chickpea is mostly cultivated in semi-arid regions and its flowering, as well as grain-filling stages, are typically faced with the lack of rainfall. These regions are classified into two major forms, stored soil moisture in subtropics with summer-dominant rainfall and rainfall in winter-dominant Mediterranean-type environments in which chickpea yield losses often occur because of terminal drought in rain-fed farming systems. Iran, among the major chickpea producer countries, has mainly been composed of arid and semi-arid lands in which shortage of rainfall owing to the Mediterranean precipitation pattern imposes water scarcity on chickpea farms at the end of spring.

The average global temperature has risen by 1.2°C over the past century and can rise up to 3°C by 2100 because of global warming [2]. Hence, an increase in the frequency and intensity of drought, accompanied by the higher temperatures and CO_2 concentrations out of the climate change is predictable in semi-arid regions. These alterations reduce water availability for crop roots that result in yield losses, threatening food security. Therefore, multiple improvement strategies are necessary for sustainable crop production, especially because over 50% of the major crop production could be reduced under drought stress conditions [3].

The development of short duration chickpea cultivars may be an applicable strategy for short-duration terminal drought environments. This strategy of breeding for drought escape has successfully provided yield stability in chickpea plants. However, the early maturing chickpeas have to pay a yield penalty because of the confined total photosynthetic period. Hence, an alternative breeding strategy may prefer exploiting the whole growth duration through the identification and utilization of traits that are known to confer drought tolerance. Nevertheless, drought tolerance is a general term for a complex phenomenon of plant responses. In a practical sense, it is the relative ability of the plant to sustain the maximum possible economic yield under increasing water scarcity during the growing season, rather than the physiological aptitude of the plant for survival. Notably, research has shown the traits conferring of drought tolerance could be different not only for various drought patterns but also across genotypes evaluated under the same conditions. These contradictory observations propose that the prerequisite to achieving drought tolerance is not only distinct breeding programs for each of Kabuli and Desi chickpea types but also research is required to account for terminal drought as well as environmental effects on each genotype. However, to screen terminal drought-tolerant chickpeas, Crop Growth Rate (CGR) and Partitioning (P) rate are among emphatic traits out of common examined agronomic traits *i.e.*, grain yield and its components, shoot biomass, and harvest index, which can simply be evaluated in the large population field studies.

A deep understanding of the contribution of multiple plant traits on the growth and development, biomass partitioning and ultimately yield under water-limited conditions could lead to an efficient user of selection criteria to achieve more drought-tolerant cultivars. Selection for drought tolerance has been a complicated procedure because of genotype by environment interactions, causing limited knowledge about the role of tolerance mechanisms to maintain yield under drought stress conditions. Drought can cause yield losses if plants do not get enough water during reproductive stages particularly in grain filling, which is a common scenario in regions with Mediterranean precipitation patterns that chickpea farms face. However, to achieve a procedure that can detect the major plant traits to screen more-adapted genotypes to terminal drought, while could be obtained in a short time and be cost-effective is of major challenges in plant breeding. Nevertheless, responses to water scarcity could explain genotypic

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variation across Desi and Kabuli chickpeas for the terminal drought tolerance. To investigate this hypothesis, a comparative study was performed based on different responses of Desi and Kabuli chickpeas under terminal drought conditions as well as full-irrigated conditions. This study aimed to explore the genetic variation among a diverse panel of chickpea genotypes and to evaluate how the associations between the agronomic traits of the plant under the two irrigation conditions.

MATERIALS AND METHODS

Field location and experimental materials

The field experiment was conducted in the research field of the Department of Agronomy and Plant Breeding, University of Tehran, Karaj-Iran (35°56'N, 50°58'E, 1112.5 m.a.s.l.). Plant materials consisted of 30 Desi and 30 Kabuli chickpea genotypes from the departmental gene bank [4].

Experimental design and data collection

The experiment was laid out in a randomized complete block Design with two replications. Each plot included 1-meter single row by 50 cm distances and 10 cm plant-to-plant spacing. The irrigation was stopped about 50% of the flowering of chickpeas in the water-limited conditions, while continued until plant maturity according to a common irrigation regime of the region in the full-irrigated conditions. The measured phenological traits included days to 50% of flowering (TF), days to 50% of podding (TP), days from flowering to maturity (TFM), and days to maturity (TM). Eight number of plants, excluding border plants, were harvested after the maturity. These harvested plants left out for shade drying in the separate flour bags before the measurement of Shoot Dry Matter (SDM), Grain Yield (GY), 100-Grain Weight (GW), and the Number of Grains (NG) at both irrigation conditions. The SDM was adjusted for an estimated 21% loss of dry matter because of leaf fall and Harvest Index (HI) was calculated according to Equation (1).

HI=(grain yield/shoot dry matter) (1)

Growth estimation

The adjusted SDM was used for the estimation of Crop Growth Rate (CGR) according to Equation (2),

CGR=Shoot dry matter/growth period (day) (2)

And the Partition (P) coefficient was calculated to estimate the assimilate remobilization rate (sink activity) proposed by Krishnamurthy, et al. according to Equation (3).

P=(grain yield/reproductive period in °C day)/CGR (3)

Where the reproductive period=°C day to maturity of the plant–°C day to 50% flowering of the plant.

Statistical model and data analysis

A visualized analysis of genotype main effect and genotype-by-environment interaction effects (GGE) was performed using the GenStat program to evaluate the yield stability of the tested chickpea genotypes in interaction by the environment according to Yan, et al. method [5]. Path analysis was conducted to examine the strength of the contribution of the measured traits on the grain yield. This purpose was followed using SmartPLS software (version 3.0, SmartPLS GmbH, Boenningstedt, Germany) with Partial Least Square Structural Equation Modeling (PLS-SEM) method developed by Wold [6]. To estimate variance components, Minimum Norm Quadratic Unbiased Estimation (MINQUE) as a linear mixed model approach was deployed in the R software environment. In addition, as deviations from the population mean, genotypic effects in the limited water conditions and full-irrigated conditions as well as in a combined (pooled) analysis were predicted separately by adjusted unbiased prediction method [7]. The significance test of interesting parameters (variance components and genetic effects) was done according to a randomized 10-group jackknife method to estimate standard errors. An R package named minque performed an estimation of variance components and prediction of genotypic effects according to Wu method [8]. These estimations were calculated using a linear mixed model for environmental, chickpea type, genotype, and the interaction of genotype-by-environment effects followed by Equation (4):

$$y_{ijk}=\mu+E_i+G_j+T_k+GE_{ij}+B_{l(i)}+e_{ijk} \quad (4)$$

Where:

y_{ijk} is an observation

μ is a population mean

E_i is an environmental effect

T_k is a type of chickpea effect

G_j is a genotypic effect

GE_{ij} is a genotype-by-environment interaction effect

$B_{l(i)}$ is a block effect within an environment

e_{ijk} is a random error

In addition, each of the irrigation conditions was analyzed separately in a completely randomized block Design with the linear mixed model followed by Equation (5):

$$y_{ij}=\mu+B_i+G_j+e_{ij} \quad (5)$$

Where:

y_{ijk} is an observation

μ is a population mean

B_i is a block effect

G_j is a genotypic effect

e_{ij} is a random error

The degree of Stress Intensity (SI) applied on plants under water-limited conditions achieved according to Equation (6).

$$SI = (1 - (\bar{Y}_s/\bar{Y}_p)) \quad (6)$$

where $\bar{Y}_S$ is the mean grain yield under water-limited treatment and $\bar{Y}_P$ is the mean grain yield under full-irrigated treatment.

RESULTS

Variance components

The estimated genotypic effect variances as the proportions of the phenotypic variances were detected significant for GY, NG, GW, SDM, TF, and TP in Kabuli chickpea genotypes under both irrigation conditions (Tables 1 and 2). Likewise, there were significant effects of genotypic variances for NG, GW, SDM, and GY in Desi chickpea genotypes grown under both irrigation conditions. In the combined model analysis, the estimated environmental variance had the largest values for GY, NG, and SDM with significant effects. The estimated variances of chickpea type were significant for GY, GW, SDM, and TF. The estimated genotypic variances were significant for NG, GW, SDM, TF, and GY. Furthermore, the genotype-by-environment interaction effects were estimated significant for NG, SDM, GY, and GW (Table 3).

TABLE 1

Estimated variance components expressed as proportions to the phenotypic variances for grain yield, number of grains, 100-grain weight and shoot dry matter of chickpeas grown in water-limited conditions

	Type	GY	NG	GW	SDM	TF	TP	TFM	TM	HI
V_B/V_P	Kabuli	0.061	0	0	0.044	0.007	0.02	0.008	0.062	0
	Desi	0.338***	0.126*	0.031	0.163**	0.016	0.11	0	0.005	0.236**
V_G/V_P	Kabuli	0.433***	0.888***	0.889***	0.676***	0.506***	0.693***	0.286	0.111	0.021
	Desi	0.191**	0.644***	0.838***	0.558***	0.142	0.09	0.024	0.045	0.055
V_e/V_P	Kabuli	0.505***	0.111**	0.110*	0.278***	0.487***	0.285***	0.705**	0.826***	0.978***
	Desi	0.470***	0.228***	0.130**	0.278**	0.841	0.799***	0.975***	0.948***	0.708***

*,**and *** significant at 5, 1 and 0.1% probability level, respectively; without staric=non-significant.

TABLE 2

Estimated variance components expressed as proportions to the phenotypic variances for grain yield, number of grains, 100-grain weight and shoot dry matter of chickpeas grown in full-irrigated conditions

	Type	GY	NG	GW	SDM	TF	TP	TFM	TM	HI
V_B/V_P	Kabuli	0.141	0.013	0.041	0.014	0	0	0.227**	0.221*	0.344***
	Desi	0.042	0.001	0.001	0.012	0.306***	0.204**	0	0.212**	0.037
V_G/V_P	Kabuli	0.390**	0.918***	0.793***	0.809***	0.582***	0.481***	0.127	0.12	0.027
	Desi	0.397***	0.951***	0.916***	0.610***	0.05	0.048	0.001	0.042	0.264
V_e/V_P	Kabuli	0.467**	0.068**	0.169***	0.176***	0.417***	0.518***	0.594***	0.657***	0.628***
	Desi	0.559***	0.047*	0.081*	0.376***	0.643***	0.747***	0.998***	0.744***	0.697***

*,**and *** significant at 5, 1 and 0.1% probability level, respectively; without staric=non-significant.

TABLE 3

Estimated variance components expressed as proportions to the phenotypic variances for grain yield, number of grains, 100-grain weight and shoot dry matter of chickpeas in combined model analysis

	GY	NG	GW	SDM	TF	TP	TFM	TM	HI
V_E/V_P	0.348***	0.579***	0	0.374***	0.144***	0.127***	0.157	0.370***	0.001
V_T/V_P	0.103***	0	0.486***	0.187***	0.119***	0.008	0	0.029	0.025
V_G/V_P	0.062**	0.104***	0.394***	0.138***	0.121***	0.130**	0.005	0.001	0.025
V_{GE}/V_P	0.154**	0.267***	0.046**	0.178***	0.019	0.0^{16}	0.037	0.048	0.07
V_{EB}/V_P	0.060*	0.006*	0.003	0.014**	0.063*	0.055*	0.001	0.002	0.133***
V_e/V_P	0.270***	0.042***	0.069***	0.107***	0.530***	0.661***	0.797***	0.547***	0.747***

*,** and *** significant at 5, 1 and 0.1 % probability level, respectively; without staric=non-significant.

Predicted genotypic effects

The Kabuli genotype 21 presented significant desirable positive predicted genotypic effects for GY, NG, GW, and SDM under both irrigation conditions as well as for the combined analysis. In the case of Desi chickpeas, genotype 321 showed the same predicted genotypic effects except for GW (Tables 4-6). Among all the 60 chickpea genotypes, two Desi genotypes (276 and 407) showed significant positive predicted genotypic effects for HI only in full-irrigated conditions. There was no significant predicted genotypic effect for TM across all the tested chickpeas. Moreover, two Kabuli genotypes (15 and 21) and seven Desi genotypes (10, 47, 51, 90, 151, 321, and 122) showed significant positive predicted genotypic effects for GY under water-limited conditions. Six Kabuli genotypes (21, 226, 302, 308, 339, and Jam) and four Desi genotypes (48, 276, 321, and 322) showed significant positive predicted genotypic effects for GY in full-irrigated conditions. In the combined analysis, seven Kabuli genotypes (21, 25, 101, 205, 302, 308, and Jam) and four Desi genotypes (10, 276, 321, and 322) presented significant positive predicted genotypic effects for GY. Eight Kabuli genotypes (15, 21, 25, 211, 240, 263, 302, and 308) along with seven Desi genotypes (10, 46, 47, 51, 90, 122, and 321) presented significant positive predicted genotypic effects for NG under water-limited conditions. Ten Kabuli genotypes (21, 101, 302, 226, 308, 311, 315, 327, 339, and Jam) along with nine Desi genotypes (46, 47, 48, 49, 50, 90, 151, 321, and 322) presented significant positive predicted genotypic effects for NG in full-irrigated conditions. In addition, eight Kabuli genotypes (21, 25, 101, 302, 308, 311, 316, and 339) and eleven Desi genotypes (46, 47, 48, 49, 50, 90, 122, 151, 276, 321, and 322) showed significant positive predicted genotypic effects for NG in the combined analysis, as well. In the case of GW, ten Kabuli genotypes (21, 25, 92, 166, 192, 205, 226, 376, Koorosh, and Jam) and seven Desi genotypes (5, 8, 9, 10, 231, 322, and Pyrooz) presented significant positive predicted genotypic effects under water-limited conditions. In full-irrigated conditions, however, thirteen Kabuli genotypes (15, 21, 101, 166, 192, 205, 226, 227, 308, 371, 376, Koorosh, and Pyrooz) and nine Desi genotypes (5, 8, 9, 10, 21, 231, 276, 333, and 407) showed significant positive predicted genotypic effects for GW. In the combined analysis, fifteen Kabuli genotypes (15, 21, 25, 92, 101, 166, 192, 205, 226, 227, 308, 371, 376, Koorosh, and Jam) and ten Desi genotypes (5, 8, 9, 10, 231, 316, 322, 333, 407, and Pyrooz) presented significant positive predicted genotypic effects for GW. Eight Kabuli genotypes (15, 21, 25, 92, 101, 166, 263, and 308) and five Desi genotypes (5, 10, 150, 321, and 322) presented significant positive predicted genotypic effects for SDM under water-limited conditions. Seven Kabuli genotypes (21, 25, 92, 101, 226, 308, and 339) and seven Desi genotypes (5, 8, 9, 10, 321, 322, and 347) presented significant positive predicted genotypic effects for SDM in full-irrigated conditions. Nine Kabuli genotypes (15, 21, 25, 92, 101, 166, 308, 339, and Jam) and six Desi genotypes (5, 9, 10, 321, 322, and 347) showed significant positive predicted genotypic effects for SDM in the combined analysis. Furthermore, three Kabuli genotypes (160, 166, and Koorosh) showed Desirable significant negative predicted genotypic effects for TF and positive predicted genotypic effects for TFM under water-limited conditions.

TABLE 4

Phenotypic Mean (PM) values and predicted Genotypic Effects (GE) of Desi and Kabuli genotypes for Grain Yield (GY), number of grains (NG), 100-Grain Weight (GW), Shoot Dry Matter (SDM), Time to Flowering (TF), Time to Podding (TP), Time from Flowering to Maturity (TFM), Time to Maturity (TM), and Harvest Index (HI) evaluated under water-limited treatment

Type	Genotype	GY (gr plant^{-1})		NG (plant^{-1})		GW (gr)		SDM (gr plant^{-1})		TF (day)		TP (day)		TFM (day)		TM (day)		HI (%)	
		PM	GE	PM	GE	PM	GE	PM	GE	PM	GE	PM	GE	PM	GE	PM	GE	PM	GE
Kabuli	15	10.01	3.32^{**}	50.35	22.10^{***}	19.69	-0.96^{**}	29.19	10.70^{**}	75.5	4.50^{***}	79	3.97^{***}	28.5	-2.09	104	0.73	34.59	0.03
Kabuli	21	11.32	4.37^{***}	49.05	20.84^{***}	22.96	2.21^{**}	31.3	12.62^{**}	69.5	-0.31	74.5	-0.05	33	0.66	102.5	0.21	36.89	0
Kabuli	25	11.66	4.4	43.36	15.35^{***}	26.69	5.76^{***}	30.41	11.81^{***}	69.5	-0.31	74	-0.51^{*}	34	1.29^{*}	103.5	0.61	37.75	-0.03
Kabuli	92	6.6	0.71	25.87	-1.42	25.64	4.79^{**}	22.3	4.55^{*}	67	-2.31^{***}	73	-1.38^{**}	34	1.3	101	-0.3	28.95	-0.26
Kabuli	101	5.82	0.1	28.47	1.04	20.52	-0.14	22.11	4.37^{**}	69.5	-0.31	74.5	-0.05	33.5	0.96	103	0.43	26.74	-0.039
Kabuli	160	3.78	-1.46^{*}	21.33	-5.78^{***}	17.93	-2.64^{**}	9.45	-6.96^{***}	67.5	-1.93^{***}	71.5	-2.75^{***}	35	1.90^{**}	102.5	0.21	40.92	-0.15
Kabuli	166	10.46	3.49	38.05	9.7	27.78	6.83^{***}	28.28	9.89^{***}	68	-1.49^{***}	73.5	-0.94^{***}	35	1.92^{**}	103	0.42	36.51	0.18
Kabuli	176	5.51	-0.12	27.3	-0.04	19.49	-1.14	15.09	-1.85	66	-3.11^{**}	73	-1.39^{***}	32.5	0.34	98.5	-1.25	35.58	0.13
Kabuli	192	5.22	-0.37	18.95	-8.10^{***}	27.68	6.71^{***}	16.26	-0.83^{*}	71.5	1.29^{*}	76.5	1.74^{*}	32.5	0.34	104	0.74	31.57	-0.1
Kabuli	205	4.36	-1.02^{**}	19.25	-7.82^{***}	21.72	1.00^{*}	15.31	-1.70^{**}	69	-0.72	74.5	-0.05	31	-0.59	100	-0.73	28.16	-0.31
Kabuli	211	5.34	-0.27	30.26	2.78^{**}	17.54	-3.01^{***}	17.38	0.11	69.5	-0.31	74	-0.50^{*}	34	1.28	103.5	0.64	30.19	-0.19
Kabuli	226	5.25	-0.35^{*}	21.6	-5.56^{***}	23.53	2.75^{***}	12.87	-3.88^{***}	70.5	0.48	74	-0.50^{*}	33.5	0.96	104	0.76	40.81	0.44
Kabuli	227	5.43	-0.19	25.48	-1.84^{***}	21.37	0.65	14.63	-2.35^{*}	68	-1.51	73.5	-0.94^{***}	32.5	0.33	100.5	-0.51	37.16	0.22
Kabuli	233	3.76	-1.48^{***}	22.54	-4.64^{***}	16.84	-3.69^{***}	14.4	-2.50^{***}	70.5	0.47	73.5	-0.96^{***}	32.5	0.37	103	0.41	26.36	-0.41
Kabuli	240	4.8	-0.68	31.46	3.94^{**}	15.79	-4.73^{***}	14.66	-2.31^{**}	73	2.49^{**}	77	2.19^{***}	28.5	-2.18^{**}	101.5	-0.13	31.52	-0.11
Kabuli	263	6.36	0.51	36.04	8.32^{***}	17.51	-3.05^{***}	23.64	5.75^{*}	72.5	2.07^{**}	77	2.19^{*}	29.5	-1.56^{*}	102	0.12	25.42	-0.47
Kabuli	302	6.36	0.47	31.82	4.29^{*}	19.76	-0.89	16.8	-0.38	71	0.88^{**}	74	-0.48	31	-0.56	102	0.1	36.71	0.19
Kabuli	308	8.02	1.78	38	10.24^{***}	21.12	0.42	27.4	9.09^{**}	70	0.08	73.5	-0.94	33	0.69	103	0.37	28.31	-0.3
Kabuli	311	4.09	-1.24^{***}	26.81	-0.51	15.32	-5.15^{***}	15.29	-1.72	71.5	1.28	73	-1.39^{**}	27	-3.12^{**}	98.5	-1.31	26.8	-0.39

Kabuli	314	3.31	-1.87*	20.61	-6.51**	15.59	-4.88***	8.28	-8.00***	71	0.89	76.5	1.73***	26.5	-3.45**	97.5	-1.59	39.81	0.38
Kabuli	315	3.07	-2.03**	18.58	-8.50***	16.47	-3.82	6.78	-9.39**	73	2.48***	78	3.07**	27.5	-2.85*	100.5	-0.44	54.1	1.77
Kabuli	316	3.2	-1.9**	20.8	-6.34***	15.19	-5.26***	9.34	-7.06***	74	3.29***	78	3.06***	28.5	-2.17*	102.5	0.19	34.29	0.05
Kabuli	327	4.88	-0.62	27.44	0.02	17.44	-3.10**	14.24	-2.71*	70	0.07	74	-0.49	30	-1.21	100	-0.68	34	0.03
Kabuli	333	3.02	-2.06***	23.23	-3.82	13.73	-6.69***	10.21	-6.27***	74	3.28***	80	4.88***	35.5	2.21	109.5	3.23	29.79	-0.21
Kabuli	339	4.11	-1.2	19.57	-7.50**	20.9	0.21	11.86	-4.82**	68	-1.50*	73	-1.37	33.5	0.95*	101.5	-0.13	34.26	0.05
Kabuli	349	4.18	-1.16	22.71	-4.49**	17.89	-2.66**	12.07	-4.61**	74.5	3.49	77	2.20***	28.5	-2.21*	103	0.36	34.25	0.05
Kabuli	371	4.85	-0.65	20.57	-6.52**	24.25	3.24	16.5	-0.63	66.5	-2.71**	72	-2.31***	34	1.21	100.5	-0.48	29.19	-0.24
Kabuli	376	5.88	0.13	23.21	-3.98	24.81	3.93***	16.64	-0.48	64	-4.70***	70.5	-3.64***	31	-0.59	95	-2.69	35.02	0.09
Kabuli	Koorosh	4.9	-0.62*	18.07	-8.94***	27.45	6.49***	15.91	-1.16*	66.5	-2.72*	72.5	-1.74	37.5	3.55*	104	0.84	31.05	0.04
Kabuli	Jam	5.78	0.05	20.87	-6.27***	27.77	6.82***	18.08	0.76	66	-3.11***	71.5	-2.58	35.5	2.23	101.5	-0.15	31.99	-0.08
Desi	5	4.37	-0.03	20.03	-10.45***	21.99	7.05***	16.98	4.29***	70.5	1.54	75.5	0.78	26.5	-0.4	97	0.15	25.41	-2.88
Desi	8	4.55	0.08	15.73	-14.32***	28.18	12.96***	15.05	2.62	66	0.25	73	-0.09	31	0.01	97	0.15	30.48	-1.63
Desi	9	2.83	-1.04	12.71	-17.07***	22.14	7.19***	11.44	-0.52	70	1.38	74.5	0.43	31	0	101	0.64	24.54	-3.28
Desi	10	6.81	1.53**	35.77	3.90***	19.74	4.89***	22.24	8.94***	64	-0.3	73	-0.07	31.5	0.06	95.5	0.02	30.07	-1.55
Desi	21	4.43	0	31.27	-0.19	14.93	0.3	12.28	0.18	64	-0.29	72.5	-0.25	32.5	0.15	96.5	0.09	36.01	-0.13
Desi	46	5.38	0.61	44.48	11.77***	12.08	-2.39***	13.78	1.5	67.5	0.62	74	0.28	44	1.23	111.5	2.21	37.69	0.42
Desi	47	5.84	0.91*	57.38	23.55***	10.12	-4.27***	12.55	0.42	68	0.86	74.5	0.49	30.5	-0.05	98.5	0.33	45.6	2.45
Desi	48	3.54	-0.56	30.5	-0.95	11.95	-2.51***	9.01	-2.67**	65.5	0.08	73	-0.07	34	0.26	99.5	0.45	39.27	0.9
Desi	49	3.53	-0.57	33.39	1.65	10.19	-3.97	10.16	-1.65	69	1.11	73	-0.05	28.5	-0.23	97.5	0.33	34.5	-0.33
Desi	50	4.01	-0.25	40.79	8	10.5	-3.91***	11.19	-0.77	64.5	-0.16	72	-0.39	32.5	0.13	97	0.15	36.2	-0.06
Desi	51	4.82	0.25**	40.08	7.83**	11.29	-3.18***	12.37	0.25	62.5	-0.68	71.5	-0.54	31.5	0.06	94	-0.09	38.84	0.6
Desi	76	3.62	-0.52	31.46	-0.05	11.28	-3.16***	10.72	-1.2	63	-0.58	72	-0.4	31.5	0.03	94.5	-0.14	32.51	-1.08
Desi	90	5.44	0.64**	45.04	12.29***	12.03	-2.46***	12.31	0.21	62.5	-0.73	71	-0.76	32.5	0.22	95	-0.08	44.14	2.06
Desi	122	5.34	0.58*	45.33	12.50**	11.55	-2.90***	13.68	1.40*	64	-0.3	73	-0.08	34.5	0.34	98.5	0.34	38.3	0.44
Desi	150	3.95	-0.29	31.63	0.15	12.32	-2.16***	10.05	-1.75*	64.5	-0.15	73.5	0.1	34	0.29	98.5	0.33	39.3	0.69
Desi	151	4.85	0.27*	31.24	-0.19	15.28	0.64	12.59	0.46	65.5	0.11	74	0.25	30	0.01	95.5	-0.02	38.15	0.45
Desi	231	3.18	-0.75	19.38	-10.99***	16.36	1.67*	9.2	-2.50***	69.5	1.08	76	0.97	14.5	-1.52	84	-2.02	34.49	-0.47
Desi	232	5.38	0.61	35.46	3.6	15.04	0.41	13.63	1.38	68.5	0.8	74.5	0.4	30	-0.07	98.5	0.34	38.09	0.27

Desi	247	3.12	-0.83***	32.52	0.95	9.98	-4.41***	8.44	-3.17***	63.5	-0.51	72	-0.39	30.5	-0.02	94	-0.2	36.92	0.02
Desi	252	4.22	-0.14	28.78	-2.28	14.76	0.13	12.37	0.29	71	1.7	75	0.63	12.5	-1.84	83.5	-1.93	34.69	-0.75
Desi	267	3.67	-0.49**	31.15	-0.24	11.97	-2.54**	8.82	-2.86**	64	-0.28	71.5	-0.58	30	-0.07	94	-0.2	41.54	1.13
Desi	276	4.01	-0.27	31.41	-0.08	12.36	-2.12***	9.51	-2.12	67.5	0.52	75	0.58	27	-0.35	94.5	-0.14	41.22	1.24
Desi	316	4.39	-0.01	27.24	-3.9	16.07	1.39	11.5	-0.5	62.5	-0.69	72	-0.41	30.5	-0.02	93	-0.32	36.77	0.23
Desi	321	9.09	3.01*	54.39	20.90***	16.39	1.74	21.87	8.60***	63	-0.58	71.5	-0.61	30	-0.11	93	-0.28	40.57	0.97
Desi	322	5.89	0.94	34.21	2.44	17.15	2.44*	13.7	1.44***	63.5	-0.44	74	0.29	31	0.01	94.5	0.02	41.93	1.1
Desi	333	2.88	-0.98	19.09	-11.25**	15.13	0.52	8.28	-3.14	66.5	0.36	73.5	0.1	30.5	-0.09	97	0.11	35.43	-0.45
Desi	347	4.83	0.25	21.84	-8.31	14.18	-0.39	15.18	2.71	67	0.56	74.5	0.5	31	-0.06	98	0.27	31.28	-1.43
Desi	407	2.8	-1.03***	17.71	-12.55***	15.87	1.2	8.17	-3.40***	54.5	-2.54	73.5	0.1	41	1.49	95.5	-0.02	34.34	-0.45
Desi	Kaka	3.21	-0.73	28.23	-3	11.33	-3.10***	7.26	-4.22***	60	-1.44	70.5	-0.95	32.5	0.15	92.5	-0.38	43.47	1.92
Desi	Pyrooz	2.54	-1.17	16.38	-13.70***	15.58	0.93*	7.26	-4.21***	60	-1.28	72.5	-0.26	34.5	0.34	94.5	-0.14	35.1	-0.38

*,** and *** significant at 5, 1 and 0.1 % probability level, respectively; without staric=non-significant.

TABLE 5

Phenotypic Mean (PM) values and predicted Genotypic Effects (GE) of Desi and Kabuli genotypes for Grain Yield (GY), Number of Grains (NG), 100-Grain Weight (GW), Shoot Dry Matter (SDM), Time to Flowering (TF), Time to Podding (TP), Time from Flowering to Maturity (TFM), Time to Maturity (TM), and Harvest Index (HI) evaluated in full-irrigated treatment

Type	Genotype	GY (gr plant^{-1})		NG (plant^{-1})		GW (gr)		SSDM (gr plant^{-1})		TF (day)		TP (day)		TFM (day)		TM (day)		HI (%)	
		PM	GE	PM	GE	PM	GE	PM	GE	PM	GE	PM	GE	PM	GE	PM	GE	PM	GE
Kabuli	15	8.2	-2.63***	26.56	-27.61***	30.69	8.84***	34.29	3.69	73	0.85	76.5	-0.06	39.5	2.21	112.5	2.33	24.25	-1.87
Kabuli	21	21.39	7.51**	92.45	36.49***	22.94	1.58***	49.83	18.19***	73.5	1.24**	77	0.3	35	0.09	108.5	0.64	42.33	0.65
Kabuli	25	12.62	0.77	57.9	2.89	21.69	0.38	33.71	3.12**	69.5	-2.10*	75.5	-0.87	34	-0.35	103.5	-1.42	37.17	-0.07
Kabuli	92	11.57	-0.05	47.33	-7.37*	24.23	2.74	34.01	3.39*	71	-0.83	75	-1.23	31	-1.84*	102	-2.12	33.69	-0.6
Kabuli	101	27.23	11.91	98.05	42.00***	28.27	6.60**	60.3	28.11***	71	0.83	75	-1.25***	34	-0.38	105	-0.79	43.64	1.48
Kabuli	160	7.73	-3.01*	40.37	-14.14***	17.85	-3.20***	19.97	-9.73**	70	-1.68*	73	-2.83***	32.5	-1.15	102.5	-1.78	42.91	1.36
Kabuli	166	10.25	-1.06	37.7	-16.76***	27.16	5.52***	30.52	0.13	70	-1.68***	74.5	-1.64***	38	1.60*	108	0.55	33.08	-0.62
Kabuli	176	12.39	0.56	56.86	1.93	21.71	0.39	26.95	-3.24	68	-3.33***	75	-1.24***	38.5	1.85**	106.5	-0.1	47.72	1.63
Kabuli	192	12.44	0.53	50.09	-4.87	24.65	3.16***	34.24	3.61	74.5	2.10***	78.5	1.48**	32.5	-1.05**	107	0.13	37.28	0.17
Kabuli	205	9.86	-1.38*	40.04	-14.46***	24.42	2.97***	30.33	0.06	75	2.51***	81	3.46*	43	4.34	118	5.13	32.09	-0.84
Kabuli	211	10.6	-0.8	51.33	-3.45*	20.64	-0.58	28.51	-1.82	75.5	2.93*	85.5	6.97*	35.5	0.41	111	1.9	37.24	-0.06
Kabuli	226	13.91	1.74**	58.78	3.69**	23.75	2.35***	35.42	4.70**	70.5	-1.25	76	-0.45	36	0.63	106.5	-0.12	39.1	0.22

Kabuli	227	8.48	-2.39***	38.25	-16.26***	22.31	0.97**	25.3	-4.74**	72	0.02	76.5	-0.09	34.5	-0.09	106.5	-0.08	33.28	-0.65
Kabuli	233	8.45	-2.44**	40.16	-14.39***	20.08	-1.13**	24.6	-5.36*	72.5	0.43	76	-0.45	33.5	-0.61	106	-0.32	34.21	-0.63
Kabuli	240	8.47	-2.43***	52.22	-2.71*	16.18	-4.78***	22.53	-7.45**	75.5	2.94*	78.5	1.51	39.5	2.39*	115	3.67	36.16	-0.35
Kabuli	263	6.21	-4.18***	37.58	-16.95***	16.32	-4.64***	16.4	-13.12***	77	4.21***	82.5	4.64***	30	-2.34*	107	0.1	36.54	-0.12
Kabuli	302	15.71	3.12**	78.43	22.89***	20.11	-1.11*	34.82	3.9	71	-0.81	75.5	-0.81	35.5	0.41	106.5	-0.13	44.9	1.1
Kabuli	308	14.24	1.96***	61.27	6.00***	23.73	2.27*	40.18	9.16***	71	-0.83***	75.5	-0.89**	35	0.13	106	-0.32	35.37	-0.34
Kabuli	311	14.48	2.2	83.4	27.61***	17.35	-3.68***	30.84	0.39	72	0	75	-1.27***	33	-0.83	105	-0.74	45.49	1.23
Kabuli	314	2.36	-6.75	17.53	-36.41***	13.42	-7.38***	11.49	-17.76***	73.5	1.25**	77	0.3	32.5	-1.14	106	-0.27	20.44	-2.61
Kabuli	315	11.05	-0.4	73.66	18.26***	14.87	-6.02***	30.26	-0.06	74.5	2.08***	78.5	1.5	34.5	-0.06	109	0.97	35.69	-0.29
Kabuli	316	11.79	0.09	83.71	26.56	14.45	-6.41***	32.73	2.18	76.5	3.78**	82.5	4.64***	34.5	-0.11	111	1.54	35.44	-0.33
Kabuli	327	10.02	-1.28	64.18	9.01***	15.48	-5.45***	22.16	-7.71**	74.5	2.10***	75.5	-0.86*	30.5	-2.14*	105	-0.74	43.14	0.63
Kabuli	333	6.16	-4.2	45.49	-9.08	13.55	-7.24***	24.15	-5.86*	76	3.35**	80	2.66***	26.5	-4.14*	102.5	-1.73	24.28	-2.27
Kabuli	339	19.59	6.07*	87.02	31.32***	22.54	1.18	42.32	11.14***	72.5	0.41	74.5	-1.66*	33	-0.84	105.5	-0.58	45.62	1.12
Kabuli	349	10.79	-0.64	67.15	11.26	16.34	-4.38	26.78	-3.38**	74.5	1.98	78.5	1.51	33.5	-0.62	108	0.5	40.15	0.22
Kabuli	371	11.32	-0.21	40.69	-13.84***	27.7	6.04***	27.17	-3.03*	69	-2.52*	73.5	-2.45***	35.5	0.38	104.5	-0.94	40.4	0.41
Kabuli	376	6.57	-3.83***	25.67	-28.54***	23.48	2.07*	14.32	-15.11***	64.5	-6.29***	71.5	-4.00***	35	0.14	99.5	-2.66	46.73	1.27
Kabuli	Koorosh	7.84	-2.87*	29.71	-24.48***	26.59	4.99***	20.05	-9.14	68	-3.32***	73	-2.68	33.5	-0.58*	101.5	-2.28	40.47	0.55
Kabuli	Jam	17.05	4.13***	66.62	11.40***	25.44	3.93***	48.28	15.86	64	-6.73***	71	-4.19	42	3.68*	106	-0.31	35.21	-0.37
Desi	5	10.67	2.05	47.91	-8.93***	22.28	7.65***	38.13	15.26***	66	-1.23	71	-1.44	42	0.07	108	-0.01	27.79	-7.75***
Desi	8	10.65	2.07	39.53	-17.11***	27.71	12.91***	25.93	4.77*	63.5	-2.13	71	-1.41	49.5	0.19	113	1.01	40.38	-0.15
Desi	9	11.93	2.99	46.11	-10.65***	25.12	10.40***	30.47	8.70**	69.5	-0.27	73.5	-0.65	31.5	-0.09	101	-1.37	37.36	-1.98
Desi	10	10.64	2.05	49.24	-7.64**	21.35	6.76***	24.69	3.72*	68.5	-0.51	77	0.26	29.5	-0.12	98	-1.84	42.26	0.99
Desi	21	7.45	-0.32	46.09	-10.74***	16.31	1.86***	17.8	-2.22	66.5	-1.1	71.5	-1.22	41.5	0.06	108	0.03	41.17	0.27
Desi	46	5.81	-1.53***	66.09	8.92***	8.94	-5.29***	18	-2.00*	69.5	-0.27	74.5	-0.41	41	0.05	110.5	0.49	31.96	-5.32*
Desi	47	6.76	-0.83	68.23	11.06*	9.92	-4.34***	19.02	-1.14	70.5	0	75.5	-0.04	35.5	-0.03	106	-0.17	35.55	-3.09
Desi	48	9.03	0.84***	76.54	19.16***	11.7	-2.5	21.41	0.93	75	1.23	81	1.15	40	0.03	115	1.06	42.28	1.09
Desi	49	9.31	0.99	87.17	29.63***	10.74	-3.54***	22.57	1.9	73	0.67	76	-0.06	35	-0.04	108	-0.1	44.87	2.7

Desi	50	9.65	1.31	81.15	23.70***	11.78	-2.56***	22.16	1.49	79	2.54	83	1.65	34	-0.05	113	0.97	43.39	1.61
Desi	51	5.7	-1.60*	54.74	-2.2	10.42	-3.86***	14.78	-4.82**	74.5	1.08	78.5	0.53	30.5	-0.05	105	-0.53	38.31	-1.43
Desi	76	4.62	-2.43**	43.3	-13.41***	10.78	-3.49***	12.51	-6.34	69	-0.59	80.5	0.96	39	0.02	108	0.48	36.81	-2.42
Desi	90	9.14	0.92	82.25	24.73***	11.17	-3.11***	22.14	1.49	74	1.02	76	0.02	36.5	-0.01	110.5	0.27	41.24	0.43
Desi	122	6.3	-1.18*	60.18	3.22	10.29	-3.97***	18.46	-1.61	82	3.36	87.5	2.71	43.5	0	125.5	3.33	33.86	-4.05
Desi	150	5.33	-1.88**	44.77	-11.90***	11.55	-2.81**	16.91	-2.96**	73	0.69	77	0.16	31.5	-0.09	104.5	-0.62	31.1	-5.92*
Desi	151	6.58	-0.96*	70.93	13.72***	9.32	-4.92***	23.72	2.91	71.5	0.27	82	1.36	50.5	0.2	122	2.6	27.91	-7
Desi	231	6.75	-0.83**	41.04	-15.57***	16.3	1.84**	16.63	-3.19	72.5	0.52	76.5	0.06	33.5	-0.06	106	-0.4	41.53	0.51
Desi	232	6.6	-0.96*	44.24	-12.47**	14.7	0.29	16.96	-2.94*	83	3.86	86	2.43	28.5	-0.05	111.5	0.62	38.76	-1.14
Desi	247	5.7	-1.62**	51.73	-5.12***	10.7	-3.59***	13.85	-5.53***	70	-0.16	76.5	0.06	31.5	-0.09	101.5	-1.05	40.93	0.2
Desi	252	4.73	-2.22	33.31	-23.26***	13.83	-0.54	14.32	-5.20**	71.5	0.27	77.5	0.28	51.5	0.41	123	3.36	34.01	-3.84
Desi	267	5.85	-1.50**	52.63	-4.25**	11.23	-3.06***	13.75	-5.67***	65	-1.56	71.5	-1.16	37.5	0	102.5	-0.99	42.36	1.03
Desi	276	13.41	4.11**	79.85	21.21	17.22	2.71**	21.94	1.4	72.5	0.57	78.5	0.44	31	-0.1	103.5	-0.75	60.73	12.49*
Desi	316	5.95	-1.42***	36.69	-19.94***	16.16	1.61	15.84	-3.88**	65	-1.51	72.5	-0.95	39.5	0.03	104.5	-0.58	38.23	-1.29
Desi	321	11.78	2.91*	83.67	26.16***	14.46	0.04	28.32	6.87**	66	-1.34	73.5	-0.61	39	-0.01	105	-0.52	41.15	0.39
Desi	322	13.29	4.02***	89.08	31.60***	14.65	0.22	32.38	10.31***	67	-1.05	75	-0.35	37	0	104	-0.56	41.24	0.39
Desi	333	8.11	0.17	51.12	-5.41	15.97	1.51***	11.71	-7.42*	67.5	-0.83	75.5	-0.2	36	-0.06	103.5	-0.9	84.3	26.67
Desi	347	6.41	-1.09**	46.68	-10.10***	13.66	-0.71**	29.64	7.97***	68	-0.85	72.5	-1.06	34	-0.05	102	-1.13	21.71	-11.24
Desi	407	4.53	-2.49***	27.29	-29.06***	16.89	2.40***	7.58	-10.93***	66	-1.28	70.5	-1.43	38	0	104	-0.72	64.64	14.39*
Desi	Kaka	5.64	-1.65**	52.33	-4.56**	12.4	-1.93***	15.09	-4.48**	69	-0.26	73.5	-0.65	34.5	-0.04	103.5	-0.78	36.24	-2.52
Desi	Pyrooz	8.04	0.11	56.21	-0.73	14.46	0.05	23.42	2.61	66.5	-1.1	74.5	-0.41	35.5	-0.03	102	-1.14	34.13	-4

*,** and *** significant at 5, 1 and 0.1% probability level, respectively; without staric=non-significant.

TABLE 6

Phenotypic Mean (PM) values and predicted Genotypic Effects (GE) of Desi and Kabuli genotypes for Grain Yield (GY), Number of Grains (NG), 100-Grain Weight (GW), and Shoot Dry Matter (SDM), Time to Flowering (TF), Time to Podding (TP), Time from Flowering to Maturity (TFM), Time to Maturity (TM), and Harvest Index (HI) evaluated in combined analysis

Type	Genotype	GY (gr plant^{-1})		NG (plant^{-1})		GW (gr)		SSDM (gr plant^{-1})		TF (day)		TP (day)		TFM (day)		TM (day)		HI (%)	
		PM	GE	PM	GE	PM	GE	PM	GE	PM	GE	PM	GE	PM	GE	PM	GE	PM	GE

Kabuli	15	9.11	0.33	38.46	-1.82	25.19	4.20***	31.74	5.96***	74.25	2.39***	77.75	1.45*	34	0.04	108.25	0.16	29.42	-1.34
Kabuli	21	16.36	4.19***	70.75	19.18***	22.95	2.03**	40.57	12.49***	71.5	0.42	75.75	0.13	34	-0.03	105.5	0.05	39.61	0.88
Kabuli	25	12.14	1.92**	50.63	5.79***	24.19	3.23***	32.06	6.22***	69.5	-0.99*	74.75	-0.52	34	0.04	103.5	-0.04	37.46	0.41
Kabuli	92	9.09	0.26	36.6	-3.03**	24.94	3.96***	28.16	3.34***	69	-1.27***	74	-1.02	32.5	-0.1	101.5	-0.11	31.32	-0.88
Kabuli	101	16.53	4.23*	63.26	14.21***	24.4	3.57*	41.21	12.92***	70.25	-0.43	74.75	-0.52	33.75	0.04	104	0	35.19	-0.15
Kabuli	160	5.76	-1.50**	30.85	-6.78***	17.89	-2.80***	14.71	-6.55***	68.75	-1.47*	72.25	-2.16***	33.75	0.01	102.5	-0.05	41.92	1.28
Kabuli	166	10.36	0.87	37.88	-2.23*	27.47	6.38***	29.4	4.26***	69	-1.27**	74	-0.98*	36.5	0.17	105.5	0.04	34.8	-0.13
Kabuli	176	8.95	0.19	42.08	0.047	20.6	-0.14	21.02	-1.92	67	-2.65***	74	-1.01**	35.5	0.09	102.5	-0.06	41.65	1.23
Kabuli	192	8.83	0.12	34.52	-4.40***	26.17	5.13***	25.25	1.2	73	1.45***	77.5	1.27	32.5	0	105.5	0.05	34.43	-0.28
Kabuli	205	7.11	-0.79***	29.65	-7.25***	23.07	2.16***	22.82	-0.58	72	0.76	77.75	1.54	37	0.19	109	0.19	30.13	-1.21
Kabuli	211	7.97	-0.34**	40.8	-0.3	19.09	-1.64**	22.95	-0.49	72.5	1.14	79.75	2.76	34.75	0.08	107.25	0.12	33.72	-0.34
Kabuli	226	9.58	0.57	40.19	-0.72	23.64	2.70***	24.15	0.39	70.5	-0.24	75	-0.35	34.75	0.08	105.25	0.06	39.96	0.93
Kabuli	227	6.96	-0.88***	31.87	-6.09***	21.84	0.98**	19.97	-2.66**	70	-0.61	75	-0.37	33.5	0.01	103.5	-0.04	35.22	0.03
Kabuli	233	6.11	-1.34***	31.35	-6.42**	18.46	-2.25***	19.5	-3.05***	71.5	0.41	74.75	-0.52*	33	-0.01	104.5	-0.01	30.29	-1.19
Kabuli	240	6.64	-1.06*	41.84	0.36	15.99	-4.61***	18.6	-3.70***	74.25	2.33***	77.75	1.42***	34	0.07	108.25	0.17	33.84	-0.39
Kabuli	263	6.29	-1.25**	36.81	-2.90*	16.92	-3.73***	20.02	-2.46*	74.75	2.68***	79.75	2.71***	29.75	-0.18	104.5	0.01	30.98	-1.04
Kabuli	302	11.04	1.30*	55.13	9.01***	19.94	-0.83	25.81	1.61	71	0.41	74.75	-0.5	33.25	0.06	104.25	0	40.81	1.31
Kabuli	308	11.13	1.34*	49.64	5.39***	22.43	1.55***	33.79	7.5***	70.5	2.33***	74.5	-0.67	34	0.04	104.5	-0.01	31.84	-0.77
Kabuli	311	9.29	0.36	55.11	8.98***	16.34	-4.28***	23.07	-0.41	71.75	0.62	74	-1.02*	30	-0.16	101.75	-0.1	36.15	0.03
Kabuli	314	2.84	-3.11***	19.07	-14.42***	14.51	-5.86***	9.89	-10.11***	72.25	0.94	76.75	0.76	29.5	-0.19	101.75	-0.02	30.13	-1.48
Kabuli	315	7.06	-0.86**	46.12	3.14	15.67	-4.92***	18.52	-3.47*	73.75	2.00***	78.25	1.79	31	-0.11	104.75	0.02	44.9	2.27
Kabuli	316	7.5	-0.59	52.26	7.15***	14.82	-5.51***	21.04	-1.88	75.25	3.03**	80.25	3.04***	31.5	-0.06	106.75	0.1	34.87	-0.19
Kabuli	327	7.45	-0.61	45.81	2.66	16.46	-4.04**	18.2	-3.99***	72.25	0.95*	74.75	-0.52	30.25	-0.15	102.5	-0.06	38.57	0.62
Kabuli	333	4.59	-2.13**	34.36	-4.47**	13.64	-6.87***	17.18	-4.69***	75	2.85***	80	2.88***	31	-0.11	106	0.1	27.04	-1.99
Kabuli	339	11.85	1.77	53.3	7.81**	21.72	0.86	27.09	2.55*	70.25	-0.43	73.75	-1.17**	33.25	-0.02	103.5	-0.02	39.94	0.95
Kabuli	349	7.49	-0.6	44.93	2.58	17.12	-3.55***	19.43	-3.10***	74.5	2.50***	77.75	1.41***	31	-0.11	105.5	0.05	37.2	0.2
Kabuli	371	8.09	-0.28	30.63	-6.93***	25.98	4.96***	21.84	-1.31	67.75	-2.08**	72.75	-1.83**	34.75	0.08	102.5	-0.06	34.8	-0.12
Kabuli	376	6.23	-1.29**	24.44	-10.94***	24.15	3.07**	15.48	-5.98***	64.25	-4.49***	71	-2.97***	33	-0.01	97.25	-0.28	40.88	1.13

Kabuli	Koorosh	6.37	-1.19***	23.89	-11.30***	27.02	5.95***	17.98	-4.14***	67.25	-2.40***	72.75	-1.84***	35.5	-0.06	102.75	-0.09	35.76	0.05
Kabuli	Jam	11.42	1.53***	43.75	1.6	26.61	5.55***	33.18	7.05***	65	-4.02***	71.25	-2.70**	38.75	0.29	103.75	-0.05	33.6	-0.38
Desi	5	7.52	0.7	33.97	-6.61***	22.14	7.14***	27.56	8.22***	68.25	0.27	73.25	-0.94	34.25	0.02	102.5	0.03	26.6	-2.61
Desi	8	7.60.	742	7.63	-10.73***	27.95	12.71***	20.49	2.96	64.75	-2.14*	72	-1.81	40.25	0.52	105	0.14	35.43	-0.58
Desi	9	7.38	0.61	29.41	-9.55***	23.63	8.57***	20.96	3.37**	69.75	1.31**	74	-0.5	31.25	-0.16	101	-0.02	30.95	-1.75
Desi	10	8.73	1.35***	42.51	-1.06	20.55	5.61***	23.47	5.20***	66.25	-1.09	75	0.14	30.5	-0.29	96.75	-0.2	36.17	-0.55
Desi	21	5.94	-0.13	38.68	-3.54***	15.62	0.91	15.04	-0.99	65.25	-1.78***	72	-1.80***	37	0.17	102.25	-0.01	38.59	0
Desi	46	5.6	-0.37	55.29	7.26***	10.51	-4.00***	15.89	-0.36	68.5	0.45	74.25	-0.32	42.5	0.46	111	0.33	34.83	-0.8
Desi	47	6.3	0.03	62.81	12.13***	10.02	-4.45***	15.79	-0.43	69.25	0.94	75	0.16	33	-0.03	102.25	0	40.58	0.43
Desi	48	6.29	0.04	53.52	6.08**	11.83	-2.73***	15.21	-0.85*	70.25	1.64	77	1.4	37	0.14	107.25	0.11	40.78	0.5
Desi	49	6.42	0.11	60.28	10.47***	10.47	-4.03***	16.37	-0.5	71	2.15**	74.5	-0.16	31.75	-0.1	102.75	0.04	39.69	0.08
Desi	50	6.83	0.33	60.97	10.95***	11.14	-3.40***	16.68	0.21	71.75	2.6	77.5	1.61	33.25	-0.02	105	0.14	39.8	0.3
Desi	51	5.26	-0.58	47.41	2.09	10.86	-3.65***	13.58	-2.07*	68.5	0.42	75	0.13	31	-0.14	99.5	-0.03	38.58	0.14
Desi	76	4.12	-1.13***	37.38	-4.37***	11.03	-3.48***	11.62	-3.60***	66	-1.26	76.25	0.95	35.25	0.08	101.25	-0.01	34.66	-0.89
Desi	90	7.29	0.53	63.65	12.65***	11.6	-2.95***	17.23	0.62	68.25	0.26	73.5	-0.82	34.5	0.04	102.75	0.06	42.69	0.91
Desi	122	5.82	-0.21	52.76	5.61**	10.92	-3.59***	16.07	-0.24	73	3.54**	80.25	3.59**	39	0.27	112	0.43	36.08	-0.51
Desi	150	4.64	-0.78	38.2	-3.6	11.94	-2.63***	13.48	-2.13**	68.75	0.6	75.25	0.32	32.75	0	101.5	0	35.2	-0.73
Desi	151	5.72	-0.27	51.09	4.49***	12.3	-2.27**	18.16	1.29	68.5	0.43	78	1.97	40.25	0.34	108.75	0.29	33.03	-1.13
Desi	231	4.97	-0.67***	30.21	-9.03***	16.33	1.58**	12.92	-2.55**	71	2.17***	76.25	0.98	24	-0.51	95	-0.26	38.01	-0.05
Desi	232	5.99	-0.12	39.85	-2.78**	14.87	0.18	15.3	-0.92	75.75	5.39*	80.25	3.52	29.25	-0.23	105	0.14	38.43	0.03
Desi	247	4.41	-0.97***	42.13	-1.38	10.34	-4.14***	11.15	-3.85***	66.75	-0.7	74.25	-0.35	31	-0.14	97.75	-0.15	38.93	0.18
Desi	252	4.48	-0.94***	31.05	-8.49***	14.3	-0.36	13.35	-2.22***	71.25	2.35***	76.25	0.95**	32	-0.66	103.25	-0.17	34.35	-0.66
Desi	267	4.76	-0.72*	41.89	-1.45**	11.6	-2.95***	11.29	-3.76***	64.5	-2.32***	71.5	-2.12***	33.75	-0.01	98.25	-0.12	41.95	0.73
Desi	276	8.71	1.34*	55.63	7.48***	14.79	0.11	15.73	-0.46	70	1.45	76.75	1.26	29	-0.24	99	-0.1	50.98	2.88
Desi	316	5.17	-0.55**	31.97	-7.91***	16.12	1.37**	13.67	-1.99**	63.75	-2.83***	72.25	-1.63*	35	0.06	98.75	-0.11	37.5	-0.14
Desi	321	10.44	2.27*	69.03	16.12***	15.43	0.71	25.1	6.22**	64.5	-2.28**	72.5	-1.44**	34.5	0.04	99	-0.11	40.86	0.26
Desi	322	9.59	1.81***	61.65	10.78	15.9	1.17*	23.04	4.90***	65.25	-1.79***	74.5	-0.17	34	0.01	99.25	-0.09	41.59	0.66
Desi	333	5.5	-0.38	35.11	-5.86***	15.55	0.83**	10	-4.74**	67	-0.58	74.5	-0.18	33.25	0.03	100.25	-0.04	59.87	5.12

Desi	347	5.62	-0.344	34.26	-6.40**	13.92	-0.72***	22.41	4.41*	67.5	-0.28	73.5	-0.8	32.5	-0.06	100	-0.03	26.5	-2.71
Desi	407	3.67	-1.36***	22.5	-14.05***	16.38	1.57**	7.88	-6.33***	60.25	-5.28	72	-1.81**	39.5	0.33	99.75	-0.07	49.49	2.11
Desi	Kaka	4.43	-0.96***	40.28	-2.54	11.87	-2.69***	11.18	-3.83***	64.5	-2.34***	72	-1.79**	33.5	-0.01	98	-0.14	39.86	0.26
Desi	Pyrooz	5.29	-0.49	36.3	-5.07***	15.02	0.33**	15.34	-0.76	63.25	1.31**	73.5	-0.79	35	0.1	98.25	-0.12	34.62	-0.91

*,** and *** significant at 5, 1 and 0.1% probability level, respectively; without staric=non-significant.

Growth and partition coefficient

Terminal drought decreased CGR of both Kabuli and Desi chickpeas by 40.77% and 33.77%, respectively. Likewise, the terminal drought resulted in an increase of Partition (P) coefficient in Desi chickpeas by 10.85% but decreased the P of Kabuli ones by 4.07%. Overall, the CGR of Kabuli genotypes were more than Desi ones, while the P values were more in the Desi chickpeas than the Kabuli ones at both irrigation conditions. In both chickpea types, the Vegetative Degree Days (VDD), as well as the Reproductive Degree Days (RDD), were greater under full-irrigated conditions than water-limited conditions. However, these reductions were more in Desi chickpeas than Kabuli ones. In addition, the mean of VDD was more in the Kabuli chickpeas than Desi ones at both irrigation conditions. In the case of RDD, Desi chickpeas showed more RDD than Kabuli ones in full-irrigated conditions, but under water-limited conditions, Kabuli chickpeas had more RDD than Desi ones.

Correlation analysis

The association of grain yield, 100-grain weight, number of grains, and shoot dry matter under the terminal drought with their potential in full-irrigated conditions were examined using correlation analysis (Figure 1). The GY of Kabuli chickpeas under water-limited conditions showed a positive and significant ($P \leq 0.05$) correlation with GY obtained in full-irrigated conditions. The correlation between NG of Desi chickpeas in water-limited conditions and NG of their counterparts grown in full-irrigated conditions was significantly positive ($P \leq 0.01$). The GW obtained in water-limited conditions showed a positive and significant ($P \leq 0.01$) correlation with GW in full-irrigated conditions both for Desi and Kabuli chickpeas. The correlations for SDM of stressed-chickpeas with those grown in full-irrigated conditions were detected positive at 0.05 probability level in Kabuli type and at 0.01 probability level in Desi type.

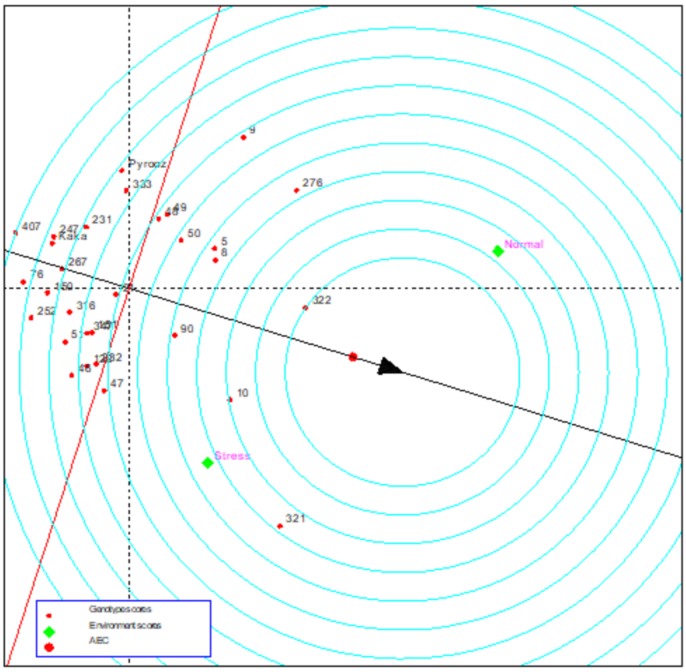

Figure 1) *GGE biplot analysis based on principal component analysis as justified 80.95% and 19.05% by PC1 (horizontal axis) and PC2 (vertical axis), respectively, genotype-focused scaling for comparison Desi chickpea genotypes with the ideal genotype. Black numbers stand for genotypes*

The Pearson's correlations among plant traits were examined for Kabuli and Desi chickpea genotypes separately (Tables 7 and 8). The GY did not show any correlations with the plant phenological traits in both chickpea types. However, in both the chickpea types, GY showed significant positive correlations with SDM, CGR, and NG under both irrigation conditions. As well, P presented a significant positive correlation with HI and a significant negative correlation with TFM in both chickpea types and irrigation conditions. TF showed a significant negative correlation with GW of both chickpea types grown in full-irrigated conditions. Furthermore, there was a significant negative correlation between TF and GW of Kabuli chickpeas under water-limited conditions. The VDD showed significant positive correlations with TF and TP in both chickpea types. The RDD showed significant positive correlations with TFM and TM, while had a negative correlation with P in both chickpea types.

TABLE 7
Pearson's correlation coefficients between the measured traits and drought tolerance indices for Kabuli chickpeas

Trait	Environment	GMP	HM	SSI	MP	STI	DI	ATI	TOL	K1STI	K2STI
TF	Stress	-0.179	-0.189	-0.048	-0.157	-0.147	0.041	0.028	-0.086	-0.123	-0.046

	Non-stress	-0.264	-0.27	0.031	-0.239	-0.211	-0.128	0.058	-0.067	-0.15	-0.179
TP	Stress	-0.245	-0.238	-0.158	-0.233	-0.187	0.088	-0.08	-0.177	-0.174	-0.044
	Non-stress	-0.24	-0.223	0.006	-0.243	-0.211	-0.087	-0.003	-0.126	-0.204	-0.145
TFM	Stress	0.319	0.334	0.178	0.281	0.288	0.02	0.05	0.122	0.199	0.201
	Non-stress	0.265	0.271	0.002	0.236	0.2	0.172	-0.004	0.05	0.094	0.212
TM	Stress	0.155	0.161	0.145	0.139	0.156	0.067	0.086	0.04	0.085	0.172
	Non-stress	0.014	0.014	0.028	0.009	0	0.045	0.045	-0.012	-0.042	0.038
NG	Stress	0.638**	0.746**	-0.459*	0.485**	0.656**	0.788**	-0.469**	-0.241	0.168	0.871**
	Non-stress	0.560**	0.381*	0.712**	0.704**	0.546**	-0.391*	0.784**	0.852**	0.781**	0.034
HI	Stress	-0.066	-0.049	-0.077	-0.08	-0.023	0.071	-0.026	-0.103	-0.123	0.075
	Non-stress	0.343	0.249	0.541**	0.414*	0.273	-0.329	0.493**	0.521**	0.425*	-0.066
SDM	Stress	0.774**	0.868**	-0.383*	0.626**	0.756**	0.769**	-0.415*	-0.133	0.292	0.903**
	Non-stress	0.815**	0.670**	0.475**	0.908**	0.783**	-0.051	0.550**	0.767**	0.888**	0.348
GW	Stress	0.497**	0.546**	-0.1	0.410*	0.431*	0.351	-0.165	-0.004	0.177	0.471**
	Non-stress	0.560**	0.559**	-0.063	0.525**	0.474**	0.368*	-0.068	0.138	0.356	0.449*
GY	Stress	0.780**	0.895**	-0.442*	0.608**	0.774**	0.845**	-0.472**	-0.21	0.226	0.985**
	Non-stress	0.801**	0.627**	0.586**	0.927**	0.771**	-0.198	0.662**	0.887**	0.965**	0.238

* and ** significant at 5 and 1% probability level, respectively; without staric=non-significant.

TABLE 8

Pearson's correlation coefficients between the measured traits for Kabuli chickpeas. Up: Irrigation conditions. Down: Water-limited conditions

Trait	TF	TP	TFM	TM	GY	SDM	GW	GN	HI	CGR	P
TF	—	0.857**	-0.321	0.551**	-0.178	-0.133	-0.542**	0.128	-0.361	-0.18	-0.107
TP	0.902**	—	-0.123	0.606**	-0.209	-0.138	-0.438*	0.041	-0.346	-0.193	-0.205
TFM	-0.593**	-0.485**	—	0.614**	0.168	0.268	0.477**	-0.028	0.005	0.211	-0.396*
TM	0.450*	0.460*	0.453*	—	-0.001	0.126	-0.031	0.082	-0.296	0.036	-0.439*
GY	-0.112	-0.115	0.234	0.136	—	0.930**	0.387*	0.847**	0.508**	0.937**	0.437*
SDM	-104	-0.123	0.253	0.165	0.943**	—	0.484**	0.734**	0.206	0.996**	0.124
GW	-0.615**	-0.527**	0.604**	-0.011	0.531**	0.496**	—	-0.108	0.108	0.486**	-0.115
GN	0.22	0.162	-0.051	0.187	0.874**	0.856**	0.076	—	0.514**	0.733**	0.545**
HI	0.061	0.123	-0.195	-0.148	0.004	-0.283	-0.027	-0.062	—	0.233	0.891**
CGR	-0.134	-0.153	0.236	0.114	0.941**	0.999**	0.502**	0.850**	-0.285	—	0.166
P	0.283	0.298	-0.584**	-0.335	-0.072	-0.333	-0.259	-0.012	0.889**	-0.326	—

* and ** significant at 5 and 1% probability level, respectively; without staric=non-significant.

Yield stability analysis

The yield stability of chickpea genotypes was evaluated using the Average Environment Coordination (AEC) method developed by Yan [9]. This method draws a line through the average environment, which has been highlighted with a red circle dot on this line that serves as the abscissa of the AEC. This abscissa line is drawn in one direction toward more yield as well as a larger genotype main effect, crossed from bi-plot origin. Upright to this line, AEC ordinate line places high yielding genotypes on its right side and those of low yielding is located on the left side. The results of the yield stability analysis showed that Kabuli genotype 21 and Desi genotype 322 were the nearest individuals to the ideal genotype, which presents high grain yield with high yield stability based on the AEC analysis. In the next grade, genotype 10 from Desi type and genotype 308 from Kabuli type had suitable yield and yield stability.

Path analysis

Figures 2-5 detail the strength of the contribution of the plant traits on the grain yield for individual experiments by path diagram analysis. The HI, NG, and SDM had direct positive contributions on the GY of Kabuli chickpeas grown in full-irrigated conditions. Furthermore, the HI, SDM, NG, and GW with positive direct effects influenced the GY of the Kabuli chickpeas in water-limited conditions. In the Kabuli chickpeas, the path analysis justified 0.975 and 0.987 of the GY variance at the full-irrigated conditions and limited water conditions, respectively. In Desi chickpeas, the direct effects of HI, SDM, NG, and GW justified 0.965 of GY variance in the full-irrigated conditions. The SDM, HI, and NG affected directly the GY of Desi chickpeas and justified 0.981 of its variances at the water-limited conditions. The path diagrams highlighted the SDM with the most influence on the GY of both chickpea types except for Desi chickpeas grown in full-irrigated conditions in which NG showed the most influence on the GY. TF showed a positive effect on the NG but affected negatively GW of Kabuli chickpeas at both irrigation conditions. For Desi chickpeas, TF had a positive effect on the NG and a negative effect on the GW in full-irrigated conditions, while under water-limited conditions affected the NG negatively and had no effect on the GW. The negative direct effect of SDM on the HI of Kabuli chickpeas was exacerbated under terminal drought compared to full-irrigated conditions; while an opposite norm was observed for Desi chickpeas.

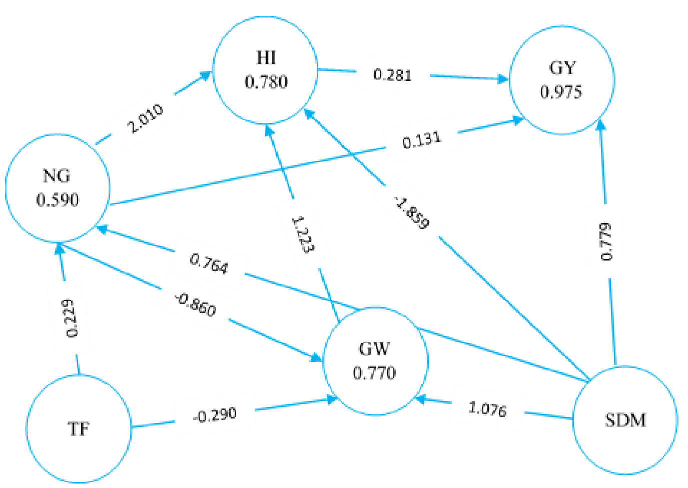

Figure 2) *Path analysis diagram of grain yield (dependent variable) and other studied traits (independent variables). Path analysis derived from structural equation modeling using partial least squares algorithm to determine complex relationship existing between grain yield and its related traits in Kabuli chickpea genotypes at the full-irrigated conditions. Path coefficients indicated with values on the arrows show direct effect between different yield related traits. R squared coefficients are indicated by values in the circles*

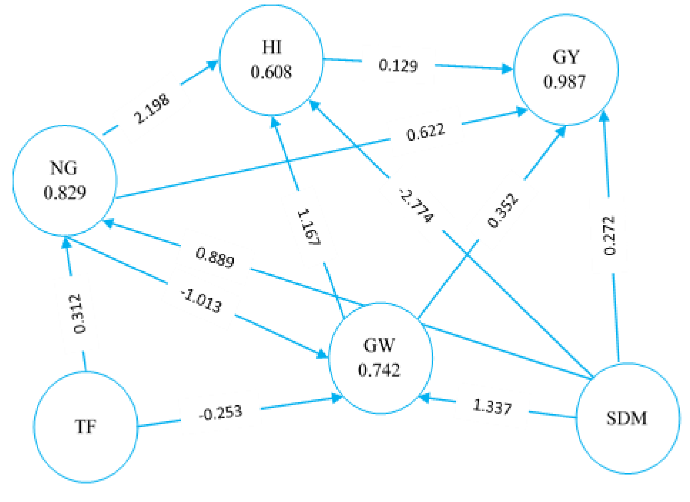

Figure 3) *Path analysis diagram of grain yield (dependent variable) and other studied traits (independent variables). Path analysis derived from structural equation modeling using partial least squares algorithm to determine complex relationship existing between grain yield and its related traits in Kabuli chickpea genotypes at the water-limited conditions. Path coefficients indicated with values on the arrows show direct effect between different yield related traits. R squared coefficients are indicated by values in the circles*

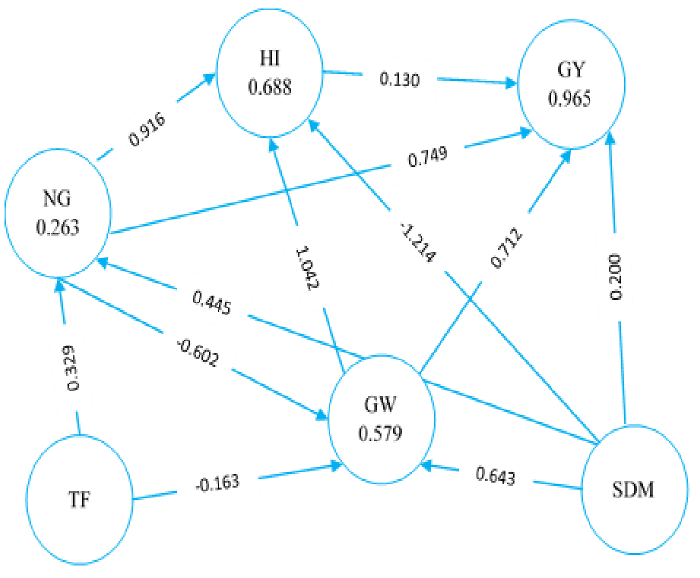

Figure 4 *Path analysis diagram of grain yield (dependent variable) and other studied traits (independent variables). Path analysis derived from structural equation modeling using partial least squares algorithm to determine complex relationship existing between grain yield and its related traits in Desi chickpea genotypes at the full-irrigated conditions. Path coefficients indicated with values on the arrows show direct effect between different yield related traits. R squared coefficients are indicated by values in the circles*

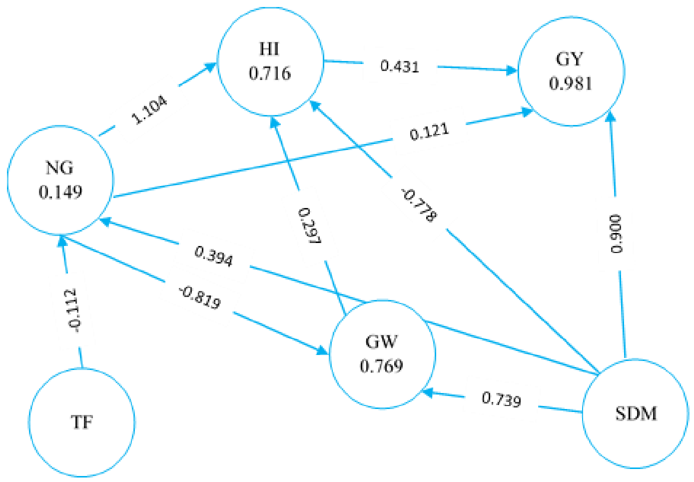

Figure 5) *Path analysis diagram of grain yield (dependent variable) and the other studied traits (independent variables). Path analysis derived from structural equation modeling using partial least squares algorithm to determine complex relationship existing between grain yield and its related traits in Desi chickpea genotypes at the water-limited conditions. Path coefficients indicated with values on the arrows show direct effect between different yield related traits. R squared coefficients are indicated by values in the circles*

DISCUSSION

Genetic variation among chickpea germplasm can be used to improve drought tolerance in future varieties. The complex nature of environmental stresses and low genetic diversity in the cultivated gene pool are the major limiting factors that have kept chickpea grain yield less than one ton per hectare. The selection of drought-tolerant genotypes can be performed in a straightforward manner through evaluation of grain yield under drought stress conditions. In such a situation, however, the improvement of chickpea performance and gaining precise knowledge about the mechanisms of drought tolerance are usually prevented because drought stress could occur in several forms as well as many genes control the grain yield. Moreover, in semi-arid regions such as Iran, unpredictable patterns of precipitation join to this problem and often persuade plants to suffer from the water constraint in an unforeseen situation, especially in late spring. In such a situation, although natural selection persuades plant survival mechanisms, plant breeders are interested to achieve an acceptable performance through the exploitation of known drought tolerance mechanisms [10]. In this respect, the present study aimed to explore genetic variation among Desi and Kabuli chickpeas in response to terminal drought.

The crop phenological processes have immense effects on their production and yield stability; therefore, an appropriate time to flowering can be a major component of crop adaptation particularly in environments with a restricted growing season due to terminal drought. Overall, Desi chickpeas showed early flowering and maturity compared to Kabuli chickpeas at both irrigation conditions. This early phenology in Desi chickpeas could be due to adaption to winter sowing at the subtropics and tropics, in which the crop flowers when day length (photoperiod) and temperature are gradually decreasing, less Growth Degree Days (GDD) required for flowering, contrary to the Kabuli chickpeas adapted to the Mediterranean region. The terminal drought decreased TM by 9 days and 7 days in Desi and Kabuli chickpea genotypes, respectively, which were inconsistent with previous studies. A light decrease of TFM was observed in Kabuli chickpeas (3 days) compared to Desi ones (7 days) in stressed plants than their counterparts have grown in full-irrigated conditions, which was in agreement with the results obtained by Nayyar, et al. [11]. The ideal genotypes for both Desi (322) and Kabuli (21) chickpeas showed TF values less and TFM values more than their own population mean under water-limited conditions. Some studies have also assumed early flowering and longer grain filling duration including attributes of spring-sown chickpea plants that may contribute to higher grain yield under Mediterranean terminal drought. However, genotype 407, the most susceptible Desi genotype, showed the same TF and TFM pattern under water-limited conditions, confirming that these attributes may not be always conferring terminal drought tolerance but also the trait(s) contributing to more terminal drought tolerance can be different among chickpea genotypes.

These two chickpea types presented an important aspect of difference by their thermal time required for vegetative and reproductive stages. Kabuli chickpeas showed more thermal time requirement for vegetative growth under both irrigation conditions. In addition, Kabuli chickpeas had a higher thermal time requirement for reproductive growth compared to Desi chickpeas in terminal drought, while there was a reverse procedure in full-irrigated conditions. Besides these differences in the thermal time requirements, comparing the present study results with research conducted in India by Purushothaman, et al. showed that Desi and Kabuli chickpeas could have inverse thermal time requirements in each of the two environments, which could be due to their adaptation in different latitudes of the Northern Hemisphere [12]. The thermal time requirement determines the time of the switch from the vegetative phase to the reproductive phase, thus it is one of the factors determining shoot biomass at flowering and later. Hence, it should be monitored well in chickpea breeding programs, especially because it could vary by change in growth conditions from optimum irrigation to terminal drought as well as from spring-sown as the present study to winter-sown in sub tropics.

Grain yield of Kabuli chickpeas under water-limited conditions showed a positive correlation with GY in full-irrigated conditions (R^2=0.16). This significant relationship ($P \leq 0.05$) confirmed that yield potential could justify only 16% of GY under terminal drought conditions, which was nearly to result of another study under severe terminal drought for spring-sown chickpea at the Mediterranean basin. However, the GY of Desi chickpeas under water-limited conditions showed a non-significant relationship with the GY in full-irrigated conditions. The poor correlations confirm that breeding efforts based on GY need to be targeted separately for irrigated and terminal drought conditions, especially for spring-sown chickpeas in semi-arid Mediterranean regions.

In this study, the intensity of applied water stress due to the terminal drought was detected as SI by 50.70 and 44.05 units on the Kabuli and Desi chickpeas, respectively. These reductions in grain yield owing to terminal drought have been reported from 15% to 80% in Kabuli chickpeas and from 21% to 66% in Desi chickpeas. This more reduction in the GY of Kabuli chickpeas than Desi ones may be explained by the report of Nayyar, et al. who found that in terminal drought conditions, Kabuli chickpeas allocated assimilates toward maintaining of the vegetative growth, while Desi chickpeas assigned assimilates toward the filling grains. This more assignment of assimilates to filling grains in Desi chickpeas can be interpreted by more harvest index as was observed in the present study at both irrigation conditions. The path diagrams also revealed a smaller negative direct effect of SDM on the HI in Desi chickpeas that means a greater contribution of SDM (about 36%) toward more HI under terminal drought than full-irrigated conditions while there was an inverse manner for the Kabuli chickpeas. One reason for the more HI in Desi chickpeas likely is their adaptation to conservative water use. Based on this water use strategy, Desi chickpeas moderate their water flow or uptake and are conservative in their water requirement than Kabuli chickpeas that prefer active soil water use during the major part of their early growth. This different soil water use could be due to diverse adaptation geographical area, as Kabuli chickpeas are known to be well adapted to spring-sown in Mediterranean regions with optimal rainfall during early growth of the crop, while Desi chickpeas have been adapted to sub tropics in which the crop uptake the summer rainfall-stored soil moisture. Moreover, a root anatomy study showed that xylem vessels of Kabuli chickpeas were more and wider relative to Desi ones and suggested that the Kabuli chickpeas are equipped to use more water with less resistance to water flow. Hence, the different water use and root anatomy can be among constituent factors for the more SDM and less HI in Kabuli chickpeas than Desi ones in the present study. It should be noted that HI alone could not be considered as a grain yield-determining trait for the selection of terminal drought-tolerant chickpeas unless accompanied by high shoot biomass. Indeed, an independent selection for HI alone has been considered to have the risk of selecting individuals with a poor plant biomass potential, like genotype 407, the most susceptible Desi genotype with a high HI but a poor SDM in this study. Harvest index is a function of Time from Flowering to Maturity (TFM) and Partitioning (P) rate of assimilates to grains. However, the correlation between the two determinants of HI was significantly negative (Tables 9-11). The P values were greater in Desi chickpeas than Kabuli ones at both irrigation conditions. It should be noted that spring-sown chickpeas experience a linear rise of temperature throughout their growth. Indeed, this more P in Desi chickpeas can be an indirect sign of the more Canopy Temperature Depression (CTD) because the more P depends on adequate mobile stored assimilates in plant organs which in turn demands enough water, especially under terminal drought [13]. The CTD has been well accepted as an indicator of total plant water status, the continuance of stomatal conductance, and canopy transpiration. Therefore, one of the main factors contributes to more terminal drought tolerance in Desi chickpeas in the present study could be considered the more resistance to water flow in their roots, which helps keep cooler canopy temperature and thus more ability to assimilate remobilization toward filling grains under the gradually increasing temperatures at the reproductive stages.

TABLE 9

Pearson's correlation coefficients between the measured traits and drought tolerance indices for Desi chickpeas

Trait	Environment	GMP	HM	SSI	MP	STI	DI	ATI	TOL	K1STI	K2STI
TF	Stress	0.162	0.104	0.072	0.218	0.079	0.009	0.153	0.224	0.222	-0.007
	Non-stress	-0.053	-0.031	-0.195	-0.072	-0.11	0.146	-0.157	-0.144	-0.137	-0.021
TP	Stress	0.031	-0.029	0.091	0.096	-0.015	-0.091	0.16	0.207	0.18	-0.121
	Non-stress	-0.012	0.019	-0.234	-0.043	-0.051	0.196	-0.197	-0.168	-0.018	0.045
TFM	Stress	-0.008	0.013	-0.081	-0.029	-0.008	0.093	-0.078	-0.096	-0.072	0.054
	Non-stress	-0.019	0.024	-0.209	-0.067	-0.024	0.143	-0.217	-0.179	-0.131	0.05
TM	Stress	0.11	0.093	-0.044	0.127	0.05	0.119	0.019	0.05	0.077	0.06
	Non-stress	-0.056	-0.002	-0.327	-0.112	-0.101	0.233	-0.306	-0.264	-0.216	0.029
NG	Stress	0.431*	0.548**	-0.569**	0.284	0.431*	0.747**	-0.562**	-0.396*	-0.018	0.667**
	Non-stress	0.579**	0.530**	0.207	0.597**	0.550**	0.12	0.205	0.362*	0.533**	0.380*
HI	Stress	0.082	0.161	-0.311	-0.009	0.1	0.321	-0.349	-0.294	-0.133	0.24
	Non-stress	-0.042	-0.12	0.412*	0.04	-0.011	-0.368*	0.390*	0.33	0.198	-0.184
SDM	Stress	0.778**	0.843**	-0.325	0.667**	0.775**	0.689**	-0.321	-0.068	0.375*	0.840**
	Non-stress	0.690**	0.598**	0.356	0.749**	0.639**	0.023	0.376*	0.565**	0.723**	0.362*
GW	Stress	0.34	0.267	0.326	0.400*	0.328	-0.13	0.332	0.412*	0.445*	0.116
	Non-stress	0.284	0.168	0.500**	0.394*	0.267	-0.315	0.512**	0.570**	0.524**	-0.025
GY	Stress	0.813**	0.918**	-0.496**	0.659**	0.826**	0.870**	-0.498**	-0.226	0.305	0.978**
	Non-stress	0.800**	0.645**	0.636**	0.918**	0.765**	-0.168	0.653**	0.858**	0.991**	0.337

* and ** significant at 5 and 1% probability level, respectively; without staric=non-significant.

TABLE 10

Pearson's correlation coefficients between the measured traits for Desi chickpeas. Up: Irrigation conditions. Down: Water-limited conditions

Trait	TF	TP	TFM	TM	GY	SDM	GW	GN	HI	CGR	P
TF	—	0.890**	-0.245	0.505**	-0.116	-0.148	-0.417*	0.263	-0.096	-0.22	0.083
TP	0.671**	—	-0.076	0.575**	-0.109	-0.16	-0.434*	0.266	-0.078	-0.243	0.04
TFM	-0.569**	-0.409*	—	0.713**	-0.13	0.064	0.041	-0.089	-0.201	-0.058	-0.581**
TM	0.05	0	0.793**	—	-0.2	-0.05	-0.265	0.111	-0.248	-0.211	-0.457*

GY	0.054	-0.076	0.054	0.106	—	0.750**	0.527**	0.554**	0.187	0.764**	0.285
SDM	0.213	0.102	-0.027	0.125	0.863**	—	0.429*	0.396*	-0.404*	0.986**	-0.332
GW	0.181	0.324	-0.142	-0.039	0.099	0.435*	—	-0.390*	0.163	0.465**	0.164
GN	-0.028	-0.292	0.175	0.191	0.708**	0.370*	-0.546**	—	0.029	0.361	0.092
HI	-0.308*	-0.374*	0.137	-0.062	0.262	-0.239	-0.644**	654**	—	-0.362*	0.882**
CGR	0.208	0.101	-0.159	-0.04	0.855**	0.986**	0.441*	0.346	-0.227	—	-0.253
P	0.345	0.263	-0.816**	-0.735**	0.06	-0.122	-0.216	0.163	0.365*	0.003	—

* and ** significant at 5 and 1% probability level, respectively; without staric = non-significant.

TABLE 11

Trail means of Crop Growth Rate(CGR) and Partition Coefficient (P) for Kabuli and Desi chickpeas in Terminal Drought (TD) and Full-Irrigated (FI) conditions

Kabuli genotype	**Irrigation condition**				**Desi genotypes**	**Irrigation condition**			
	CGR (g m^{-2} °Cd^{-1})		**P (%)**			**CGR (g m^{-2} °Cd^{-1})**		**P (%)**	**P (%)**
	TD	**FI**	**TD**	**FI**		**TD**	**FI**	**TD**	**FI**
15	5.61	6.1	5.55	2.95	5	3.5	7.06	4.43	3.24
21	6.11	9.18	5.11	5.79	8	3.1	4.59	4.57	4.2
25	5.88	6.51	5.28	5.16	9	2.27	6.03	3.69	5.74
92	4.42	6.67	4.1	5.07	10	4.66	5.04	4.54	6.74
101	4.29	11.49	3.68	6.23	21	2.54	3.3	5.21	4.9
160	1.85	3.9	5.41	5.54	46	2.47	3.26	4.38	3.8
166	5.49	5.65	4.99	4.2	47	2.55	3.59	7.09	4.72
176	3.07	5.06	5.29	5.71	48	1.81	3.72	5.46	5.17
192	3.13	6.4	4.6	5.23	49	2.08	4.18	5.6	5.56

205	3.06	5.14	4.24	3.77	50	2.31	3.92	5.19	6.12
211	3.36	5.14	4.23	4.98	51	2.63	2.81	5.77	5.88
226	2.48	6.65	5.7	5.15	76	2.27	2.32	4.99	4.52
227	2.91	4.75	5.33	4.57	90	2.59	4.01	6.38	5.4
233	2.8	4.64	3.75	4.8	122	2.78	2.94	5.35	3.95
240	2.89	3.92	5.28	4.66	150	2.04	3.24	5.46	4.66
263	4.64	3.07	4.2	5.84	151	2.64	3.89	5.98	2.82
302	3.29	6.54	5.59	5.99	231	2.19	3.14	10.05	5.67
308	5.32	7.58	4.14	4.77	232	2.77	3.04	6.16	6.28
311	3.1	5.88	4.53	6.65	247	1.8	2.73	5.62	6.04
314	1.7	2.17	6.88	2.96	252	2.96	2.33	11.4	3.31
315	1.35	5.55	7.53	5	267	1.88	2.68	6.43	5.43
316	1.82	5.9	5.55	4.94	276	2.01	4.24	7.15	9.15
327	2.85	4.22	5.26	6.89	316	2.47	3.03	5.8	4.58
333	1.87	4.71	3.96	4.4	321	4.7	5.39	6.39	5.14
339	2.34	8.02	4.85	6.56	322	2.9	6.23	6.45	5.29

349	2.35	4.96	5.61	5.64	333	1.71	2.26	5.34	9.13
371	3.28	5.2	4.08	5.51	347	3.1	5.81	4.8	2.98
376	3.5	2.88	5.31	6.19	407	1.71	1.46	3.95	7.54
Jam	3.56	9.11	4.27	4.09	Pyrooz	1.54	4.59	4.82	4.58
Koorosh	3.06	3.95	3.93	5.46	Kaka	1.57	2.92	6.37	5.08

Crop Growth Rate (CGR) is considered as an integrated expression of both transpiration and transpiration efficiency, which could simply be measured at large-scale field studies. The CGR seems to be one of the determinant traits of chickpea grain yield in the field studies, as it had more values than the population means in both ideal Desi and Kabuli genotypes as well as fewer values than the population means in susceptible genotypes in both irrigation conditions. There was a significant positive correlation between the CGR and GY in both chickpea types grown in either irrigation conditions. This positive relationship has also been observed in the studies at semi-arid tropics, indicating that CGR can be considered among reliable conferring terminal drought tolerance traits in both the growing chickpea regions.

The Kabuli chickpeas had more SDM compared to Desi ones at both irrigation conditions. However, the terminal drought reduced the SDM of Kabuli chickpeas (43.37%) more than Desi ones (40.72%). In addition, the strength of the contribution of SDM on GY was dissimilar between Desi and Kabuli chickpeas. For Kabuli chickpeas, the SDM had the greatest direct effect on the GY in the full-irrigated conditions, but the effect was poor under terminal drought. Desi chickpeas, however, showed an inverse manner of this effect under the two irrigation conditions. Biomass production could be considered as one of the most important traits in chickpea breeding because it has shown the most contribution to chickpea grain yield whether for optimal irrigation or for terminal drought and even under salinity conditions. The biomass production is known as a function of plant transpiration efficiency, which is defined as the ratio of biomass produced per unit of water transpired. Farooq, et al. stated that transpiration efficiency in Desi type is more than in Kabuli type under water-limited conditions [14]. Desi chickpeas had also more SDM relative to Kabuli ones under purely rain-fed conditions in India. Besides, the less reduction of SDM of Desi chickpea limited water conditions in the present study showed that this chickpea type might be more talented in producing dry matter underwater constraint conditions. Hence, the more total SDM of Kabuli chickpea in the present study is likely due to its more adaptation than Desi type to chickpea growing areas in Iran, especially that the transpiration efficiency is predominantly affected by climatic factors such as temperature, air vapor pressure deficit, solar radiation, etc.

Terminal drought reduced GW of Kabuli chickpeas by 2.82%, while increased GW of Desi chickpeas by 2.22% compared to full-irrigated conditions. Behboudian, et al. also reported terminal drought did not decrease GW but also increased the accumulation of soluble sugars, amino acids, and proteins in grains of Desi chickpeas [15]. Noor, et al. proposed additive gene effects for GW of chickpea-based on high heritability with the high genetic advance in rain-fed conditions [16]. Although the significant positive relationship between GW under terminal drought and GW under optimal irrigation conditions provides a selection for GW of chickpeas for terminal drought through an indirect selection in optimal irrigation conditions, the ideal genotypes of Kabuli and Desi chickpeas were ranked in 12th and 7th within their own populations, respectively. Therefore, it could be suggested that the selection of large-grained genotypes may not be associated with more terminal drought tolerance in chickpea.

A relationship significant in 0.01 probability level confirmed that 33% of GN in Desi type yielded under terminal drought conditions could be explained by the inherent potential of the crop. However, this relationship was not observed in Kabuli genotypes. In Desi and Kabuli chickpea genotypes, terminal drought decreased up to 44.71% and up to 50.10% of GN, respectively. GN of tested genotypes was influenced by water limitation more than other attributes. STI and HM indices were the best indicators to select genotypes having more GN in Kabuli and Desi chickpeas, respectively. GN had a positive effect on GY at both chickpea types and conditions, which was in agreement with Pushpavalli, et al. [17].

The greatest direct effect on HI has belonged to GN in both chickpea types either in stress and non-stress conditions. Although HI in Kabuli genotypes did not affect directly by SDM, in Desi genotypes the SDM had a positive effect on HI, which could be evidence of the photosynthetic mobilization to grains. On the other, at both chickpea types, there was not any correlation between HI and the drought tolerance indices in water-limited conditions. However, some of the indices such as GMP, MP, ATI, TOL, and K1STI in Kabuli type as well as TOL and ATI in Desi showed positive and significant correlations with HI under full irrigation conditions. According to these results, it seems that the improvement of HI in chickpeas grown under optimal water conditions is a straighter approach than selection under terminal water stress.

Considering the non-significant estimated genotypic variance of GY in the combined analysis, which could be due to the complexity of involved mechanisms, it seems that indirect selection through each of GW, SDM, and GN could result in more repeatable outcomes. Breeding for drought tolerance by selection based on GY solely is difficult, because of the low heritability of GY under drought conditions, which is due to small genotypic variance or large genotype by environment interaction variances. Environmental factors highly influenced the genetic structure and phenotypic expression of a quantitative trait such as GY, thus genotype by environment interactions is a major barrier for understanding that of inheritance. The contribution of genotypic variances as equivalent to the heritability of GY, GN, GW, and SDM in Desi chickpeas were greater in full irrigation conditions than water-limited condition. Hence, it could be said that selection without terminal drought conditions will lead to more repeatable results than selection under terminal water stress. In Kabuli chickpeas, however, the greater genotypic variances were detected for GN and SDM in full irrigation condition, and for GY and GW were observed under limited-water condition. Therefore, according to the objectives of the selection, doing this selection under conditions with greater genotypic variances dedicated to each trait is better. Hence, as Desi chickpea genotypes 8, 10, 47, and 321 showed significant positive predicted genotypic effects under optimal conditions for the selection, involving these genotypes in multi-parent recombination crosses could be resulting in increased efficiency performance. In Kabuli chickpeas, the genotypes 101, 21, 15, 25, and 166 were detected as those of better ones with significant positive predicted genotypic effects.

According to Yan and Kang, an ideal genotype should have a high yield mean among stress and non-stress environments as well as show high stable performance [18]. Rad, et al. stated that the ideal genotype could be found in the center of the concentric circles of AEC method analysis [19]. As AEC abscissa direction toward more stable grain yield, as shown in Figure 6, the ideal chickpea genotypes have been presented closely to the location of the limited water environment as well as the average environment. As a result, which found consistent with Golabadi, et al. in durum wheat concluded that for high stable grain yield, selection of chickpea in moisture-stress environments as well as based on the average of drought stress and non-drought stress conditions could be more advantageous compared with indirect selection only at the non-drought stress conditions [20].

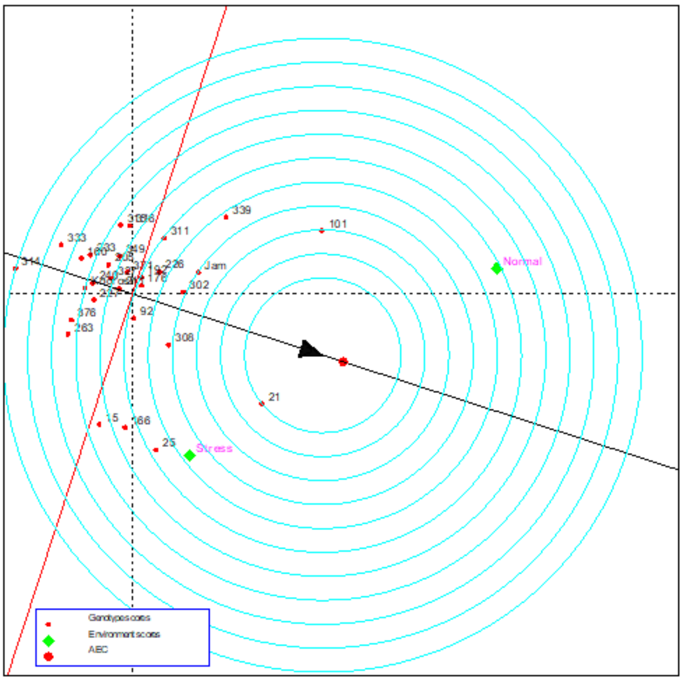

Figure 6) *GGE biplot analysis based on principal component analysis as justified 83.34% and 16.66% by PC1 (horizontal axis) and PC2 (vertical axis), respectively, genotype-focused scaling for comparison Kabuli chickpea genotypes with the ideal genotype. Black numbers stand for genotypes*

CONCLUSION

Results of this study showed that tested chickpea genotypes responded differently under different water treatments, suggesting the importance of assessment of genotypes under these conditions in order to identify the best genotype make up for each particular condition. As water stress severity was applied equally, therefore it was thought to be more serious in genotypes with a greater life cycle. However, it seems that chickpea plants have been adapted to the terminal drought stress, which could be due to the same time of vegetative growth with filling pods and transfer capability of photosynthesis assimilates towards more grain yield in tolerant genotypes. It seems to change in plant phenology due to the terminal drought stress more affected GN and GW in Desi and Kabuli chickpeas, respectively. These differences could be clear points for the leadership of breeding programs towards more adaptation of both Desi and Kabuli chickpea types to terminal water stress, respectively. Moderate to the high proportion of G × E effects were observed in combined analysis for GY, GN, and SDM compared to genotypic effects, suggesting that G × E effects played a greater role than genotypic effects. The ideal genotype of Kabuli type *i.e.*, genotype 25 had greater GY as well as SDM in water-limited conditions, while genotype 321 as ideal Desi genotype showed acceptable GY and SDM, but could be compensated with higher GN.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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