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Phenotypic diversity for morphological and agronomic characteristics in chickpea core collection

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Summary

The chickpea (*Cicer arietinum* L.) core collection consists of 1956 accessions, of which 1465 are desi, 433 kabuli, and 58 intermediate types. This core collection was evaluated for 7 morphological descriptors and 15 agronomic characteristics to estimate phenotypic diversity. All the three groups differed significantly for flower colour, plant colour, dots on seed testa, seed testa texture, plant width, days to maturity, pods per plant, 100-seed weight and plot yield. The kabuli and intermediate types were not significantly different for growth habit and seed colour, they differed, however, significantly from desi types for both traits. Desi, kabuli, and intermediate types were significantly different for plant width, days to maturity, pods per plant, 100-seed weight, and plot yield. Kabuli plants have broad plant width, matured late, have lowest average number of pods, highest 100-seed weight, and lowest plot yield. There were significant phenotypic correlations among the various characteristics. Two of these, between days to 50% flowering and flowering duration and between pod number and plant yield, explained 50% variation in the other trait in all three groups. Principal component analysis showed that days to 50% flowering, plant width, apical secondary branches, tertiary branches, dots on seed testa, 100-seed weight, flowering duration, basal secondary branches, seed colour, and seed testa texture were important traits in explaining multivariate polymorphism. Growth habit and basal primary branches did not significantly account for variation in the first five principal components of desi, kabuli, and intermediate types as well as for the entire core collection, indicating their low importance as chickpea descriptors. The average phenotypic diversity index was highest in the intermediate types (0.2653) and lowest in the kabuli types (0.1490). The Shannon-Weaver diversity index varied among traits between the three groups, and the diversity within a group depended upon the traits recorded.

Introduction

Chickpea is an important food legume in several countries including Algeria, Ethiopia, India, Iran, Mexico, Morocco, Myanmar, Pakistan, Spain, Syria, Tanzania, Tunisia, and Turkey. Van der Maesen (1987) has described origin and history of chickpea, which most probably originated in an area of present–day southeastern Turkey and northern Syria, around the upper reaches of the Tigris and Euphrates rivers (Lev-Yadun et al., 2000). Vavilov (1926) designated two primary centers of diversity of chickpea – southwest Asia and the Mediterranean and a secondary center in Ethiopia. He noted that the large-seeded cultivars abounded around the Mediterranean basin and the small-seeded cultivars predominated eastwards. Two types of chickpea groups, kabuli and desi types are recognized. The kabuli types have owl-shaped, large cream coloured seeds whereas the desi types have angular-shaped, small and dark coloured seeds. A third type based on seed shape, intermediate type, which have pea-shaped seeds, is also recognized (IBPGR, ICRISAT & ICARDA, 1993).

The emphasis on importance of preserving important crop germplasm has led to collection and maintenance of very large germplasm collections.

Although representativeness of collections can be achieved through large collection sizes (Frankel & Bennett, 1970); the accessibility and usefulness of a collection is inversely related to its size (Frankel & Soule, 1981). The ICRISAT genebank contains 16 991 germplasm accessions of chickpea from 44 countries. These accessions were acquired mainly by donations from different countries, and supplemented by conducting a total of 64 collecting missions (52 in Asia and 12 in Africa). Of the 16 991 accessions, 4150 are from collecting missions, 1123 from six African countries and 3027 from eight Asian countries. The remaining 12 841 accessions have been acquired by donations from Asia, Africa, the America, Europe, and Oceania. The collections have been assembled using different sampling techniques and without discrimination for origin and characteristics. Upadhyaya et al. (2001) have developed a core collection consisting of 1956 entries using data on geographic distribution and 13 quantitative traits to enhance the use of genetic resources in improvement programs. The data on 13 traits used in developing this core subset was recorded over a period of 25 years, (1974 to 1998), however introducing likely bias due to genotype × environment interactions. Hence, the main objectives of this study were to assess phenotypic diversity for various morphological descriptors and agronomic traits and determine associations among them in the core subset and most diverse genotypes.

Materials and methods

The core subset consisted of 1465 desi, 433 kabuli, and 58 intermediate types. These 1956 accessions were sown by hand in a vertisol (Kasireddipally series-Isohyperthermic Typic Pellustert) field in the 1999/2000 postrainy season at ICRISAT (Patancheru, India). Each plot consisted of a 4 m row on a ridge, with 60 cm as distance between rows and 10 cm between plants. Care was taken to ensure uniform depth of planting. The plots received 46 kg P_2O_5, 18 kg N ha^{-1} as basal fertilizer, and three irrigations (7 cm water per irrigation). In each accession five competitive plants were selected at random to record plant height (cm), plant width (cm), and numbers of apical primary branches, apical secondary branches, basal primary branches, basal secondary branches, and tertiary branches, pods per plant, seeds per pod; 100-seed weight (g), plant yield (g). Morphological descriptors (flower colour, plant colour, growth habit, seed colour, seed shape, dots on seed testa, and seed testa texture) were recorded according to a descriptor list (IBPGR, ICRISAT, and ICARDA, 1993) on whole plot basis. Days to 50% flowering (days from sowing to the stage when 50% plants have begun flowering), days to maturity (from sowing to the stage when 90% pods have matured and turned yellow), flowering duration (days between 50% flowering and end of flowering in 50% plants), and plot yield were also recorded by plot. The yield of the five sampled plants was added for total plot yield.

Means of the desi, kabuli, and intermediate types were compared using Newman-Keuls procedure (Newman, 1939; Keuls, 1952) for all traits. The homogeneity of variances of these three groups was tested using Levene's test (Levene, 1960). Phenotypic correlations were calculated among all traits in the core collection and among 21 traits (seed shape excluded) in the desi, kabuli, and intermediate types independently. The mean observations for each accession were standardized by subtracting from each observation the mean value of the character and subsequently dividing by its respective standard deviation. This resulted in standarized values for each trait with average 0 and standard deviation of 1 or less. The standardized values were used to perform principal component analysis (PCA) on Genstat 5 Release 4.1 to know the importance of different traits in explaining multivariate polymorphism.

A phenotypic distance matrix was created by calculating the differences between each pair of entries for each characteristic. The diversity index was calculated by averaging all the differences in the phenotypic values for each trait divided by respective range (Johns et al., 1997). The diversity index (H′) of Shannon & Weaver (1949) was calculated and used as a measure of phenotypic diversity of each trait. The index was estimated for each character over all entries in three types.

Results and discussion

Morphological characteristics

The frequency distribution of the core collection entries for the seven morphological descriptors revealed a large degree of variation for different traits.

Flower colour

The pink flower colour, which is generally characteristic of desi type, was the most predominant represented by 1329 of 1956 core subset accessions. This was followed by white flower, which is characteristic of kabuli type, was present in 481 accessions and light pink in 118 entries. White flower with pink streaks was a trait in two accessions only.

Plant colour

All three types of plant colours (IBPGR, ICRISAT & ICARDA, 1993) were observed; 652 accessions have no anthocyanin, 1254 have low anthocyanin, and 50 show high anthocyanin.

Growth habit

All the five types of growth habit based on angle of primary branches at the mid-pod filling stage, were found. Semi-erect was the most predominant growth habit (1579 accessions) followed by semi-spreading (343 accessions). Prostrate growth habit was observed in only one accession.

Seed colour

Of the 24 classes of seed colour, yellow brown was the most common represented (690 accessions) followed by beige (439 accessions). Orange was seen in only one accession.

Seed shape

The angular seed shape, which is characteristic of desi types, was most frequent (1465 accessions) followed by the owl shape of kabuli type (433 accessions) and pea shape of the intermediate type (58 accessions).

Dots on seed testa

Minute black dots were present on the seed testa of 1307 accessions and in the remaining 649 the black dots were absent.

Seed testa texture

Three types of seed testa texture were recorded: 1437 accessions show rough while 473 are smooth, and 46 tuberculated.

The mean, range and variances of six morphological characteristics (excluding seed shape) are given in Table 1. The mean scores for flower colour, plant colour, dots on seed testa, and seed testa texture were significantly different among all three types. On average, growth habit and seed colour were not significantly different between kabuli and intermediate types but both were significantly different from desi types (Table 1). The variances for all morphological descriptors were heterogeneous (p = 0.0001–0.0006).

Agronomic characteristics

The means of desi, kabuli, and intermediate types were significantly different from each other for plant width, days to maturity, pods per plant, 100-seed weight and plot yield. The kabuli types have greater plant width, matured later, have the lowest average number of pods, highest 100-seed weight, and lowest plot yield (Table 1). The range for most of the traits was different in three types. Desi types represented 100% range variation of total core collection for 13 traits, kabuli for three traits, and intermediate for only two traits. Overall, desi types captured 93.10% range variation of total core collection compared with 79.28% by kabuli types, and 68.29% by intermediate types. The variances between chickpea types were homogeneous for days to flower, number of apical secondary branches, basal secondary branches, and tertiary branches, and plant yield (Table 1).

Any correlation coefficient with 1954 degrees of freedom (e.g. for entire core collection) with an absolute value greater than 0.1 will be significant at p = 0.0001. However, the correlation coefficients greater than 0.71 or smaller than –0.71 have been suggested to be biologically meaningful (Skinner et. al., 1999), as more than 50% of the variation in one trait is predicted by the other (Snedecor & Cochran, 1980). In our study, we found such meaningful relationships in the entire core subset between days to 50% flowering and flowering duration (r = –0.753), flower colour and seed shape (r = 0.782), and pod number and plant yield (r = 0.745). In the desi, kabuli, and intermediate types the correlations between days to 50% flowering and flowering duration (r = –0.753 in desi, r = –0.845 in kabuli and r = –0.888 in intermediate) and between pod number and plant yield (r = 0.796 in desi, r = 0.677 in kabuli and r = 0.830 in intermediate) were maintained (Table 2). These results indicate the stability of these important relationships in the three types. Further, these relationships suggested that in future germplasm evaluations, traits like days to flowering and plant yield should be considered. Both of these

Table 1. Mean, range, and variance of 15 quantitative characters for three chickpea types (Patancheru, India, 1999/2000 postrainy season)

Character	Mean[1]			Range			Variance[2]			F value	*p*
	Desi (1465)[3]	Kabuli (433)	Intermediate (58)	Desi (1465)[3]	Kabuli (433)	Intermediate (58)	Desi (1465)[3]	Kabuli (433)	Intermediate (58)		
Days to flower	61.72a	66.93b	63.26a	30–88	27–90	39–87	77.0	75.5	97.8	0.815	0.4407
Flowering duration (days)	40.91a	41.10a	41.33a	24–71	21–67	26–52	31.1	39.8	36.9	3.399	0.0336
Plant height (cm)	45.69a	51.23b	51.4b	12.8–82.0	21.2–86.8	31.4–91.6	60.9	75.7	134.21	2.105	0.0001
Plant width (cm)	45.53a	49.73b	47.17c	26.8–69.0	29.4–72.2	34.0–62.4	33.2	47.8	36.9	9.951	0.0001
Apical primary branches (No.)	1.63a	1.53a	1.58a	0.0–7.67	0.0–6.0	0.0–5.33	2.17	1.75	2.09	2.808	0.0606
Apical secondary branches (No.)	6.57a	6.26a	6.98a	0.33–20.67	0.00–19.00	3.00–16.00	6.82	8.35	8.18	1.872	0.1541
Basal primary branches (No.)	2.86a	2.94a	2.71b	1.0–6.0	1.33–6.00	1.33–4.00	0.50	0.64	0.50	4.248	0.0144
Basal secondary branches (No.)	4.14a	3.83a	4.09a	0.33–10.33	0.00–12.00	1.00–9.00	2.73	2.59	2.81	0.219	0.8033
Tertiary branches (No.)	2.35a	2.11a	2.60a	0.00–9.67	0.00–8.00	0.00–7.33	3.06	3.30	3.57	0.753	0.4712
Days to maturity	114.9a	120.1b	117.4c	100–129	100–128	106–127	31.4	21.2	23.7	10.427	0.0001
Pods per plant (No.)	89.4a	56.7b	75.3c	18–239	9–181	20–219	1431	784	1181	11.486	0.0001
Seeds per pod (No.)	1.35a	1.17b	1.18b	1.0–2.6	1.0–2.3	1.0–1.9	0.10	0.07	0.06	14.338	0.0001
100-seed weight (g)	14.5a	26.7b	19.0c	7.4–37.3	9.4–64.2	8.8–56.1	18.9	110.2	47.1	142.200	0.0001
Plant yield (g)	15.3a	14.3a	14.8a	3.3–46.0	3.7–39.0	3.7–44.0	35.8	33.1	44.8	0.561	0.5709
Plot yield (kg ha^{-1})	1741a	1283b	1477c	158–3129	171–2563	196–2267	255845	194017	252478	6.244	0.0020
Flower colour	1.21a	4.94b	3.19c	1–8	1–5	1–7	0.63	0.21	3.28	25.986	0.0001
Plant colour	1.91a	1.03b	1.19c	1–3	1–2	1–2	0.15	0.03	0.16	28.884	0.0001
Growth habit	2.41a	2.12b	2.22b	1–5	1–4	1–4	0.69	0.28	0.60	29.502	0.0001
Seed colour	9.19a	11.02b	10.93b	1–24	7–18	1–24	35.9	0.4	36.7	388.000	0.0001
Dots on seed testa	1.88a	1.00b	1.31c	1–2	1–1	1–2	0.11	0.00	0.22	50.573	0.0001
Seed testa texture	1.07a	1.99b	1.71c	1–3	1–2	1–2	0.12	0.01	0.21	7.330	0.0006

[1] Differences between means of desi, kabuli, and intermediate types tested by the Newman-Keuls test. Means followed by same letter are not significantly different at $p = 0.05$.
[2] Variance homogeneity tested by Levene's test.
[3] Numbers within the parenthesis indicate number of accessions in each subset of core collection.

Table 2. Correlation coefficients between 21 characters measured in three subsets of the chickpea core collection (Patancheru, India, 1999/2000 postrainy season)

	DF	FLCL	PLCL	FD	GH	PLHT	PLWD	APB	ASB	BPB	BSB	TB	DM	PN	SDPD	SDCL	SDD	SDT	SDWT	YPP	YKGH	Types
DF[−1]		0.064*[2]	−0.077**	−0.753**	−0.236**	0.475**	0.331**	−0.254**	0.039	0.214**	0.268**	0.102**	0.596**	−0.213**	−0.003	0.125**	−0.034	−0.226**	−0.043	−0.24**	−0.38**	Desi
		0.069	−0.012	−0.845**	−0.249**	0.354**	0.383**	−0.132**	0.026	0.119*	0.164**	0.02	0.613**	−0.164*	−0.051	0.082	0	−0.046	0.009	−0.122**	−0.36**	Kabuli
		0.139	0.131	−0.888**	−0.285*	0.26*	0.19	−0.311*	0.187	0.401**	0.239	−0.139	0.578**	−0.254	−0.042	0.138	−0.067	0.396**	0.141	−0.191	−0.463**	Intermediate
FLCL			−0.406**	0.021	−0.086**	0.118**	0.055*	0.042	0.028	0.012	−0.04	−0.014	0.146**	−0.093**	−0.074**	0.138**	0.037	−0.028	0.112**	−0.055*	−0.124**	Desi
			−0.1*	−0.079	0.031	0.017	0.042	−0.134**	−0.111*	0.01	−0.056	−0.036	0.061	−0.084	0.034	0.257**	0	0.113*	0.01	−0.074	−0.081	Kabuli
			−0.345**	−0.148	0.119	0.092	−0.139	−0.025	−0.237	0.089	−0.206	−0.292*	−0.061	−0.117	0.019	0.512**	−0.528**	0.089	0.078	−0.161	−0.254	Intermediate
PLCL				−0.046	0.062*	−0.188**	−0.119**	−0.001	0.001	−0.037	0.087**	0.078**	−0.171**	0.134**	0.141**	−0.244**	−0.189**	0.044	−0.269**	0.052*	0.087**	Desi
				−0.043	−0.065	−0.034	0.051	−0.043	−0.043	0.054	−0.061	−0.041	−0.097*	0.058	−0.064	−0.006	0	0.02	0.012	0.023	−0.05	Kabuli
				−0.165	−0.027	−0.037	0.021	−0.143	0.117	0.031	0.257*	0.049	0.112	−0.023	−0.157	−0.053	0.531**	−0.172	0.084	−0.016	0.065	Intermediate
FD					0.05	−0.22	−0.114**	0.239**	0.113**	−0.174**	−0.079**	0.105**	−0.125**	0.077**	−0.026	−0.106**	−0.068**	0.107**	0.111**	0.128**	0.192**	Desi
					0.193**	−0.254**	−0.289**	0.202**	0.071	−0.083	−0.054	0.135**	−0.276**	0.086	−0.007	−0.106*	0	0.049	0.085	0.124**	0.321**	Kabuli
					0.119	−0.044	−0.023	0.22	−0.089	−0.358**	−0.122	0.214	−0.365**	0.201	0.221	−0.212	0.007	−0.267*	−0.119	0.187	0.39**	Intermediate
GH						−0.332**	−0.137**	−0.015	−0.238**	−0.063**	−0.228**	−0.237**	−0.35**	0.143**	−0.012	0.038	0.146**	0.075**	−0.069**	0.13**	0.161**	Desi
						−0.299**	−0.145**	0.006	−0.17**	−0.053	−0.154**	−0.161**	−0.251**	0.047	−0.011	−0.008	0	−0.048	0.046	0.099*	0.147**	Kabuli
						−0.54**	−0.19	0.008	−0.194	−0.159	−0.151	−0.029	−0.334**	0.225	0.03	0.374**	0.096	−0.306*	−0.053	0.264*	0.355**	Intermediate
PLHT							0.606**	−0.006	0.067**	0.162**	0.099**	0.083**	0.436**	−0.24**	−0.099**	0.056*	−0.159**	−0.097**	0.201**	−0.163**	−0.11**	Desi
							0.606**	0.059	0.001	0.158**	0.077	0.033	0.349*−*	−0.112*	−0.111*	0.06	0	−0.042	0.015	−0.098*	−0.088	Kabuli
							0.314*	−0.056	0.092	0.137	0.16	−0.051	0.316*	−0.201	−0.034	0.069	−0.138	0.318**	0.24	−0.137	−0.309*	Intermediate
PLWD								−0.002	0.026	0.151**	0.075**	0.151**	0.376**	−0.123**	−0.065*	0.068**	−0.107**	−0.073**	0.132**	−0.073**	0.059*	Desi
								−0.077	−0.174**	0.203**	−0.059	−0.102*	0.299**	−0.115*	−0.117*	−0.02	0	0.014	0.098*	−0.052	−0.103*	Kabuli
								0.015	0.111	0.139	−0.019	0.114	0.381**	0.03	0.14	−0.122	−0.035	0.239	0.152	0.088	0.016	Intermediate
APB									0.157**	−0.071**	−0.081**	0.109**	−0.045	0.153**	−0.002	−0.1**	−0.102**	0.043	0.119**	0.2**	0.084**	Desi
									0.242**	0.043	0.045	0.171**	0.01	0.124**	−0.126**	−0.023	0	−0.022	0.019	0.134**	0.161**	Kabuli
									−0.094	−0.068	−0.104	0.069	−0.095	0.235	−0.058	0.033	0.13	−0.385**	0.098	0.316*	0.259*	Intermediate
ASB										0.05	0.482**	0.502**	0.268**	0.252**	0.003	−0.073**	−0.139**	−0.035	−0.015	0.212**	0.005	Desi
										0.03	0.545**	0.544**	0.18**	0.333**	0.093*	−0.064	0	0.031	−0.126**	0.337**	0.27**	Kabuli
										0.223	0.565**	0.347**	0.337**	0.261*	0.117	0.049	0.096	0.121	−0.064	0.256	0.254	Intermediate
BPB											0.173**	0.064**	0.093**	0.103**	0.009	0.074**	0.01	−0.066**	−0.05	0.071**	−0.013	Desi
											0.051	0.007	0.072	0.093*	0.011	−0.005	0	−0.026	−0.062	0.049	0.011	Kabuli
											0.388**	0.154	0.127	0.135	−0.12	0.08	0.062	−0.066	0.295*	0.242	−0.121	Intermediate
BSB												0.537**	0.374**	0.251**	0.056*	−0.01	−0.043	−0.097**	−0.087**	0.195**	0.046	Desi
												0.496**	0.223**	0.336**	0.118*	0.018	0	−0.013	−0.084	0.383**	0.226**	Kabuli
												0.499**	0.241	0.306*	0.041	0.011	0.227	−0.081	−0.108	0.373**	0.259*	Intermediate
TB													0.37**	0.206**	0.031	−0.08**	−0.178**	−0.043	−0.044	0.182**	0.007	Desi
													0.242**	0.267**	0.014	−0.056	0	0.014	−0.051	0.277**	0.202**	Kabuli
													0.218	0.391**	0.056	−0.155	0.115	−0.189	−0.169	0.461**	0.263*	Intermediate
DM														−0.19**	−0.065*	0.061*	−0.132**	−0.205**	0.095**	−0.183**	−0.302**	Desi
														−0.227**	−0.127**	0.028	0	−0.02	0.144**	−0.079	−0.268**	Kabuli
														−0.091	−0.187	−0.101	−0.083	0.34**	0.178	−0.055	−0.179	Intermediate
PN															0.044	0.054*	0.091**	0.068**	−0.204**	0.796**	0.306**	Desi
															0.198**	0.001	0	−0.036	−0.388**	0.677**	0.356**	Kabuli
															0.081	0.059	0.113	−0.266*	−0.267*	0.83**	0.295*	Intermediate
SDPD																−0.06*	−0.12**	−0.097**	−0.326**	0.023	0.043	Desi
																0.005	0	0.026	−0.405**	0.023	0.19**	Kabuli
																−0.075	−0.106	0.258*	−0.364**	0.029	0.012	Intermediate
SDCL																	0.502**	0.117**	0.051*	0.022	0.024	Desi
																	0	−0.536**	−0.018	−0.035	−0.021	Kabuli
																	−0.073	−0.159	0.169	0.124	0.144	Intermediate
SDD																		0.034	0.246**	0.17**	0.286**	Desi
																		0	0	0	0	Kabuli
																		−0.469**	0.033	0.138	0.126	Intermediate
SDT																			0.055**	0.046	0.129**	Desi
																			−0.009	−0.053	−0.034	Kabuli
																			−0.063	−0.333**	−0.328*	Intermediate
SDWT																				0.152**	0.019	Desi
																				0.129**	−0.342**	Kabuli
																				0.085	−0.16	Intermediate
YPP																					0.379**	Desi
																					0.271**	Kabuli
																					0.312*	Intermediate

[1] DF – days to flower, FLCL – flower colour, PLCL – plant colour, FD – Flowering duration (days), GH – growth habit, PLHT – plant height (cm), PLWD – plant weidth (cm), APB – apical primary branches (no.), ASB – apical secondary branches (no.), BPB – Basal primary branches (no.), BSB – basal secondary branches (no.), TB – tertiary branches (no.), DM – days to maturity, PN – pods per plant (no.), SDPD – Seeds per pod (no.), SDCL – seed colour, SDD – dots on seed testa, SDT – seed testa texture, SDWT – 100 –seed weight (g), YPP – plant yield (g), YKGH – plot yield (kg ha $^{-1}$). [2] * and ** indicate significant correlations at $p = 0.05$ and 0.01, respectively.

Table 3. Vector loadings and percentage of variation explained by the first five principal components after assessing morphological and agronomic characteristics in subsets of chickpea core collection

Characteristics	Principal components				
	1	2	3	4	5
Entire core collection					
Variation explained (%)	25.46	12.6	11.08	6.87	5.59
Latent root	5.60	2.77	2.44	1.51	1.23
Days to flower	0.221	–0.313	–0.330	0.151	0.148
Flower colour	0.353	0.105	0.179	0.075	0.141
Plant colour	–0.319	–0.097	–0.156	–0.125	–0.048
Flowering duration (days)	–0.070	0.197	0.391	–0.286	–0.232
Growth habit	–0.143	0.246	0.020	0.273	0.092
Plant height (cm)	0.239	–0.213	–0.118	0.048	–0.448
Plant width (cm)	0.206	–0.170	–0.082	0.149	–0.511
Apical primary branches (No.)	–0.040	0.004	0.265	–0.138	–0.391
Apical secondary branches (No.)	–0.026	–0.362	0.286	–0.165	0.112
Basal primary branches (No.)	0.039	–0.178	–0.048	0.292	–0.073
Basal secondary branches (No.)	–0.030	–0.447	0.152	–0.010	0.221
Tertiary branches (No.)	–0.018	–0.389	0.255	–0.195	0.053
Days to maturity	0.264	–0.309	–0.044	–0.106	–0.034
Pods per plant (No.)	–0.245	–0.166	0.278	0.325	0.081
Seeds per pod (No.)	0.145	0.070	0.071	0.113	0.226
Seed colour	0.078	0.016	–0.024	0.477	0.053
Dots on seed testa	–0.311	–0.044	–0.166	0.206	–0.129
Seed shape	0.331	0.102	0.207	0.056	0.168
Seed testa texture	0.282	0.157	0.226	0.093	0.147
100-seed weight (g)	0.279	0.115	0.161	0.076	–0.120
Plant yield (g)	–0.129	0.126	0.396	0.388	–0.002
Plot yield (kg ha^{-1})	–0.240	–0.006	0.173	0.195	–0.258
Desi type					
Variation explained (%)	17.01	12.89	9.98	8.70	6.24
Latent root	3.57	2.71	2.09	1.83	1.31
Days to flower	0.435	–0.040	0.038	–0.308	0.003
Flower colour	0.107	–0.079	–0.255	0.160	–0.362
Plant colour	–0.118	0.132	0.398	–0.143	0.262
Flowering duration (days)	–0.244	0.112	–0.074	0.470	–0.065
Growth habit	–0.259	–0.122	–0.016	–0.183	0.080
Plant height (cm)	0.368	–0.014	–0.140	0.094	0.393
Plant width (cm)	0.281	0.033	–0.158	0.054	0.514
Apical primary branches (No.)	–0.102	0.153	–0.082	0.332	0.137
Apical secondary branches (No.)	0.101	0.425	–0.025	0.137	–0.210
Basal primary branches (No.)	0.126	0.095	–0.066	–0.251	0.145
Basal secondary branches (No.)	0.177	0.418	0.006	–0.135	–0.167
Tertiary branches (No.)	0.145	0.436	0.021	0.112	–0.114
Days to maturity	0.409	0.129	–0.054	0.085	–0.099
Pods per plant (No.)	–0.214	0.398	–0.121	–0.246	0.029
Seeds per pod (No.)	–0.037	0.077	0.276	–0.145	–0.070
Seed colour	0.034	0.095	0.386	0.287	0.216
Dots on seed testa	–0.111	–0.101	–0.432	–0.308	–0.143
Seed testa texture	–0.148	–0.025	–0.102	0.057	0.085
100-seed weight (g)	0.042	–0.079	–0.407	0.256	0.150
Plant yield (g)	–0.213	0.369	–0.254	–0.150	0.130
Plot yield (kg ha^{-1})	–0.242	0.157	–0.204	–0.101	0.343

Table 3. Continued

Characteristics	Principal components				
	1	2	3	4	5
Kabuli type					
Variation explained (%)	17.12	14.24	8.53	7.70	6.92
Latent root	3.42	2.85	1.71	1.54	1.38
Days to flower	–0.374	0.316	–0.128	–0.045	0.112
Flower colour	–0.094	–0.036	–0.102	0.078	0.240
Plant colour	–0.011	–0.028	–0.001	–0.058	–0.276
Flowering duration (days)	0.334	–0.210	0.275	0.091	–0.064
Growth habit	0.139	–0.244	–0.043	0.135	–0.062
Plant height (cm)	–0.259	0.249	0.029	–0.003	–0.353
Plant width (cm)	–0.293	0.159	0.006	–0.064	–0.467
Apical primary branches (No.)	0.142	0.091	0.265	0.161	–0.186
Apical secondary branches (No.)	0.233	0.384	0.129	–0.002	0.180
Basal primary branches (No.)	–0.049	0.130	–0.087	–0.049	–0.404
Basal secondary branches (No.)	0.163	0.422	0.018	0.035	0.171
Tertiary branches (No.)	0.189	0.361	0.196	0.049	0.204
Days to maturity	–0.268	0.326	0.171	0.059	0.192
Pods per plant (No.)	0.338	0.225	–0.217	–0.019	–0.230
Seeds per pod (No.)	0.137	0.044	–0.435	–0.289	0.150
Seed colour	0.064	0.017	0.367	0.585	0.076
Dots on seed testa	0.000	0.000	0.000	0.000	0.000
Seed testa texture	0.014	–0.030	0.269	–0.606	0.078
100-seed weight (g)	–0.146	–0.091	0.493	0.315	0.020
Plant yield (g)	0.283	0.231	0.064	0.169	–0.204
Plot yield (kg ha^{-1})	0.342	0.072	–0.140	–0.036	–0.191
Intermediate type					
Variation explained (%)	19.21	15.60	10.21	9.56	7.77
Latent root	4.04	3.28	2.15	2.01	1.63
Days to flower	0.380	0.224	0.182	0.021	–0.193
Flower colour	0.150	–0.229	0.288	0.392	–0.000
Plant colour	–0.019	0.201	0.085	–0.461	–0.159
Flowering duration (days)	–0.316	–0.149	–0.312	0.050	0.253
Growth habit	–0.248	–0.163	0.286	0.072	–0.252
Plant height (cm)	0.250	0.124	–0.110	0.089	0.363
Plant width (cm)	0.106	0.179	–0.182	0.088	0.304
Apical primary branches (No.)	–0.205	–0.026	0.078	0.031	0.432
Apical secondary branches (No.)	–0.022	0.381	–0.083	0.142	–0.151
Basal primary branches (No.)	0.096	0.283	0.278	0.103	0.081
Basal secondary branches (No.)	–0.064	0.433	0.023	0.072	–0.174
Tertiary branches (No.)	–0.195	0.321	–0.146	0.118	0.023
Days to maturity	0.247	0.298	–0.059	0.023	0.112
Pods per plant (No.)	–0.305	0.213	0.050	0.273	–0.013
Seeds per pod (No.)	0.041	0.032	0.319	0.266	0.250
Seed colour	–0.001	–0.054	0.472	0.251	–0.077
Dots on seed testa	–0.171	0.181	0.098	–0.480	–0.049
Seed testa texture	0.322	–0.002	–0.292	0.203	–0.133
100-seed weight (g)	0.126	0.037	0.304	–0.121	0.464
Plant yield (g)	–0.296	0.259	0.151	0.249	0.145
Plot yield (kg ha^{-1})	–0.334	0.074	–0.011	0.046	–0.038

traits are less laborious to measure than the flowering duration and pod number (Upadhyaya et al., 2001).

Table 3 shows the percentage of variation for the first five principal components (PC) and the vector loadings for each character and PC. The first five PCs explained 61.6% variation in the core collection of chickpea and reduced the original 22 characters to 13 characters. The first five PCs explained, 54.8% variation in desi, 54.5% in kabuli, and 62.4% in internediate types and reduced the 21 characters to 12, 11, and 13 characters, respectively. PC 1 which is first and the most important component accounted for 17% in desi and kabuli types, 19% in intermediate types and 26% in the total core collection. The eigen values of PC1 were 3.57 in desi, 3.42 in kabuli, and 4.04 in intermediate types compared to 5.60 in the total core subset.

The PC 1 separates accessions on days to 50% flowering, plant height, plant width, and days to maturity in the desi types, days to 50% flowering, pod number, plus plot yield in kabuli types, and days to 50% flowering, flowering duration, seed testa texture, and plot yield in intermediate types. However, in the entire core subset flower colour, seed shape, plant colour, dots on seed testa, texture of seed testa, and 100-seed weight separated the accessions. Interestingly, days to 50% flowering, which has highest loadings in the PC 1 of all types has very low loadings in the total core subset. Also, the loadings for this trait were positive in desi and intermediate types, but negative in the kabuli types. Considering the analyses of desi, kabuli, and intermediate types and total core subset together, 10 traits had high loadings and occurred at least three times out of four, in the first five PCs, indicating their importance for chickpea as descriptors. These traits are days to 50% flowering (desi, kabuli, intermediate), plant width (desi, kabuli, total), apical secondary branches (desi, kabuli, intermediate, total), tertiary branches (desi, kabuli, intermediate, total), dots on seed testa (desi, intermediate, total), 100-seed weight (desi, kabuli, intermediate, total), flowering duration (desi, intermediate, total), basal secondary branches (kabuli, intermediate, total), seed colour (kabuli, intermediate, total), and seed testa texture (kabuli, intermediate, total). Growth habit and basal primary branches had no contribution in explaining variation in the first five PCs of desi, kabuli, intermediate types and total core collection, indicating their low importance as chickpea descriptors.

The grouping of similar genotypes depends on the dissimilarity among them, which can be determined by a phenotypic diversity index. The average diversity index was highest in the intermediate types (0.2653) and lowest in the kabuli types (0.1490) (Table 4). The low average diversity in the kabuli types may have arisen because in this group, unlike other groups, the dots on seed testa are absent and the phenotypic diversity index is based on 20 traits only. The range of phenotypic diversity was highest in the intermediate types. The closest lines were ICCs 3776 and 4168 in the desi types, ICCs 13453 and 9395 in the kabuli types (total core subset also), and ICCs 10864 and 9775 in the intermediate types. The largest phenotypic diversity index was observed between ICCs 1069 and 14528 in the desi types, ICCs 14446 and 6160 in the kabuli types, ICCs 5988 and 6305 in the intermediate types, and ICCs 14614 and 8512 in the entire core subset (Table 4). It would be interesting to involve the lines showing highest phenotypic diversity index in the hybridization and selection program for various traits.

The Shannon-Weaver diversity index was calculated to compare phenotypic diversity index (H') among characters and groups. A low H' indicates a extremely unbalanced frequency classes for an individual trait and a lack of genetic diversity. The estimates of H' were made for each trait and three groups and pooled across traits and groups (Table 5). The average H' across traits was similar for desi and intermediate types and higher than the kabuli types. The H' values averaged over three groups ranged from 0.122 (texture of seed testa) to 0.621 (plant width). The diversity values were variable among traits and among types. Thus, the diversity within a group depended upon the traits. The H' values in the entire core subset ranged from 0.249 for growth habit to 0.856 for seed colour (data not given). Growth habit had the lowest H' value since the number of classes was five and the frequency distribution of entries was extremely skewed towards semi-erect (1579) and semi-spreading (343) types. In contrast seed colour had the highest number of 24 classes and several of these classes had 10 or more entries in the core subset.

The results of this study indicated that there is a significant variation for morphological and agronomic traits in this chickpea core collection. The phenotypic correlations depended upon the type (classified on the seed shape basis, i.e., desi, kabuli, and intermediate) for the morphological descriptors only. The mean number of pods per plant and seed per pod are highest in the desi type but the 100-seed weight is lowest in this group while it is opposite in the kabuli types, i.e., the number of pods per plant and seeds per pod are

Table 4. Phenotypic diversity index in the desi, kabuli, and intermediate types (excluding seed shape) and in the total core subset (including seed shape) of chickpea

	Desi	Kabuli	Intermediate	Total core subset
Mean phenotypic diversity index	0.1656	0.1490	0.2653	0.1937
Minimum phenotypic diversity index	0.0264	0.0217	0.0666	0.0179
Between	ICC 3776 and ICC 4168	ICC 13543 and ICC 9395	ICC 10864 and ICC 9775	ICC 13453 and ICC 9395
Maximum phenotypic diversity index	0.4429	0.4475	0.5119	0.4803
Between	ICC 1069 and ICC 14528	ICC 14446 and ICC 6160	ICC 5988 and ICC 6305	ICC 14614 and ICC 8512

Table 5. Shannon-Weaver diversity index for 21 characters in the desi, kabuli, and intermediate types of chickpea

Character	Desi	Kabuli	Intermediate	Average ± s.e.
Days to flower	0.643	0.601	0.568	0.604 ± 0.0216
Flower colour	0.195	0.045	0.520	0.254 ± 0.1403
Plant colour	0.227	0.055	0.211	0.164 ± 0.0548
Flowering duration (days)	0.623	0.619	0.593	0.612 ± 0.0096
Growth habit	0.266	0.149	0.315	0.243 ± 0.0493
Plant height (cm)	0.626	0.614	0.556	0.599 ± 0.0214
Plant width (cm)	0.625	0.628	0.616	0.621 ± 0.0053
Apical primary branches (No.)	0.622	0.598	0.588	0.602 ± 0.0100
Apical secondary branches (No.)	0.590	0.596	0.522	0.569 ± 0.0238
Basal primary branches (No.)	0.642	0.599	0.586	0.609 ± 0.0171
Basal secondary branches (No.)	0.496	0.528	0.477	0.501 ± 0.0149
Tertiary branches (No.)	0.545	0.506	0.542	0.531 ± 0.0126
Days to maturity	0.613	0.559	0.610	0.594 ± 0.0175
Pods per plant (No.)	0.604	0.586	0.528	0.573 ± 0.0230
Seeds per pod (No.)	0.480	0.346	0.352	0.393 ± 0.0437
Seed colour	0.753	0.038	0.902	0.564 ± 0.2667
Dots on seed testa	0.160	0.000	0.269	0.143 ± 0.0781
Seed testa texture	0.071	0.032	0.263	0.122 ± 0.0714
100-seed weight (g)	0.573	0.591	0.492	0.552 ± 0.0304
Plant yield (g)	0.609	0.593	0.542	0.581 ± 0.0203
Plot yield (kg ha^{-1})	0.631	0.630	0.597	0.619 ± 0.0112
Average ± s.e.	0.504 ± 0.0424	0.424 ± 0.0544	0.507 ± 0.0338	

lowest and the 100-seed weight highest. The plot yield followed the pod number pattern, highest in desi types and lowest in kabuli types. The information presented in this study could be used to reduce the size of this core further and develop a core of core subset (Upadhyaya & Ortiz, 2001), which may be of value to the plant breeder to evaluate extensively and use genetic resources in crop improvement.

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