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Identification of diverse agronomic traits in chickpea (*Cicer arietinum* L.) germplasm lines to use in crop improvement

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Abstract

A chickpea (*Cicer arietinum* L.) collection consisting of 445 Kabuli-type collected from different locations of Iran was evaluated based on six qualitative and 14 quantitative morphological descriptors. Chickpea accessions were widely varied in plant height, the number of pods per plant, plant dry weight, 100-grain weight, grain yield, and harvest index. Grain yield was positively correlated with the number of pods per plant ($r = 0.39^{**}$), pod fertility percentage ($r = 0.42^{**}$), dry weight per plant ($r = 0.88^{**}$), and harvest index ($r = 0.30^{**}$). The highest value for the Shannon–Weaver diversity index was observed in growth habit (0.98) and leaf color (0.88). The first and second components of the principal component analysis (PCA) explained 17.97% and 16.20% of the total variations, respectively. The cluster analysis results revealed that the accessions with higher pod, leaflet, and peduncle length were grouped in cluster I, whereas cluster II indicated the dominant contribution for the number of pods per plant, plant dry weight, and grain yield. The highest phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) were observed for grain yield per plant (44.3% and 48.3%), the number of pods per plant (44.3% and 45.1%), and dry weight per plant (44.4% and 44.8%). The heritability estimates were also more significant for the number of pods per plant, plant dry weight, and harvest index. These accessions might be used in the chickpea breeding programs to expand high-yielding Kabuli-type cultivars with a broad genetic base.

KEYWORDS

chickpea accessions, descriptors, heritability, principal component, Shannon–Weaver diversity index

1 | INTRODUCTION

Chickpea (*Cicer arietinum* L.) is an important grain legume crop with an annual production of ~15 M tonnes, which is globally cultivated in ~15 M ha with average productivity of 1000 kg ha^{-1} (Bapurao et al., 2018; FAO, 2022). India (65%), Pakistan (7%), Turkey (7%), and Iran (3%) are considered the main chickpea-producing countries in Asia (FAO, 2014). Chickpea with the ability to biological nitrogen fixation at a rate up to 140 kg N ha^{-1} year^{-1}, plays an essential role in preserving soil fertility and health (Flowers et al., 2010). Two types of chickpeas, including desi and Kabuli, are recognized; the Kabuli-type has owl-shaped, large cream-colored grains, whereas the desi-type has angular-shaped (Upadhyaya et al., 2006). The desi-type is mainly consumed in Asia and accounts for nearly 80% of global chickpea production and equally plays a role in the total chickpea trade (Archak et al., 2016).

Models for estimating genetic diversity, including molecular markers or morphological traits, can be diverse (Rao et al., 2007). Such quantitative characteristics as cluster analyses and principal component analysis (PCA) provide estimations of genetic diversity (Ghafoor et al., 2001); these have been utilized successfully in classifying and measuring the genetic pattern variations in plant germplasms (Seid et al., 2021). The PCA and cluster analysis provide methodical and efficient ways of estimating the genetic diversity of agromorphological traits in plants, including chickpea (Gupta et al., 2011; Kayan & Adak, 2012; Parameshwarappa et al., 2011). Upadhyaya et al. (2006) developed a chickpea core collection consisting of 1956 accessions to increase the utilization of chickpea genetic resources in breeding programs, representing 84% and 100% of the variation range of the entire collection in plant height, 100-grain weight, numbers of pods per plant, days to maturity, and grain yield. Working on 13 chickpea accessions, Khan et al. (2006) reported that although the genotypic coefficient of variation was relatively low for days to flowering, days to maturity, plant height, and the number of pods per plant, it was high for 100-grain weight.

Besides the lack of adapted varieties, several biotic and abiotic stresses contribute to the fluctuations in chickpea yield (Rasool et al., 2015). Ascochyta blight (*Ascochyta rabiei*), phytophthora root rot (*Phytophthora medicaginis*), Fusarium wilt (*Fusarium oxysporum* f. sp. Ciceri), and Botrytis gray mold (*Botrytis cinerea Pers*. ex Fr.) (Ahmad et al., 2005; Knights et al., 2008; Nabati et al., 2021; Singh et al., 2008), and drought, extreme temperatures, and salinity are among biotic and abiotic stresses, respectively, that significantly limit the chickpea productivity (Jha et al., 2014; Nabati et al., 2021). Furthermore, low genetic variation for yield, yield components, and the resistance to major diseases are the main limitation to reaching high yield potential (Malik et al., 2014). Therefore, the wide use of few and closely related germplasm in crop improvement may lead to the vulnerability of newly developed cultivars to pests and diseases (Govindaraj et al., 2015). As a result, it is necessary to identify the different germplasm characteristics of a plant because it provides information about the available variety and helps to choose one or more specific traits (Kathiresan, 2000).

The purpose of this study was the management of the germplasm bank of the Mashhad Chickpea Collection (MCC) at the Research Center for Plant Sciences, Ferdowsi University of Mashhad, Iran. To this, morphological and phenological traits were studied in 445 Kabuli-type chickpeas to enhance their genetic potential, and chickpea accessions with low maintenance values were removed.

2 | MATERIALS AND METHODS

2.1 | Plant material and experimental design

Chickpea Seed Collection at the Research Center for Plant Sciences, Ferdowsi University of Mashhad, is one of the most important chickpea seed collections in Iran. This collection was gathered from different agro-ecological regions of Iran. Four hundred forty-five Kabuli-type chickpea accessions were planted in early March in a field experiment at the Faculty of Agriculture, Ferdowsi University of Mashhad, in 2020 (36°15′ N and 59°38′ E, and an altitude of 985 m). Seeds of each accession were sown on four rows (with and within row space of 50 and 5 cm, respectively) in plots of 4 m long and 1.5 m apart. The plots were surface irrigated twice (once after planting and once at the flowering stage). Hand weeding was performed twice in mid-April and mid-May. To control the legume pod borer (*Heliothis viriplaca*), indoxacarb (Sc 15%; 200 ml ha^{-1}) and carbaryl (Wp 85%, 3 Kg ha^{-1}) were foliar applied twice at the flowering stage at one-week intervals, respectively. Climate data during the experiment are presented in Figure 1.

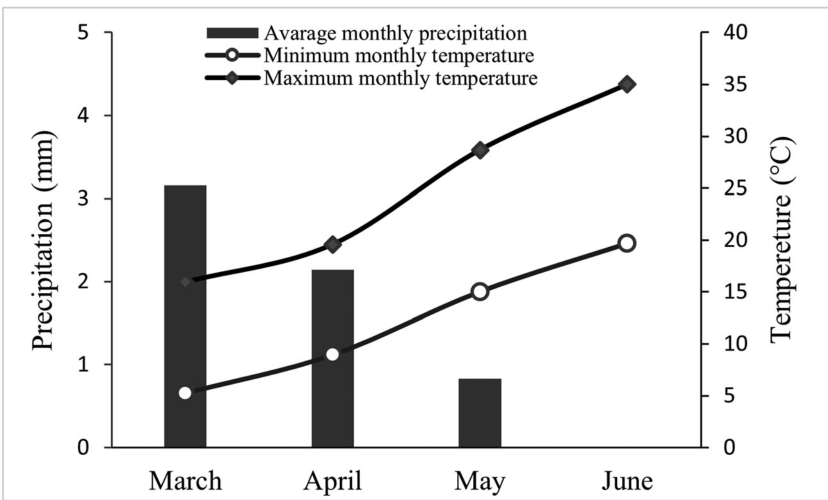


FIGURE 1 Weather characteristics of the experimental field

2.2 | Agromorphological descriptors used for characterization

Twenty agromorphological traits (six qualitative and 14 quantitative) were considered for characterization per a list of descriptors presented by Mahajan et al. (2000). The qualitative traits were growth habit (GH), seed color (SC), seed shape (SS), seed texture (ST), flower color (FC), and leaf color (LC). The quantitative traits included days to 50% emergence (DE), days from 50% emergence to 50% flowering (DF), plant height (PH), number of leaflets per leaf (NLPL), leaflet length (LL), peduncle length (PEL), pod length (POL), number of branches per plant (NBPP), number of pods per plant (NPP), pod fertility percentage (FP), plant dry weight (PDW), 100-grain weight (SDWT), grain yield per plant (SYPP), and harvest index (HI).

2.3 | Statistical analysis

The experiment was carried out in a randomized complete block design replicated three times. The descriptive statistics—range, mean, and standard deviation—of the accessions were computed. A chi-square test for qualitative traits was performed to evaluate the similarity of the distribution frequencies in chickpea collections. The Shannon–Weaver diversity index (H′) was measured using the phenotypic frequencies of qualitative characters (Shannon & Weaver, 1949). Correlation coefficients were estimated to determine the level of the interrelationship between the traits.

The PCA and cluster analyses were also conducted to analyze morphogenetic traits (Sneath & Sokal, 1973). The cluster analysis was performed using Ward's minimum variance dendrogram clustering (Ward, 1963). The PCA was performed to determine the characters accounted for the total variation. The data were standardized before computing principal calculating analysis. The estimation of genetic parameters, which included phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), and heritability (H_2), as a whole, gives an idea of the mode of gene action in the expression of a character (Burton & Devane, 1952; Jandong et al., 2020; Johnson et al., 1955; Majidi et al., 2009).

$$Genetic\ Variance = \frac{Genotype\ Mean\ Square\,(GMS) - Error\ Mean\ Square\,(EMS)}{Number\ of\ replications\,(r)} \quad (1)$$

Environmental Variance (Ve) and error mean square (EMS)

$$Genetic\ Variance = \frac{Genotypic\ Variance\,(Vg) + Environmental\ Variance\,(Ve)}{Number\ of\ replications\,(r)} \quad (2)$$

Genotypic, phenotypic, and environmental coefficients of variation were calculated as follows:

$$PCV\% = \frac{\frac{\sqrt{Vp}}{X} * 100\, GCV\% = \sqrt{Vg}}{X} * 100 \quad (3)$$

where $PCV\%$ = phenotypic coefficient of variation, Vg = genotypic variance, Vp = phenotypic variance, $GCV\%$ = genotypic coefficient of variation, and X = average trait.

Heritability (H2) on entry mean basis was calculated as follows:

$$H2 = \frac{Vg}{Vp} \quad (4)$$

Expected genetic advance (GA) was calculated as:

$$GA = \mathrm{K} \times H2 \times \sqrt{Vp} \quad (5)$$

where K = 2.06 at 5% selection intensity, $H2$ = heritability, and Vp = phenotypic variance.

The statistical analyses were performed using Excel, SAS 9.1, and JMP 4.1.

3 | RESULT

3.1 | Agromorphological variation in chickpea germplasm

Means and ranges for 14 quantitative characteristics of the 445 chickpea accessions are presented in Table 1. The days to 50% emergence in 98% of chickpea accessions were between 50 and 60 days. A wide range was also observed for the days from 50% emergence to 50% flowering: <50 days in 33% of chickpea accessions (145 samples), between 50 and 60 days in 65% of the accessions (288 samples), and >60 days in 12 accessions (Table 1). The plant height of chickpea accessions was significantly varied. Plant height varied between 10 and 50 cm in chickpea accessions. The highest frequency of the accessions was in the range of 21–30 cm (Figure 2a).

Among chickpea accessions, semi-erected type (55.9%) was the major plant growth habit (Figure 2a). The frequency distribution of the qualitative descriptors showed homogeneity of distribution in six traits, whereas significant differences ($p \le 0.05$) observed in growth habit, seed color, seed shape, testa texture, flower color, and leaf color ($p \le 0.0001$) confirmed the homogeneity of the distribution in chickpea accessions (Table 2). The H′ of the growth habit (0.98) and leaf color (0.88) showed the highest value, indicating the high diversity of these traits (Table 2).

3.2 | Yield and yield components

Chickpea germplasm showed a wide range of yield and yield components (Table 1). The number of pods per plant widely ranged from 7 to 262. Among the accessions, 39% had <50, 54% had 100–50, and

TABLE 1 Descriptive statistic results for agronomic traits among accessions of Kabuli-type chickpea

Traits	Range	Mean	Genotypes that have a grain yield of more than 21 g·plant^{-1}
DE	13–21	17	14–21
DF	43–62	52.5	45–62
PH (cm)	11.3–48.7	30	11.3–42.3
NBPP	1.67–7	4.33	3–6.33
NLPL	9.70–19.0	14.35	11.5–18.3
LL (cm)	0.67–2.10	1.38	1.03–1.87
PEL (cm)	1.20–3.33	2.26	1.30–2.83
PL	1.70–3.57	2.63	1.80–3.03
NPP	7.33–262	134.66	17–262
FP (%)	24–97	60.5	67–96
SDWT (g)	6.74–41.99	24.36	6.74–38.65
PDW (g)	6.48–119.73	63.10	30.6–119.73
SYPP (g)	0.43–41.65	21.04	20.9–41.7
HI (%)	4–95	49.5	31–78

Abbreviations: DE, days to 50% emergence; DF, days from 50% emerging to 50% flowering; FP, pod fertility percentage; HI, harvest index; LL, leaf length; NBPP, number of branches per plant; PL, pod length; NLPL, number of leaflets per leaf; NPP, number of pods per plant; PDW, plant dry weight; PEL, peduncle length; PH, plant height; SDWT, 100-seed weight; SYPP, seed yield per plant.

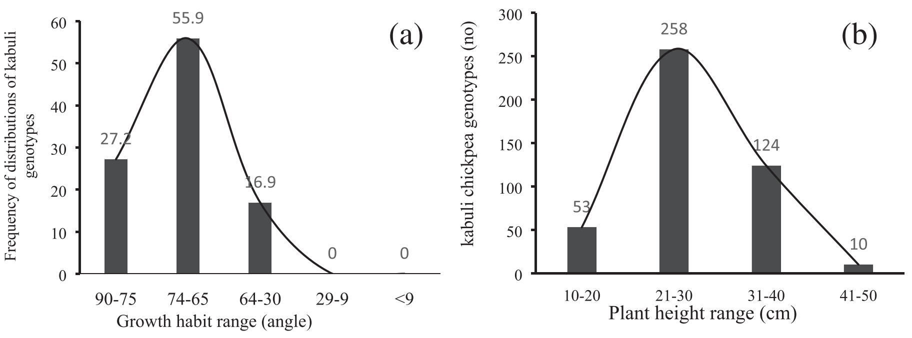


FIGURE 2 Chickpea accessions in different plant height (a) and growth habit (b) ranges

TABLE 2 Chi-square test for comparison of frequency distribution and Shannon–Weaver diversity index for qualitative traits in Kabuli chickpea

	Plant growth habit	Seed color	Seed shape	Testa texture	Flower color	Leaf color
χ^2 value	106.37	534.23	324.21	340.91	536.74	591.05
p value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
H′	0.98	0.59	0.34	0.30	0.09	0.88

Note: H′, Shannon–Weaver diversity index.

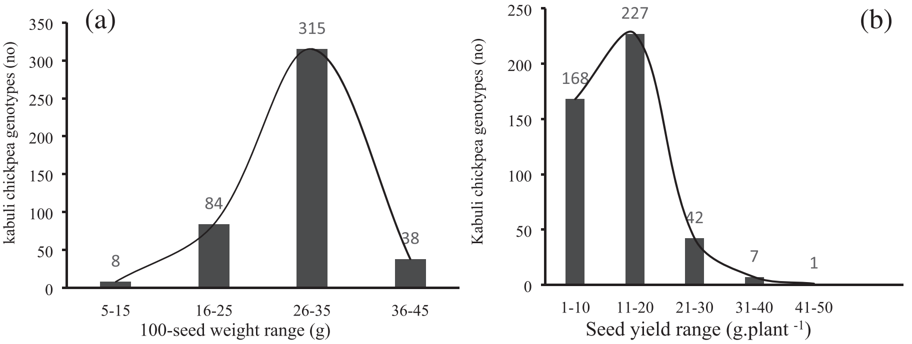


FIGURE 3 Chickpea accessions in different 100-seed weight (a) and grain yield (b) ranges

TABLE 3 Mean and deviation from mean of groups in cluster analysis for traits in Kabuli chickpea accessions under the field conditions

Group	1		2		3		4		5		6	
Accessions	MCC1310, MCC1235, MCC1445, MCC2177, MCC1394, MCC2162, MCC2092, MCC1446		MCC2100, MCC1460		MCC2075, MCC2137, MCC2164, MCC1450, MCC2163, MCC1082, MCC1574, MCC1282		MCC1443, MCC1823, MCC1568, MCC1307, MCC1527, MCC1552, MCC1629		MCC1440, MCC1262, MCC1454, MCC1457, MCC1906, MCC2135, MCC1238, MCC1987, MCC1992, MCC1402, MCC1425		MCC1783, MCC2105, MCC2102, MCC1826, MCC2084, MCC2113, MCC1447, MCC1456, MCC1973, MCC1775, MCC1076, MCC1401, MCC1917, MCC2166	
Traits	Group mean	Deviation from mean	Group mean	Deviation from mean	Group mean	Deviation from mean	Group mean	Deviation from mean	Group mean	Deviation from mean	Group mean	Deviation from mean
DE	17.2	0.434	15.2	−1.56	16.6	−0.202	17.4	0.605	18.1	1.27	15.6	−1.21
DF	49.4	−2.47	49.0	−2.84	56.1	4.29	57.0	5.16	50.9	−0.931	49.4	−2.48
PH (cm)	26.0	1.09	22.3	−2.62	29.3	4.34	30.2	5.28	20.9	−3.97	22.7	−2.24
NBPP	3.63	−0.458	4.17	0.083	4.40	0.313	3.90	−0.179	3.85	−0.235	4.43	0.345
NLPL	14.3	−0.130	15.1	0.703	13.9	−0.443	14.1	−0.285	14.9	0.589	14.3	−0.094
LL (cm)	1.48	0.029	1.58	0.125	1.50	0.055	1.46	0.012	1.35	−0.104	1.46	0.010
PEL (cm)	2.47	0.409	2.66	0.601	2.09	0.041	1.94	−0.115	1.70	−0.357	2.05	−0.005
PL	2.63	0.225	2.77	0.359	2.27	−0.137	2.52	0.116	2.17	−0.235	2.43	0.025
NPP	72.8	−8.835	93.0	11.4	142	60.4	59.9	−21.7	82.8	1.22	60.4	−21.2
FP (%)	83.1	−5.710	89.2	0.422	88.6	−0.186	90.4	1.59	90.5	1.69	90.0	1.19
SDWT (g)	24.2	−3.996	35.0	6.82	25.3	−2.87	28.9	0.814	28.7	0.554	30.3	2.11
PDW (g)	59.4	5.283	96.5	42.4	72.3	18.2	35.9	−18.1	52.3	−1.85	45.1	−8.96
SYPP (g)	26.8	0.736	39.8	13.8	29.0	2.98	24.7	−1.49	24.6	−1.42	24.4	−1.62
HI (%)	46.3	−4.288	41.2	−9.36	42.1	−8.53	65.2	14.6	48.3	−2.34	53.8	3.19

Abbreviations: DE, days to 50% emergence; DF, days from 50% emerging to 50% flowering; FP, pod fertility percentage; HI, harvest index; LL, leaf length; MCC, Mashhad Chickpea Collection; NBPP, number of branches per plant; PL, pods length; NLPL, number of leaflets per leaf; NPP, number of pods per plant; PDWT, plant dry weight; PEL, peduncle length; PH, plant height; SDWT, 100-seed weight; SYPP, seed yield per plant.

7% had >100 pods per plant (Table 1). The pod fertility percentage ranged from 38% to 97%. The highest frequency of 100-grain weight was observed between 26 and 35 g in 71% of 315 accessions (Figure 3a).

There was considerable variation in plant dry weight and grain yield in chickpea accessions (Table 1). The harvest index of chickpea accessions also widely ranged from 4 to 95 (Table 1). The results showed that 51% of the accessions had 11–20 g, 38% had >10 g, and 11% (50 accessions) had >21 g grain yield per plant (Figure 5).

3.3 | Cluster analysis

Based on a grain yield of >21 g plant^{-1}, 50 accessions of chickpeas were selected, and cluster analysis was performed. Clusters analysis showed the distribution of accessions according to the adjusted mean of 14 traits (Table 3). The accessions were grouped into six clusters (Figure 4). The highest mean values for 100-grain weight, plant dry weight, and grain yield were recorded from cluster II (MCC2100, MCC1460). Cluster V was classified by days to 50% emerging, pod per plant, and filled pod percentage. The maximum mean values of days from 50% emerging to 50% flowering, plant height, and harvest index were recorded from accessions in clusters III, VI, and VI, respectively (Table 3).

3.4 | PCA

The PCA summarizes the important information of the data and lowers the number of traits responsible for the maximum percentage of overall variation of the experimental data (Figure 5a). The PCA1 explained 17.97% of the total variation, and three traits showed positive contribution value; major contributors in the variation were pod length, leaflet length, and peduncle length. The PCA2 explained 16.20% of the total variation, and the traits with major contributions in this component were the number of leaflets per leaf, number of pods per plant, plant dry weight, and plant grain yield (Figure 5b). The accessions related to cluster IV, despite being superior in the number of days from 50% emergence to 50% flowering, plant height, and harvest index, were not included in the main components in the analysis dimensions.

3.5 | Genetic analysis

Table 4 depicts the quantitative data for the 14 agromorphological traits. The GCV, PCV, and heritability provide an idea of the mode of gene action in the expression of a trait. The highest PCV and GCV were recorded for grain yield per plant (44.3% and 48.3%), the number of pods per plant (44.3% and 45.1%), and dry weight per plant (44.4% and 44.8%). Heritability estimates were greater for the number of pods per plant (96.4%), dry weight per plant (92.9%), and harvest index (90%) in the chickpea accessions. Harvest index (18.53) and percentage of fertile pods (14.89) expressed high GA. The high value of heritability coupled with high to moderate GA was observed in the percentage of fertile pods, 100-seed weight, plant dry weight, and harvest index.

3.6 | The correlations between yield and yield components

Grain yield showed positive correlations with the number of pods per plant (0.39**), pod fertility percentage (0.42**), dry weight per plant

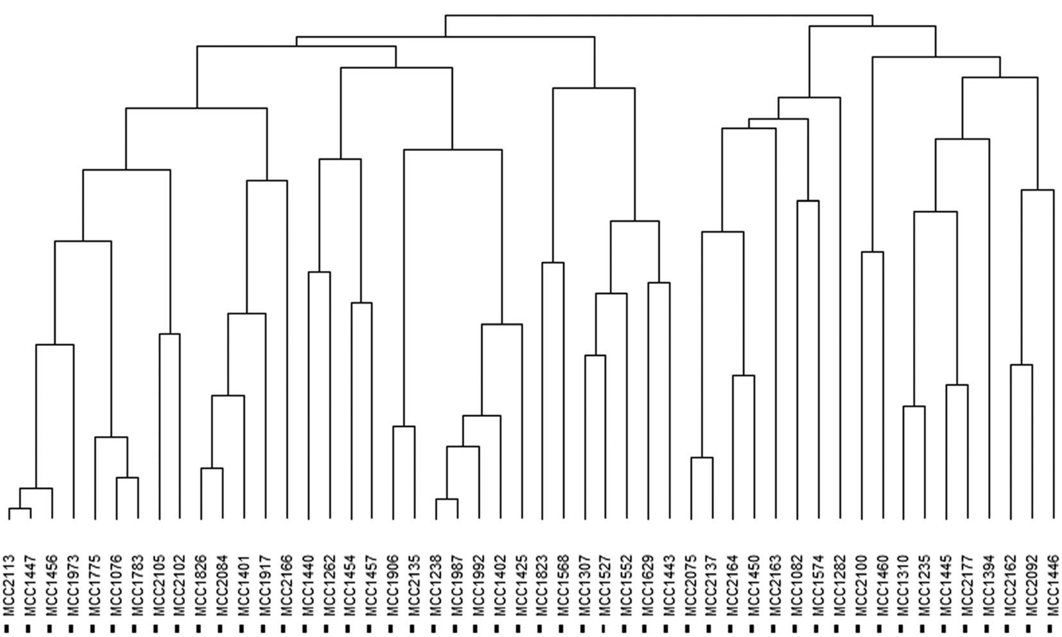
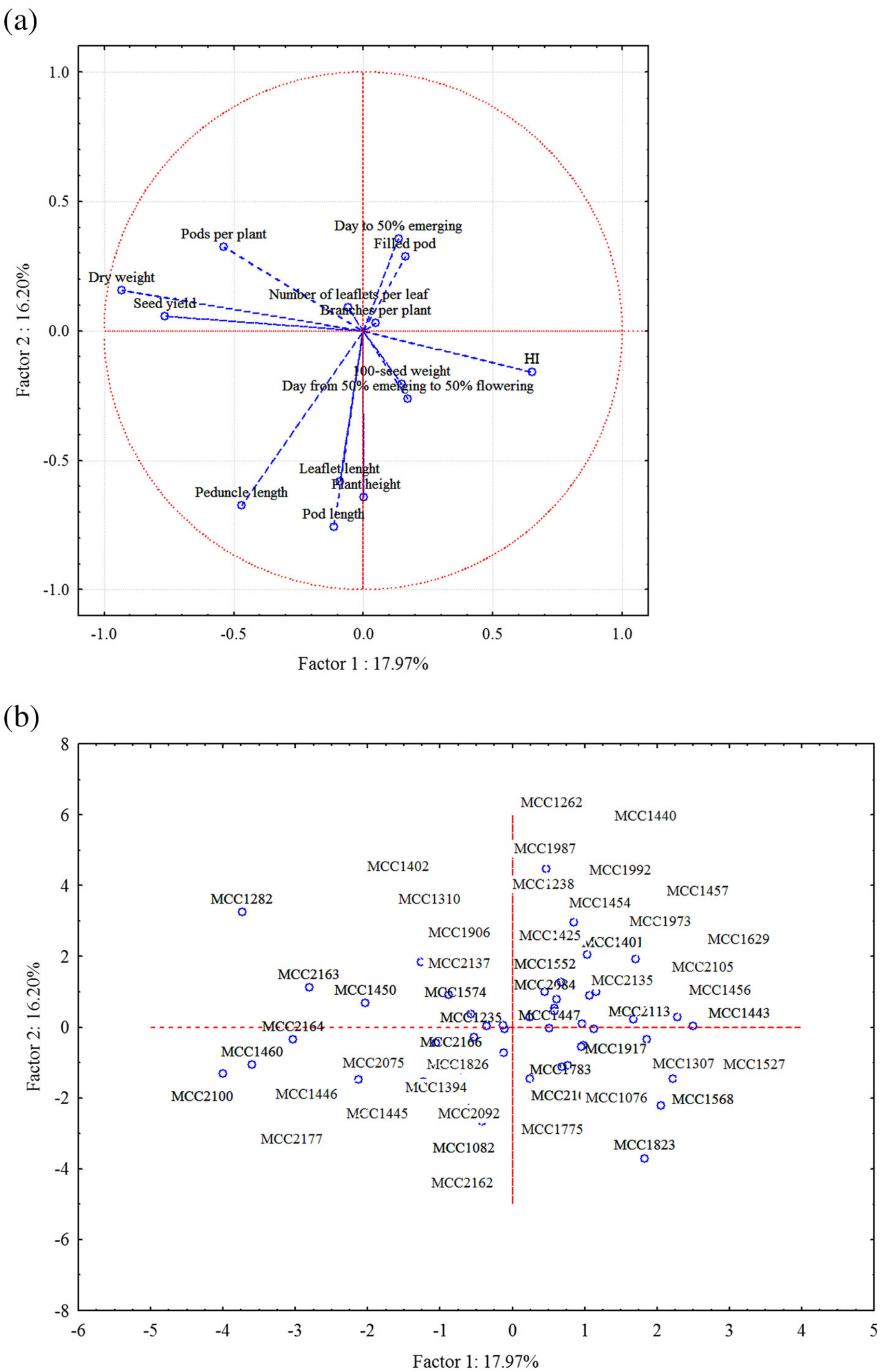


FIGURE 4 Cluster grouping of Kabuli chickpea accessions based on studied characteristic under field conditions. MCC, Mashhad Chickpea Collection

FIGURE 5 Biplot based on two major principal component (PC) factors in Kabuli-type chickpea accessions. HI, harvest index



(0.88**), and harvest index (0.30**) (Table 5). A positive correlation was also observed between the number of days to emergence with the days to flowering, plant height, 100-grain weight, and plant dry weight (Table 5).

4 | DISCUSSION

For effective and efficient germplasm collections in breeding programs, the description of agronomically important traits is an essential prerequisite (Byrne et al., 2018). Thus, the evaluation of morphological traits, individually or in combinations, is necessary to identify populations with desired characteristics (Archak et al., 2016). Descriptor development is one of the first systematic attempts to document plant species diversity. A genetic statistical method for evaluating intraspecies diversity through morphological genes was proposed by Smiryaev and Bocharnikova (2002). Similar studies were carried out to develop descriptors for medicinal and aromatic herbs (Singh et al., 2003), fruit trees (subtropical and tropical) (Mahajan et al., 2002), cereals (Mahajan et al., 2000), and vegetables (Srivastava et al., 2001).

In the present study, ample variabilities were observed for both quantitative and qualitative traits in the chickpea germplasm. The variability of the 20 traits was documented by developing appropriate descriptors. In this study, 445 accessions of Kabuli-type chickpeas were examined. Wide range values were observed for plant height, the number of pods per plant, plant dry weight, 100-grain weight, grain yield, the number of branches per plant, and harvest index. Higher values of variances in plant height, 100-grain weight, and the number of pods per plant were also reported by previous studies in chickpea accessions. This indicates the importance of these traits in increasing plant productivity (Archak et al., 2016; Khan et al., 2006; Malik et al., 2014).

Low variability observed in some traits, namely, days to 50% emergence and days from 50% emergence to 50% flowering, indicates the limitation of selection based on these traits in the accessions. Analyzing yield components and their relative contribution to yield provides a better opportunity to select high-yielding accessions (Malik et al., 2014). More than 1000 morphological markers have been identified in barley (*Hordeum vulgare*) (Dhanapal & Govindaraj, 2015). A set of descriptors for *Jatropha curcas* and guayule (*Parthenium argentatum* Gray) were also developed based on the germplasm collected around India by Sunil et al. (2013) and Coffelt and Johnson (2011), respectively.

The frequency distribution of the six qualitative descriptors (plant growth habit, seed color, seed shape, testa texture, flower color, and leaf color) revealed a different degree of variation for different traits. The Shannon–Weaver diversity index (H′) is used in genetic studies as a convenient measurement of both allelic richness and evenness (Upadhyaya et al., 2006). The H′ index was estimated to compare phenotypic variety. The value of H′ for growth habit and leaf color showed the highest values, indicating the high diversity of those traits. These findings are in agreement with Archak et al. (2016). The H′ for testa texture and flower color was low, which indicated a lack of

TABLE 4 Estimation of genetic parameters for different traits in chickpea

Traits	VG	VP	GCV	PCV	H^2	GA
DE	1.43	3.22	7.35	11.04	44.31	1.64
DF	9.08	12.63	5.85	6.90	71.92	5.27
PH (cm)	42.91	65.71	41.21	29.45	65.30	10.90
NBPP	0.28	1.03	13.64	26.16	27.18	0.57
NLPL	0.12	0.18	28.56	20.10	67.27	0.59
LL (cm)	1.70	4.76	15.48	14.95	35.71	1.60
PEL	0.01	0.06	13.86	16.73	22.88	0.12
PL	0.17	0.21	16.54	18.73	78.04	0.74
NPP	7.32	7.59	44.30	45.12	96.38	5.47
FP (%)	59.56	67.84	8.91	9.51	87.78	14.89
SDWT (g)	20.18	25.19	15.47	17.29	80.10	8.28
PDW (g)	18.1	19.5	46.82	48.59	92.86	8.45
SYPP (g)	32.58	38.80	44.25	48.26	83.96	10.77
HI (%)	89.88	99.86	35.73	39.54	90.00	18.53

Abbreviations: DE, days to 50% emergence; DF, days from 50% emerging to 50% flowering; FP, percentage of fertile pods; GA, genetic advance; GCV, genotypic coefficient of variation; HI, harvest index; H^2, heritability; LL, leaf length; NBPP, number of branches per plant; PL, pods length; NLPL, number of leaflets per leaf; NPP, number of pods per plant; PCV, phenotypic coefficient of variation; PDW, plant dry weight; PEL, peduncle length; PH, plant height; SDWT, 100-seed weight; SYPP, seed yield per plant; VG, genotypic variation; VP, phenotypic variation.

TABLE 5 Correlation coefficients of quantitative descriptors in Kabuli collections

Trait	DE	DF	PH	NBPP	NLPL	LL	PEL	PL	NPP	FP	SDWT	PDWT	SYPP	HI
DE	1													
DF	0.19**	1												
PH (cm)	0.16*	0.43**	1											
NBPP	−0.06	0.04	0.08	1										
NLPL	−0.05	0.02	0.01	−0.11	1									
LL (cm)	0.20**	0.10	0.13	−0.06	−0.09	1								
PEL	0.22**	0.07	0.44**	−0.04	0.12	0.04	1							
NLL	−0.02	0.02	0.11	−0.11	0.56**	−0.07	0.19**	1						
NPP	0.01	−0.08	−0.05	0.00	0.20**	0.24**	0.01	0.15	1					
FP (%)	0.02	−0.05	−0.05	−0.09	0.06	−0.08	0.02	0.00	0.09	1				
SDWT (g)	0.16*	−0.06	0.12	0.39*	0.20	−0.03	0.26**	0.34**	0.05	0.23**	1			
PDW (g)	0.17**	0.03	0.00	0.05	−0.05	−0.05	0.01	0.01	0.47**	0.15	0.00	1		
SYPP (g)	0.16*	−0.02	−0.08	0.06	−0.08	−0.03	−0.04	−0.01	0.39**	0.42**	0.10	0.88**	1	
HI (%)	−0.03	0.16*	−0.17	−0.01	−0.07	0.07	−0.14	−0.02	0.12	0.28	0.28	−0.13	0.30**	1

Abbreviations: DE, days to 50% emergence; DF, days from 50% emerging to 50% flowering; FP, pod fertility percentage; HI, harvest index; LL, leaf length; NBPP, number of branches per plant; PL, pods length; NLPL, number of leaflets per leaf; NPP, number of pods per plant; PDW, plant dry weight; PEL, peduncle length; PH, plant height; SDWT, 100-seed weight; SYPP, seed yield per plant. * and ** significant at 0.05 and 0.01 probability levels.

genetic variation and eminently unbalanced frequency classes for an individual trait.

The accessions can be grouped by cluster analysis based on morphogenetic traits. Such multivariate methods of analysis as the PCA and cluster analysis revealed the germplasm clustering in black gram (*Vigna mungo*) (Ghafoor et al., 2001), sorghum (*Sorghum bicolor*) (Grenier et al., 2001), sugarcane (*Saccharum officinarum*) (Tai & Miller, 2002), and chickpea (*C. arietinum*) (Agrawal et al., 2018; Tsehaye & Fikre, 2020). The results of the PCA analysis and biplot of chickpea accessions showed that PCA1 described 17.97% of variations in leaflet traits, the number of pods per plant, plant dry weight, and grain yield. While the PCA2 explained most of the traits related to plant grain yield by 16.20%. On the other hand, MCC2162, MCC1082, MCC2092, MCC1394, MCC2166, MCC1826, MCC2075, MCC1460, MCC2164, MCC2100, MCC2177, and MCC1446 showed desired phenological characteristics such as pod, peduncle, and leaflet length. In our study, the results of correlation coefficients were supported by the cluster analysis, which indicates that the yield of chickpeas can be increased by simultaneously improving plant height, the number of branches, and the number of pods per plant, accumulating in one accession (Zali et al., 2011).

The values of genotypic and phenotypic variation coefficients for the traits given in Table 5 indicated significant variations among the accessions. The degree of variation in phenotypic traits associated with genetic variation is measured by heritability (Barreto et al., 2021). It suggests the likelihood of a selection benefit and/or a correlation response based on a range of environmental variables related to crop production (Malosetti et al., 2013; Nayak et al., 2014). The heritability values of the number of pods per plant, dry weight per plant, and harvest index in the present study were above 0.96, 0.92, and 0.90, respectively, suggesting strong genetic components for the studied traits. High heritability accompanied by a low level of relationship between PCV and GCV for all traits indicated less environmental influence on their expression; hence, it can be used in establishing the distinctness between the chickpea accessions. These results were in agreement with the findings of Noor et al. (2003) and Farshadfar et al. (2013). Mushtaq et al. (2013) also reported the maximum heritability estimates for days to flowering, days to maturity, pods per plant, the total weight of plants, secondary branches per plant, plant height, 100-grains weight, and grain yield. Also, low heritability was also evidenced by low values of PCV and GCV for days to 50% emergence, the number of branches per plant, the leaf length, and the peduncle length. When the heritability estimates of qualitative and quantitative traits are high (i.e., >60%), the phenotypic appearance would provide a close assay of the genotypic value, and selection on the basis of phenotypic performance alone may be effective. If the heritability is low (i.e., <30%), the environmental influence is high in the expression of those traits (Joshi et al., 2018).

The genetic gain, which can be expected by the selection of a character, is estimated by the GA (Joshi et al., 2018). High heritability coupled with the GA observed for harvest index and percentage of fertile pods indicated the presence of additive gene action for this trait (Patil & Phadnis, 1977). Whereas high heritability coupled with low GA as observed for days from 50% emerging to 50% flowering, the number of leaflets per leaf, the number of leaflets per leaf, and the number of pods per plant revealed the presence of non-additive gene action. Bicer and Şakar (2007) have also reported that plant height showed moderate to low heritability, and environmental conditions played a major role in this trait. The present findings were also in agreement with the previous research (Ali et al., 2008; Patil et al., 2010).

The grain yield of a plant is determined by the interaction of various traits and is influenced by the genetic makeup and environment. In our study, grain yield showed positive correlations with plant height, the number of pods per plant, pod fertility percentage, number of branches per plant, plant dry weight, 100-grain weight, and harvest index. Positive correlations between grain yield with HI and the number of pods per plant suggest the feasibility of yield improvement through indirect selection based on the number of pods per plant and HI (Kumar et al., 2003). Arshad et al. (2004) also found chickpea (*C. arietinum* L.) grain yield showed positive correlations with plant height, pods per plant, 100-grain weight, and biological yield. Accordingly, highly positive correlations were observed between the grain yield and filled pod ($r = 0.96^{**}$) and grain number per plant ($r = 0.95^{**}$) in Arman and Hashem chickpea (*C. arietinum* L.) cultivars (Biabani & Katozi, 2011).

5 | CONCLUSIONS

Systematic documentation of diversity greatly improves the efficiency of germplasm use. Qualitative traits serve as morphological markers and help to identify useful germplasm lines in a short time. The chickpea accessions represented the variation available in the Kabuli-type chickpea germplasm preserved in the Iranian Genebank. These genetic resources may be useful for screening desirable traits in chickpeas. These accessions can be used in chickpea breeding programs to develop high-yielding Kabuli varieties with a broad genetic basis. High variability observed in plant height, the number of pods per plant, plant dry weight, 100-grain weight, grain yield, the number of branches per plant, and harvest index could indicate the importance of these traits in yield improvement. The cluster analysis indicated that plant height, the number of branches, and the number of pods per plant might be simultaneously improved and accumulated in a single accession for grain yield improvement in chickpea plants.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ETHICS APPROVAL

Not applicable.

AUTHOR CONTRIBUTIONS

Supervision, conceptualization, methodology, investigation, project administration, review and editing, and validation: Jafar Nabati. *Methodology and resources*: Seyedeh Mahbubeh Mirmiran. *Data*

collecting and data curation: Afsaneh Yousefi. *Review and editing and validation*: Mohammad Zare Mehrjerdi. *Writing – review and editing*: Mohammad Javad Ahmadi-Lahijani. *Validation and supervision*: Ahmad Nezami.

DATA AVAILABILITY STATEMENT

None.

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