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Identification of diverse germplasm lines for agronomic traits in a chickpea (*Cicer arietinum* L.) core collection for use in crop improvement

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Abstract

Utilization of exotic and diverse germplasm is needed to enhance the genetic diversity of cultivars. Genetically diverse lines provide ample opportunity to create favorable gene combinations, and the probability of producing a unique genotype increases in proportion to the number of genes by which the parents differ. Representative core collections (10% of the entire collection) have been suggested as a means to identify useful parents for crop improvement programs. The chickpea core collection (1956 accessions) was evaluated for 14 agronomic traits in two seasons to identify diverse agronomically superior chickpea germplasm. Season (year) and genotypic effects were significant for 13 of the 14 traits, while genotype × season effect was significant for 8 traits. The desi, kabuli, and intermediate type chickpeas differed significantly for days to maturity, basal secondary branches, pods per plant, seed yield, and 100-seed weight. In comparison to controls, 12 accessions flowered early, 15 produced greater seed yield, and 29 had greater 100-seed weight. Based on days to 50% flowering, pods per plant, seed yield, and 100-seed weight, 19 desi, 15 kabuli and 5 intermediate type chickpea germplasm lines originating from 10 countries were selected. The selected desi accessions produced 8.5% more seed yield and had 32% larger seeds than the control cultivar Annigeri while the selected kabuli accessions yielded at par with control L 550 but had 84% larger seeds. The 39 selected accessions and two control cultivars (Annigeri and L 550) were grouped by their first five principal components (PCs) into three clusters. Cluster 1 consisted of early maturing large-seeded kabuli types, cluster 2 early and late maturing desi types, and cluster 3 late maturing intermediate and kabuli types. Clusters 2 and 3 accessions had small to medium sized seeds. These accessions can be used in chickpea breeding programs to develop high yielding desi and kabuli cultivars with a broad genetic base.

Keywords: Chickpea; Desi; Diversity; Evaluation; Germplasm; Intermediate; Kabuli

1. Introduction

Chickpea (*Cicer arietinum* L.) is one of the most important grain-legume crops in the world, with the Asia region contributing most to the production, 7.67 million tonnes (Mt) of the 10.38 Mt of the world chickpea production (FAO, 2004). The major chickpea producing countries in Asia are India, Turkey, Pakistan, and Iran. Africa and North Central America contribute about 3–4% of the world chickpea production, with Ethiopia in Africa and Mexico in North Central America being the main producers of chickpea in these regions. Large variations in chickpea yield are reported: from 0.35 t ha^{-1} in Iran to 1.60 t ha^{-1} in Mexico. Chickpea productivity between 1965/1974 and 1995/2004 increased consistently in India and Mexico while it declined in Turkey, Pakistan, and Iran (FAO, 1965–2004; http://www.faostat.fao.org/site/408/default.aspx). Several biotic and abiotic stresses, besides lack of adapted varieties, contribute to the fluctuations in chickpea yield. Ascochyta blight [*Ascochyta rabiei* (Pass.) Labr.], botrytis gray mold (*Botrytis cinerea* Pers. ex Fr.), fusarium wilt [*Fusarium oxysporum* Schlechtend.emend W.C. Snyder. & H.N. Hans. f. sp. *ciceris* (Padwick) W.C. Snyder & H.N. Hans.], fusarium root rot [*Fusarium solani* (Mart.) Sacc. f. sp. *eumartii* (C. Carpenter) W.C. Snyder & H.N. Hans.], dry root rot [*Rhizoctonia bataticola* (Taubenhaus) E.J. Butler], nematodes (*Heterodera ciceri* Vovlos, Greco & Di Vito and *Meloidogyne* spp.), pod borer (*Helicoverpa armigera* Hübner), and leaf miner (*Liriomyza cicerina* Rondani) among the biotic stresses and drought, salinity, and high and low temperature, among the abiotic stresses, are the major constraints to chickpea

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productivity (Upadhyaya et al., 2006). Worldwide these stresses together cause yield losses worth US$ 2559 million annually, of which it is estimated that US$ 1185 million (46%) could be recovered by developing improved chickpea cultivars with multiple resistances to biotic and abiotic stresses (ICRISAT, 1992).

Utilization of exotic germplasm in breeding programs is needed to enhance the productivity and diversity of cultivars. However, breeders in general make use of only their own working collection, which they often recycle in breeding programs (Duvick, 1995; Cox et al., 1988). Extensive use of few and closely related germplasm/breeding lines in crop improvement could result in vulnerability of newly developed cultivars to pests and diseases (Duvick, 1984; Cox et al., 1986). For example, low genetic diversity led to the epidemic of southern corn leaf blight [*Bipolaris maydis* (Nisik) Shoemaker] in corn (Holley and Goodman, 1989). Lack of genetic diversity also led to a plateau in genetic improvements of yield in common bean (McClean et al., 1993). Diverse genetic backgrounds among parental lines provide the allelic variation necessary to create favorable new gene combinations, and the probability of producing unique genotypes increases in proportion to the number of genes by which the parents differ. To enhance utilization of chickpea genetic resources in breeding, Upadhyaya et al. (2001) developed a chickpea core collection of 1956 accessions representing between 84% and 100% of the variation range of the entire collection for plant height, days to maturity, numbers of pods per plant and seeds per pod, seed yield, and 100-seed weight. Multi-environmental evaluation of such core collections has been suggested as a method to identify diverse germplasm with beneficial traits (Upadhyaya et al., 2001). The main objective of this study was to evaluate the chickpea core collection for agronomic traits to identify diverse germplasm for enhancing the genetic potential of chickpea cultivars.

2. Materials and methods

One thousand nine hundred and fifty-six chickpea core collection accessions, consisting of 1465 desi (74.9%), 433 (22.1%) kabuli, and 58 (3.0%) intermediate types, were grown in single row plots in an augmented design with three control cultivars (Annigeri, G 130, and L 550) widely grown in India (Saxena and Singh, 1987). Annigeri (ICC 4918) is an early maturing high yielding desi cultivar and G130 (ICC 4948) is late maturing high yielding desi cultivar. L 550 (ICC 4973) is a high yielding medium duration kabuli cultivar. One of the controls was repeated after every nine-test entries. The experiment was conducted under high input conditions (100 kg ha^{-1} diammonium phosphate as basal dose and full protection against diseases and insect pests) in vertisol field at ICRISAT Center Patancheru, India during the 1999/2000 and 2000/2001 postrainy seasons. Data of the 1999/2000 season has been used to study diversity in this core collection (Upadhyaya et al., 2002) and to develop the mini core collection (Upadhyaya and Ortiz, 2001). Solarization was done to control soil-borne diseases (Katan et al., 1987). Each plot consisted of a single row of 4 m with spacing of 60 cm between rows and 10 cm between plants within a row. The experiment received two irrigations (5 cm each), one at flowering and another at podding stage, in addition to one to support germination. Pre-emergence herbicide, Glyphosate (Roundup) at 8 kg in 600 l water ha^{-1} was applied 1 month before sowing to control weeds. Six sprays of Acephate (Starthane) at 1 kg in 325 l water ha^{-1} and two sprays of Lannate (Methomyl) at 1 kg in 325 l water ha^{-1} were applied to control legume pod borer (*H. armigera*). IBPGR, ICRISAT, and ICARDA (1993) chickpea descriptors were used to record observations on days to 50% flowering, flowering duration, plant height and width (cm), days to maturity, and number of basal primary branches, apical primary branches, basal secondary branches, apical secondary branches, and tertiary branches, pods per plant, seeds per pod, seed yield (kg ha^{-1}), and 100-seed weight (g). Five traits, days to flowering and maturity, flowering duration, 100-seed weight, and seed yield were recorded on plot basis, and the remaining nine traits on representative five plants (Table 1).

Statistical analysis was performed following the Residual Maximum Likelihood (REML) on GENSTAT 6.1 for both years separately and on the combined data. Variance components due

Table 1
Chickpea descriptors used for evaluating core collection at ICRISAT Patancheru, 1999/2000 and 2000/2001 seasons

Trait	Descriptor
Days to 50% flowering (no.)	Number of days from sowing or first irrigation to the stage when 50% of plants in a plot have begun flowering
Flowering duration (no.)	Number of days between 50% flowering and end of flowering in 50% plants of a plot
Plant height (cm)	Average canopy height (cm) of five representative plants at the end of flowering
Plant width (cm)	Average spread (cm) of five representative plants at the end of flowering
Basal primary branches (no.)	Average number of basal primary branches of five representative plants
Apical primary branches (no.)	Average number of apical primary branches of five representative plants
Basal secondary branches (no)	Average number of basal secondary branches of five representative plants
Apical secondary branches (no.)	Average number of apical secondary branches of five representative plants
Tertiary branches (no.)	Average number of tertiary branches of five representative plants
Days to maturity (no.)	Number of days from sowing or first irrigation to the stage when 90% of pods have matured or turned yellow
Pods per plant (no.)	Average number of pods of five representative plants
Seeds per pod (no.)	Average of 10 pods each from five representative plants
100-Seed weight (g)	100-Seed weight (g) measured at 10% (air dry) moisture content
Seed yield (kg ha^{-1})	Seed yield per plot (kg ha^{-1})
Seed shape	Seed shape (1 = angular (desi type), 2 = owl's head (kabuli type), and 3 = pea shaped (intermediate type)

to genotype (δ^2_g), genotype × environment (years) (δ^2_{ge}), residual (δ^2_e) and their standard errors were estimated. In the combined analysis, seasons were considered as fixed and genotypes as random. Best linear unbiased predictors (BLUPs) were obtained for each trait. The means, ranges, and variances of all the traits were separately calculated for desi, kabuli, and intermediate groups. For individual traits, the means of these three groups were compared using the Newman–Keuls procedure (Newman, 1939; Keuls, 1952). Homogeneity of variances was tested using Levene's test (Levene, 1960). Principal component analysis (PCA) was performed for 14 traits. Subtracting from each observation the mean value of the trait, and subsequently dividing by its respective standard deviation, gave standardized observations of traits with average 0 and standard deviation of 1 or less. These standardized values were used to perform the PCA using GENSTAT 6.1. Correlation coefficients between the first 5 principal component scores and the 14 agronomic traits were calculated to determine the relationship between principal components and traits. Cluster analysis using scores of first five PCs was performed following the method of Ward (1963).

3. Results and discussion

REML analysis indicated that the variance component due to genotype was nonsignificant for three traits (basal secondary branches, tertiary branches, and seeds per pod) in 1999/2000 and for five traits (basal and apical primary branches, basal and apical secondary branches, and tertiary branches) in 2000/2001 (data not given). However, in the combined analysis the genotype variance was significant for 13 of the 14 observed traits (days to 50% flowering, flowering duration, plant height and width, days to maturity, basal primary and secondary branches, apical secondary branches, tertiary branches, pods per plant, seeds per pod, seed yield, and 100-seed weight) (Table 2). This indicated that differences existed between the core collection accessions for these traits. Season's effect was significant for all observed traits except for 100-seed weight (data not given). Genotype × season (environment) interaction was significant for days to 50% flowering, flowering duration, plant 50% flowering, days to maturity, apical primary branches, tertiary branches, pods per plant, and 100-seed weight indicating differential performance of core collection genotypes in the two seasons. The reason for the occurrence of G × E interaction in this study possibly could be due to differential response of genotypes to variation in climatic and soil factors in two seasons that the core collection was evaluated. For example, minimum temperature was lower by 2 °C when the chickpea crop was in seedling and vegetative/pod formation stage in 1999/2000 than in 2000/2001 crop season. The maximum temperature and solar radiation in the two seasons remained similar, however, both solar radiation (19.34 MJ m^{-2}) and temperature 33.6 °C) were higher in February 2001 than during the same period in 2000 (solar radiation 16.69 MJ m^{-2} and temperature 31.2 °C) thus possibly forcing the crop to mature early in the 2000/2001 crop season, which might have adversely affected the expression of reproductive traits.

Based on seed shape, three types of chickpea—desi, kabuli, and intermediate are recognized. Desi types are angular-shaped, small-seeded, and dark-colored; kabuli types are owl head-shaped, large-seeded, and cream-colored; and the intermediate types have pea-shaped seeds. The estimates of variance due to genotype in desi type chickpea accessions were significant for three traits (apical primary branches, pods per plant, and seeds per pod) in 1999/2000 and for five traits (days to 50% flowering, days to maturity, apical primary branches, pods per plant, and seeds per pod) in 2000/2001, while in combined analysis, except for tertiary branches, estimates of variance due to genotype were significant for all traits (data not given). In the kabuli group, the estimates of genotypic variance were significant for three traits (plant width, basal primary branches, and 100-seed weight) in 1999/2000 and for one trait (100-seed weight) in 2000/2001 but in combined analysis, except for basal and apical primary branches and tertiary branches, estimates of genotypic variance were significant for all traits (data not given). In the intermediate group, variance due to genotype was significant for plant height

Table 2
Estimates of components of variance due to genotype (δ^2_g) and genotype × environment (δ^2_{ge}) and their standard error (S.E.) for 14 agronomic traits in a chickpea core collection evaluated for two seasons at ICRISAT Center, Patancheru, India

Trait	δ^2_g	S.E.	δ^2_{ge}	S.E.
Day to 50% flowering (no.)	62.04**	2.206	7.07**	0.611
Flowering duration (no.)	18.45**	0.859	6.12**	0.750
Plant height (cm)	30.42**	1.560	12.10**	1.630
Plant width (cm)	7.18**	0.790	2.45	1.520
Days to maturity (no.)	10.62**	0.466	1.16**	0.396
Basal primary branches (no.)	0.03**	0.009	0.002	0.0064
Apical primary branches (no.)	0.05	0.033	0.13*	0.065
Basal secondary branches (no.)	0.19**	0.036	0.01	0.023
Apical secondary branches (no.)	0.24**	0.064	0.16	0.085
Tertiary branches (no.)	0.07*	0.031	0.10*	0.049
Pods per plant (no.)	191.70**	20.100	71.3*	34.5
Seeds per pod (no.)	0.02**	0.002	0.0006	0.00104
Seed yield (kg ha^{-1})	125,422**	7866	7115	4676
100-Seed weight (g)	57.10**	1.845	0.33**	0.100

* Significant at $P = 0.05$.
** Significant at $P = 0.01$.

Table 3
Range of variation for agronomic traits among accessions belonging to desi, kabuli, and intermediate types in chickpea core evaluated for two seasons at ICRISAT Center, Patancheru, India

Trait	Entire core collection	Desi	Kabuli	Intermediate
Day to 50% flowering (no.)	32.8–84.6	39.5–83.3	32.8–84.6	45.6–79.2
Flowering duration (no.)	25.3–55.1	25.4–53.3	25.3–55.1	30.2–45.7
Plant height (cm)	27.9–68.8	27.9–63.2	33.2–66.6	37.1–68.8
Plant width (cm)	41.3–53.5	41.3–53.5	44.5–53.4	44.0–52.3
Days to maturity (no.)	106.9–122.0	106.9–122.0	109.4–122.0	110.5–119.4
Basal primary branches (no.)	2.5–2.8	2.5–2.8	2.5–2.8	2.5–2.7
Apical primary branches (no.)	1.5–1.7	1.5–1.7	1.5–1.7	1.5–1.6
Basal secondary branches (no.)	3.0–4.1	3.0–4.1	3.1–4.0	3.1–3.9
Apical secondary branches (no.)	5.0–6.2	5.0–6.1	5.0–5.7	5.1–6.2
Tertiary branches (no.)	1.5–2.0	1.6–1.9	1.5–1.9	1.6–2.0
Pods per plant (no.)	42.8–102.2	45.3–102.2	42.8–87.4	49.2–91.3
Seeds per pod (no.)	1.1–1.6	1.1–1.6	1.1–1.5	1.2–1.5
Seed yield (kg ha^{-1})	975.5–2554.2	991.2–2554.2	975.5–2351.0	980.4–2192.3
100-Seed weight (g)	8.5–63.0	8.5–36.8	9.9–63.0	9.3–52.2

in 1999/2000 and for plant height and tertiary branches in 2000/2001 while in the combined analysis, except for four traits (basal and apical primary branches and basal and apical secondary branches), it was significant for all observed traits (data not given). Table 3 gives the range of variation for 14 agronomic traits among accessions belonging to the desi, kabuli, and intermediate groups of chickpeas in this core collection. The range for days to 50% flowering, flowering duration, and 100-seed weight was wider among kabuli chickpeas while the range for plant height and width, days to maturity, pods per plant, seeds per pod, and seed yield was greater among desi chickpeas. For intermediate types, the range was closer to that for desi types for days to 50% flowering, flowering duration, and number of apical secondary branches while it was closer to that for kabuli types for plant height and plant width, days to maturity, number of basal secondary branches, pods per plant, seeds per pod, seed yield, and 100-seed weight. The range of variation among desi types represented from 53% (100-seed weight) to 100% (plant width, basal secondary branches, apical primary branches, days to maturity, and seeds per pod) of the ranges recorded for the entire core collection. Among kabuli types the variation ranged from 61% (apical secondary branches) to 100% (days to 50% flowering and flowering duration) of that observed for the entire core collection while for intermediate types it ranged from 52% (flowering duration) to 91% (tertiary branches). There were significant differences among the means of desi, kabuli and intermediate types (Table 4). The three types chickpeas differed significantly for days to maturity, basal secondary branches, pods per plant, seed yield, and 100-seed weight. The desi and kabuli chickpeas differed significantly for days to 50% flowering, plant height and width, and for seeds per pod. In comparison to desi, the kabuli accessions were later in maturity, taller with a broader plant canopy (as measured by plant width), possessed less number of pods per plant and seeds pod, had lower seed yields but had greater 100-seed weight. The intermediate types differed from kabuli types for days to 50% flowering, plant width, apical secondary branches and tertiary branches. There were no differences among the means of the three types of chickpeas for flowering duration, basal primary branches, and apical primary branches.

Table 4
Mean for agronomic traits among accessions belonging to desi, kabuli, and intermediate types in chickpea core evaluated for two seasons at ICRISAT Center, Patancheru, India

Trait	Entire core collection	Desi[a]	Kabuli[a]	Intermediate[a]
Day to 50% flowering (no.)	61.47	60.35 b	65.18 a	62.24 b
Flowering duration (no.)	38.41	38.47 a	38.23 a	38.16 a
Plant height (cm)	44.50	43.76 b	46.71 a	46.56 a
Plant width (cm)	47.51	47.32 b	48.17 a	47.55 b
Days to maturity (no.)	114.03	113.33 c	116.31 a	114.76 b
Basal primary branches (no.)	2.63	2.63 a	2.64 a	2.62 a
Apical primary branches (no.)	1.56	1.56 a	1.56 a	1.56 a
Basal secondary branches (no.)	3.50	3.51 b	3.48 c	3.53 a
Apical secondary branches (no.)	5.39	5.39 b	5.38 b	5.43 a
Tertiary branches (no.)	1.72	1.72 a	1.72 a	1.74 b
Pods per plant (no.)	64.20	66.26 a	57.22 c	62.10 b
Seeds per pod (no.)	1.28	1.29 a	1.23 b	1.24 b
Seed yield (kg ha^{-1})	1819.10	1883.10 a	1617.68 c	1707.01 b
100-Seed weight (g)	17.45	14.86 c	25.99 a	19.12 b

[a] Differences between means of desi, kabuli, and intermediate type chickpea were tested by Newman–Keuls test. Means followed by the same letter are not significantly different at $P = 0.05$.

Days to 50% flowering, pods per plant, 100-seed weight, and seed yield are important agronomic traits. Based on significant superiority or performance similar to the controls (Annigeri for desi and L 550 for kabuli and intermediate types) for the above mentioned traits, we identified 19 desi, 15 kabuli, and 5 intermediate chickpea accessions originating from 10 countries that can be used in breeding programs to enhance the genetic potential of chickpea (Table 5). For example, among desi type, 6 accessions flowered early, 8 produced greater seed yield, and 13 had larger 100-seed weight than control Annigeri. Among kabuli types, 5 accessions flowered early, 6 produced greater seed yield, and 15 had larger 100-seed weight than control L 550. In intermediate type chickpeas, one accession each flowered early, produced greater seed yield, and had greater 100-seed weight than L 550. Few accessions showed superiority over controls for a number of traits among the three

Table 5
List of accessions that were either similar or showed significant superiority over respective controls for days to 50% flowering, pods per plant, seed yield, and seed weight for use in genetic enhancement of chickpea

ICC	Origin country	Year received/collected	Biological status	Days to 50% flowering (no.)	Plant height (cm)	Pods per plant (no.)	Seed yield (kg ha^{-1})	100-Seed weight (g)
Desi								
1230	India	1973	Landrace	54	43.9	74.2	2455.8	20.6
1692	India	1973	Landrace	56	46.6	63.3	2504.6	20.3
1836	India	1973	Landrace	68	47.8	69.1	2395.3	31.0
5449	India	1973	Landrace	54	42.7	71.6	2403.7	21.0
5697	India	1973	Landrace	50	42.5	63.2	2080.7	36.8
5970	India	1973	Landrace	50	45.0	73.0	2168.6	24.8
6122	India	1973	Landrace	40	43.3	64.0	1832.2	34.6
8324	India	1974	Landrace	46	39.7	72.0	2251.8	21.7
8332	India	1974	Breeding material	52	46.8	64.1	2554.2	18.7
8348	India	1974	Landrace	44	46.9	61.5	2471.7	34.9
8474	Spain	1974	Landrace	43	46.5	53.5	2036.8	34.6
10819	India	1976	Landrace	48	44.5	57.1	2041.3	33.8
11152	India	1978	Landrace	42	38.5	65.3	2130.6	20.9
12197	India	1981	Breeding material	44	41.1	72.0	2178.3	28.6
13124	India	1984	Landrace	48	40.0	53.5	2188.4	33.9
13200	Iran	1984	Landrace	50	46.6	57.2	2027.6	36.7
14230	India	1985	Landrace	49	48.5	55.1	2166.8	33.7
16862	India	1994	Landrace	45	41.7	74.0	2288.0	25.2
16934	India	1994	Landrace	48	40.5	72.0	2212.9	23.1
Kabuli								
3410	Iran	1973	Landrace	54	42.9	65.0	2138.7	21.8
5644	India	1973	Landrace	61	46.3	60.3	2138.8	23.3
6160	Syria	1974	Landrace	59	42.2	66.0	1996.1	40.5
6239	Tunisia	1974	Landrace	69	43.7	52.5	2029.6	33.0
6246	Tunisia	1974	Landrace	63	40.9	68.0	1898.0	21.8
7200	Egypt	1974	Breeding material	62	43.9	58.9	2171.4	21.5
8042	Iran	1974	Landrace	59	50.9	55.4	2075.8	30.8
8155	USA	1974	Unknown	41	38.5	45.2	1233.4	60.2
10755	Turkey	1976	Landrace	61	45.7	57.7	2014.7	31.4
10783	Turkey	1976	Landrace	61	45.3	60.0	2167.2	35.6
11904	Morocco	1981	Advanced cultivar	63	48.8	62.1	2117.7	25.0
12034	Mexico	1981	Advanced cultivar	36	40.6	48.4	1382.4	59.1
14190	India	1985	Landrace	43	46.6	48.9	1297.1	63.0
14203	Mexico	1985	Landrace	46	42.3	50.8	1632.4	57.3
15763	Syria	1989	Landrace	59	44.0	69.0	1886.2	26.0
Intermediate								
4871	India	1973	Landrace	51	42.6	61.6	2018.6	28.3
5899	India	1973	Landrace	59	45.2	84.4	2192.3	26.1
7574	Morocco	1974	Landrace	71	59.4	56.7	1790.1	30.6
8350	India	1974	Landrace	61	46.3	64.8	2017.6	27.2
16345	India	1991	Breeding material	64	49.8	49.2	1283.5	52.2
Control								
Annigeri (desi)	India	1973	Released cultivar	50	41.6	70.0	2057.5	21.3
L 550 (kabuli)	India	1973	Released cultivar	63	45.5	64.0	1858.2	19.9
GM				61.42	44.50	64.25	1821.13	17.46
S.E.±				1.89	2.38	5.94	68.52	0.53
CV%				4.00	10.85	38.77	24.08	6.21

chickpea seed types. For example, ICC 8348, ICC 12197 and ICC 16862 in desi type, and ICC 3410 in kabuli type were early in flowering, produced greater seed yield and had higher 100-seed weight than controls. ICC 5899 belonging to the intermediate type was better than controls for pods per plant, seed yield, and 100-seed weight. These accessions were not evaluated for reaction to ascochyta blight in this study, however, information available on nine accessions in the database, indicated that only ICC 1692, a desi landrace from India was moderately resistant (score of 4 on a 1–9 scale, where 1 = immune and 9 = highly susceptible) and ranked second for seed yield (Table 5). Accessions having high seed yield and greater 100-seed weight than controls were ICC 1836 among desi types and ICC 5644, ICC 7200, ICC 8042, ICC 10783, and ICC 11904 among kabuli types. The most desirable accessions possessing early maturity and greater 100-seed weight than controls, were ICC 6122, ICC 8474, and ICC 12197 in desi; ICC 8155, ICC 12034, ICC 14190, and ICC 14203 among kabuli types; and ICC 4871 among intermediate types. These accessions are good sources of new germplasm that should be exploited in breeding programs to derive high yielding cultivars in chickpea.

The principal component analysis (PCA) was used to provide a reduced dimension model that would indicate measured differences among the 39 most diverse accessions identified in this study (Fig. 1). The PC 1, which is the most important component, accounted for 33.0% variation and separated accessions on five traits: days to 50% flowering, flowering duration, days to maturity, plant width, and apical secondary branches. Similarly, PC2 separated accessions based on plant height, apical primary branches, and pods per plant; PC3 on tertiary branches and seed yield; PC4 on seeds per pod; and PC5 on basal secondary branches. This was also evident from high correlations of the first five PCs with these different traits. Thus PC1 was highly correlated with days to 50% flowering (−0.829), flowering duration (0.796), days to maturity (−0.683), apical secondary branches (−0.668), and plant width (−0.664); PC2 with pods per plant (0.666), plant height (−0.630), and apical primary branches (0.596); PC3 with seed yield (0.710), and 100-seed weight (g) (−0.430); PC4 with seeds per pod (0.866); and PC5 with basal secondary branches (0.337). A hierarchical cluster analysis conducted on the first five principal components accounted for 80.5% variation and formed three distinct clusters: cluster 1 represented exclusively the kabuli types that flower early with exceptionally high 100-seed weight (57–63 g); cluster 2 represented desi types with a mixed group of early and late flowering types having 100-seed weight between 21 and 37 g; and cluster 3, that also included Annigeri and L 550, represented late flowering kabuli and intermediate types with 100-seed weights between 19 and 40 g. For breeding high yielding early maturing kabuli types with large 100-seed weights, ICC 8155, ICC 12034, ICC 14190, and ICC 14203 included in cluster 1 could be crossed with some of the highest yielding kabuli accessions (ICC 3410, ICC 5644, ICC 7200, and ICC 10783) and desi accessions (ICC 1230, ICC 1692, ICC 8332, and ICC 8348). The selected intercrossing between the desi and kabuli types might result in superior lines that combine the beneficial/desirable traits from both groups.

Crop genetic resources will be the main contributing factor to the most of future progress in developing new cultivars. However, the greatest challenge before the genebank curators/plant breeders is to identify useful genetic variation from the existing large germplasm collections, especially for traits of economic importance that require replicated multilocational evaluation. Establishing core collections was suggested as a means to overcome the size-induced low use of germplasm in applied breeding (Frankel, 1984; Frankel and Brown, 1984). The limited evaluation of a chickpea core collection in this study provided an opportunity to identify accessions superior in performance and diverse from control cultivars, thus providing new sources of variation for agronomic traits that can be

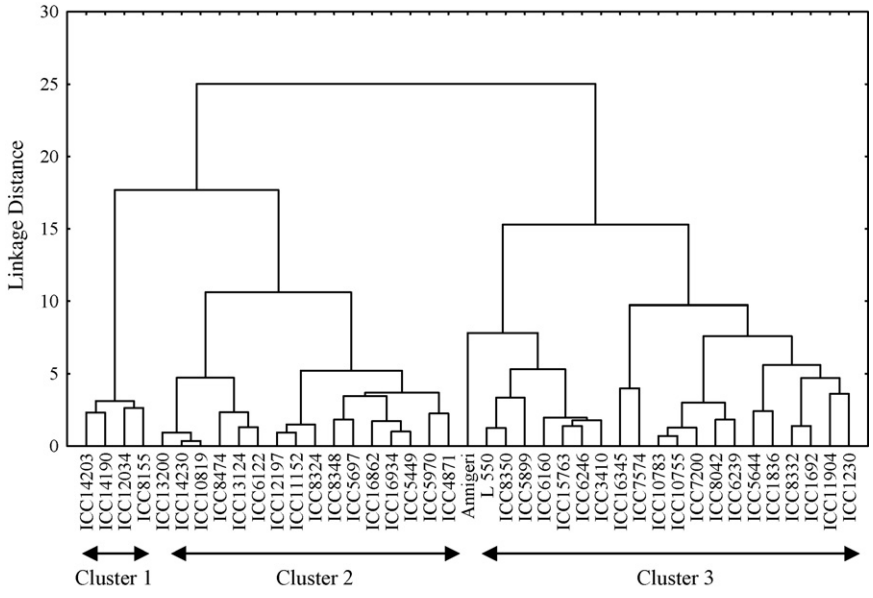

Fig. 1. Dendogram of 41 chickpea accessions based on scores of first five principal components.

exploited to enhance the genetic potential of desi and kabuli chickpeas. It is expected that when such diverse lines are involved in breeding programs, as a result of reshuffling of the alleles due to recombination, there will be better chances for the appearance of transgressive segregants with beneficial traits that can be selected to extract high yielding lines with desirable trait combinations. Since these lines have good agronomic value (Table 5), their use will not adversely affect the speed of improvement programs resulting from epistatic effects. It is important to consider genetic background and agronomic performance while selecting exotic germplasm lines for inclusion in applied plant improvement programs, as it will be useful in predicting their behavior in hybrid combinations with adapted genotypes (Upadhyaya et al., 2005). If the diversity between lines is less, it is more likely that additive gene effects will play a primary role in the inheritance of quantitative traits (Isleib and Wynne, 1983). However, as the diversity between parents increases, dominance and epistatic effects have more significant roles (Halward and Wynne, 1991) that would have implications in choosing an appropriate selection strategy in a self-pollinated crop such as chickpea.

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