Euphytica **132:** 343–352, 2003.

Geographical patterns of variation for morphological and agronomic characteristics in the chickpea germplasm collection

Hari D. Upadhyaya
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), P.O. Patancheru 502 324, Andhra Pradesh, India (For correspondence: e-mail: H.Upadhyaya@CGIAR.ORG)

Received 15 July 2002; accepted 26 April 2003

Key words: agronomic traits, chickpea, *Cicer arietinum*, diversity, geographical regions, morphological descriptors, world collection

Summary

The characterization of diversity in germplasm collections is important to plant breeders for crop improvement and to genebank curators for efficient and effective management of collection. The objective of our study was to describe the phenotypic diversity of the 16 820 accessions of chickpea (*Cicer arietinum* L.) germplasm contained in the ICRISAT genebank. The germplasm accessions were characterized for seven morphological descriptors, reaction to fusarium wilt, and 13 agronomic traits to determine phenotypic variation in different geographical regions. Phenotypic variation was found for most traits in all the regions. The means for different agronomic traits differed significantly between regions. The variances for all the traits among regions were heterogeneous. South Asia contained maximum range variation for all the traits. The Shannon-Weaver diversity index was variable in different regions for different traits. Among morphological traits seed colour and among agronomic traits days to 50% flowering showed the highest pooled diversity index. The Mediterranean region, which is the primary center of diversity, and Africa, which has the secondary center of diversity in Ethiopia, were poorly represented. Principal component analysis (PCA) using 13 traits and clustering of the first three PC scores delineated two regional clusters consisting Africa, South Asia, and Southeast Asia in the first cluster and the Americas, Europe, West Asia, Mediterranean region, and East Asia in the second cluster.

Introduction

Chickpea is a major food legume in many countries including Algeria, Ethiopia, India, Iran, Mexico, Morocco, Myanmar, Pakistan, Spain, Syria, Tanzania, Tunisia, and Turkey. Chickpea does not contain any specific antinutritional factors such as beta-oxyl-diamino-propionic acid in grass pea (*Lathyrus sativus* L.), vicin in faba bean (*Vicia faba* L.) and trypsin inhibitor in soybean (*Glycine max* (L.) Merrill), although it has oligosaccharides which cause flatulence (Williams and Singh, 1987). In 2001, the crop was cultivated on 8.58 million hectares in the world producing 6.06 million tonnes and average productivity was 0.71 t ha^{-1} (Food and Agriculture Organization of the United Nations, 2001). Of the world production, 78.6% is produced in Asia on 84.5% area, 5.4% in Africa on 6.1% area, 10.7% in North and Central America (mainly Canada and Mexico) on 5.5%, 3.9% in Oceania (mainly Australia) on 2.7%, and 1.1% in Europe on 1.1%. In Asia, India accounts for 67.3% of the area and 71.1% production. Other important countries in Asia are Iran (7.6% area, 3.3% production), Myanmar (2.3% area, 2.5% production), Pakistan (12.4% area, 8.3% production), and Turkey (7.9% area, 11.3% production). Productivity in these countries ranges from 0.29 t ha^{-1} in Iran to 0.94 t ha^{-1} in Turkey. The average world productivity of chickpea is low and improving the genetic potential of crop for yield is an important objective in most breeding programs (Singh, 1987). It is estimated that major biotic and abiotic stresses reduce at least 50% potential yield of this crop in major production regions of the world (Ryan, 1997). Therefore, other important breeding goals are breeding for resistance to biotic stresses such as, ascochyta blight [*Ascochyta rabiei* (Pass.) Labr.], fusarium wilt [*Fusarium oxysporum* Schlecht. emend. Snyd. & Hans. f. sp. *ciceri* (Padwick) Snyd. & Hans], root rots [*Fusarium solani* Kuhn and *Rhizoctonia bataticola* (Taub.) Butler], pod borer (*Helicoverpa armigera* Hübner) and leaf miner (*Liriomyza cicerina* Rondani) and abiotic stress like drought.

The importance of increasing the use of genetic resources to enhance genetic potential of the crop and in alleviating biotic and abiotic stresses has been well recognized (Singh, 1987). The emphasis on preservation of crop germplasm led to assembling and maintaining a very large number of germplasm collections. At ICRISAT, the genebank contains 16 992 accessions from 44 countries. Of these, 4150 accessions were obtained from 65 collection missions in 14 countries (Afghanistan, Bangladesh, Ethiopia, India, Kenya, Malawi, Morocco, Myanmar, Nepal, Pakistan, Syria, Tanzania, Turkey, and Uganda). The other 12 842 accessions of cultivated species were obtained from donations by 42 countries.

There are limited reports on variation in chickpea germplasm (Murty, 1975; Narayan & Macefield, 1976; Moreno & Cubero, 1978; Robertson et al., 1997). These studies, except that of Narayan & Macefield (1976) who used 5477 accessions from 16 countries, used a limited number of accessions from a few countries. Moreno & Cubero (1978) studied 150 accessions selected from five geographical regions and Murty (1975) 459 from 16 countries. The ICRISAT genebank contains the largest collection of 16 992 accessions of chickpea from 44 countries. The germplasm accessions have been characterized for morphological and agronomic traits over a period of time (1974–1998). However, the extent of variation in different geographical regions for various traits has not been described. The objective of the present research was to describe phenotypic variation found in the ICRISAT chickpea collection from different geographical regions of the world and to determine the similarities between regions.

Material and methods

In total 16 820 accessions originating from 43 countries and contained in the ICRISAT genebank were used for this study. A total of 172 accessions was excluded from this study- three from Australia because of the low seed number, and another 169 accessions, due to lack of information on origin. The accessions consisted of 12 648 (75.2%) desi (angular shaped seeds), 3541 (21.0%) kabuli (owls' head shaped), and 631 (3.8%) intermediate (pea shaped) types. The regions used for Asia were South Asia (consisting of Bangladesh, Sri Lanka, Nepal, India, Pakistan), West Asia (Afghanistan, Iran, Iraq, Jordan), Mediterranean region (Algeria, Cyprus, Egypt, France, Greece, Israel, Italy, Lebanon, Morocco, Spain, Syria, Tunisia, Turkey, Yugoslavia) and East Asia (Russia, China) (Table 1). Data on six morphological descriptors, flower colour, growth habit, seed colour, seed shape, seed texture, and dots on seed testa were recorded on a plot basis on all 16 820 accessions, and plant colour on 14 683 accessions at ICRISAT Center Patancheru, India from 1974 to 1998. (IBPGR, ICRISAT & ICARDA, 1993). The number of entries characterized/evaluated during 25 years depended upon acquisition of new accessions and availability of sufficient seed and ranged from 3984 in 1974 to 64 in 1998. In all the years augmented design was used. Three control cultivars, JG 62, L 550, and G 130 were included in evaluations from 1974 to 1980, and Annigeri, L 550, and G 130 from 1981 to 1998. The control cultivars were repeated after every 20 test entries from 1974 to 1979 and after every 10 test entries from 1980 to 1998. In each entry five representative plants were selected randomly to record data on plant height (cm), plant width (cm), number of basal primary branches, apical primary branches, basal secondary branches, apical secondary branches, and tertiary branches, number of pods per plant, and number of seeds per pod. 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), 100-seed weight (g) and plot yield were also recorded on plot basis in all the accessions. The reaction of 12 549 accessions to fusarium wilt was assessed on a scale 1 (resistant, 0–10% diseased plants), 2 (moderately resistant, 11–40% diseased plants, and 3 (susceptible, $> 41\%$ diseased plants).

Phenotypic proportions of seven morphological descriptors and reaction to fusarium wilt were calculated in each region. Statistical analysis of quantitative traits data was performed using Residual Maximum Likelihood (REML) approach. Data was first analysed separately for each of the year and combined for 25 years to estimate components of variance due to entry (genotype) and entry $\times$ year interactions and to obtain predicted means of each of the entries. Later on re-

Table 1. Number and percentage (within brackets) of chickpea accessions from different countries available in ICRISAT genebank

Country/region	Number of accessions		Country/region	Number of accessions	
East Asia	156	(0.9)[1]	Algeria	15	(1.2)
China	24	(15.4)	Tunisia	31	(2.5)
Russia	132	(84.6)	Turkey	402	(32.4)
West Asia	5564	(33.1)	Yugoslavia	6	(0.5)
Afghanistan	685	(12.3)	Africa	1123	(6.7)
Iran	4838	(87.0)	Ethiopia	928	(82.6)
Iraq	17	(0.3)	Kenya	1	(0.1)
Jordan	24	(0.4)	Malawi	81	(7.2)
South east Asia	129	(0.8)	Nigeria	3	(0.3)
Myanmar	129	(100.0)	Sudan	12	(1.1)
South Asia	7873	(46.8)	Tanzania	97	(8.6)
Bangladesh	170	(2.2)	Uganda	1	(0.1)
India	7174	(91.1)	Americas	619	(3.7)
Nepal	80	(1.0)	Chile	139	(22.5)
Pakistan	446	(5.7)	Colombia	1	(0.2)
Sri Lanka	3	(0.0)	Mexico	396	(64.0)
Mediterranean	1240	(7.4)	Peru	3	(0.5)
Cyprus	44	(3.6)	USA	80	(12.9)
Egypt	52	(4.2)	Europe	116	(0.7)
France	2	(0.2)	Bulgaria	9	(7.8)
Greece	22	(1.8)	Czechoslovakia	8	(6.9)
Israel	47	(3.8)	Germany	11	(9.5)
Italy	45	(3.6)	Hungary	4	(3.5)
Lebanon	19	(1.5)	Portugal	84	(72.4)
Morocco	246	(19.8)			
Spain	106	(8.6)			
Syria	203	(16.4)	Total	16 820	

[1] Figures in the brackets are percentage of accessions in a region over total accessions or in a country within a region.

gions (as fixed) and years (as random) were considered using predicted mean of entry from previous analysis to determine importance of regions and region × year interactions. The mean, range and variances of all the quantitative traits were calculated for each of the regions. The means of different regions for all traits were compared using the Newman-Keuls procedure (Newman, 1939; Keuls, 1952). The homogeneity of variances of regions was tested using Levene's test (Levene, 1960).

The diversity index (H') of Shannon & Weaver (1949) was used as a measure of phenotypic diversity for each trait. The index was estimated for each character over all accessions and for all characters within a region. By pooling various characters across geographical regions, the additive properties of H' were used to evaluate the diversity of the regions and characters within populations.

Principal component analysis (PCA) of data of 13 quantitative traits was performed. The mean observations of traits for each region were standardized by subtracting from each observation the mean value of the character and subsequently dividing by its respective standard deviation. This resulted in standardized 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. Cluster analysis (Ward, 1963) was performed using scores of first three principal components.

Results and discussion

South Asia is represented by the largest number of accessions (7873 accessions, 46.8% of the total) followed by West Asia (5564, 33.1%) in the ICRISAT genebank. India in South Asia with 7174 accessions (91.1% of the region) and Iran with 4838 accessions (87.0% of the region) in West Asia are the two major germplasm contributing countries (Table 1). The Mediterranean region, which is one of the two primary centers of diversity, contributed only 1240 accessions (7.4%) and was under-represented. Ethiopia, which is the secondary center of diversity, and is grouped in Africa (1123 accessions, 6.7% of the total), was also under-represented by 928 accessions (82.6% of the region).

The seven morphological descriptors showed differences among geographical regions in their distribution and range of variation (Table 2). None of the morphological descriptors was monomorphic and most showed at least two relatively frequent phenotypic classes. Plant colour showed a pattern typical to the regions in which different chickpea types are grown. Non- anthocyanin containing accessions which are characteristic of kabuli chickpeas were less frequent in the South Asia, Southeast Asia, and Africa where desi chickpeas having low- or high-anthocyanin accessions are cultivated. Similarly, East Asia, the Mediterranean region, and Europe, the non-anthocyanin accessions are cultivated. The pattern for flower colour, seed colour, seed shape, and seed surface across different regions was similar to plant colour. Thus kabuli characteristics such as white flower, owls' head seed shape, a smooth seed surface, and beige seeds were more frequent in East Asia, the Mediterranean region, and Europe. Accessions with pink flowers, brown or yellow-brown seeds, angular seed shape, and rough seed surface, were abundant in South Asia, Southeast Asia, and Africa. Erect, prostrate and spreading growth habits had a very low frequency across all the regions except East Asia. Semi-erect and semi-spreading growth habits were evenly distributed in South Asia, whereas in the rest of the regions, except Southeast Asia, semi-erect accessions were predominant (Table 2). Accessions resistant to fusarium wilt were available from all regions, however, their proportion was slightly higher in the accessions from South Asia, Southeast Asia, and West Asia. This may be due to the fact that although fusarium wilt is a widespread disease in large chickpea-growing countries (Nene et al., 1991), it is more serious disease in these three regions (Nene & Reddy, 1987).

The variance component due to entry was significant for most of the traits in all the 25 years indicating that significant variability was added to the ICRISAT chickpea collection during this period. In the combined analysis the entry component was significant for 10 traits; days to 50% flowering, plant height, plant width, days to maturity, number of basal primary branches, apical primary branches, basal secondary branches, and apical secondary branches, seeds per pod, and 100-seed weight (data not given) and the entry × year interaction component was significant for all the traits. In the analysis involving regions and years, the regions differed significantly for all the traits, except number of tertiary branches, and region × year interaction for all the traits (data not given).

There were significant differences among regions for all 13 agronomic traits (Table 3). Accessions from Africa took the least number of days to 50% flowering (54.4 days) and accessions from Southeast Asia for maturity (109.7 days) whereas accessions from East Asia were the latest to flower (70.1 days), and accessions from Europe, to mature (124.6 days). The accessions from Europe had the highest number of pods per plant (53.2) and produced highest plot yield (1469 kg ha^{-1}) compared to those from Southeast Asia (925 kg ha^{-1}). The highest 100-seed weight was observed in the accessions from Europe (25.7 g) followed by the Mediterranean region (22.6 g), Americas (21.1 g), East Asia (20.9 g), and the lowest was in the accessions from Africa (14.8 g), indicating the relative importance of seed size in these regions. In Europe, the Mediterranean region, and Americas, large-seeded kabuli cultivars are preferred whereas in South Asia, Southeast Asia, and Africa mostly small-seeded desi cultivars are grown.

All regions, except Southeast Asia, showed more than 66% average range of the entire collection. South Asia and West Asia showed 100% range for the seven morphological descriptors and reaction to fusarium wilt, and the Mediterranean region showed 100% range variation for all morphological descriptors except for plant colour (data not shown). The 13 agronomic traits showed a large range for different traits in different regions. South Asia showed a 100% range of entire collection for three traits, days to 50% flowering, number of basal secondary branches, and apical secondary branches, and 73.1% to 99.6% range for the remaining 10 traits (Table 4). On average South Asia

Table 2. Phenotypic proportions (%) of morphological descriptor traits in different regions for chickpea germplasm

Character	East Asia	West Asia	Southeast Asia	South Asia	Mediterr-anean	Africa	Americas	Europe
Plant colour								
High anthocyanin	0.0	0.5	0.0	0.5	0.0	9.3	0.2	0.0
Low anthocyanin	30.7	45.7	90.6	86.7	22.4	75.4	51.4	10.3
No anthocyanin	69.3	53.8	9.4	12.9	77.6	15.3	48.5	89.7
Growth habit								
Erect	27.6	0.2	0.0	0.5	2.1	0.0	0.5	11.2
Prostrate	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Spreading	0.0	0.3	0.0	0.4	0.0	0.0	0.0	0.0
Semi-erect	63.5	71.3	19.4	50.7	81.5	67.9	84.2	84.5
Semi-spreading	9.0	28.2	80.6	48.5	16.4	32.1	15.3	4.3
Flower colour								
Blue	0.0	0.0	0.0	0.6	0.2	0.0	0.0	0.0
Dark pink	10.3	0.1	0.0	0.3	1.3	0.0	0.2	2.6
Light blue	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Light pink	2.6	17.9	0.0	1.7	2.9	0.2	1.1	0.0
Pink	21.8	50.2	93.0	88.1	23.4	90.4	55.3	11.2
Very light pink	0.0	0.0	0.0	0.1	0.2	0.9	0.2	0.0
White	65.4	31.8	7.0	9.1	71.9	8.5	43.3	86.2
White with pink streaks	0.0	0.0	0.0	0.2	0.1	0.0	0.0	0.0
Seed colour								
Brown	8.3	13.2	3.1	27.1	4.5	11.6	5.5	0.9
Brown beige	1.9	11.6	0.0	0.6	6.5	1.0	0.5	0.9
Beige	58.3	31.2	7.0	5.7	70.2	7.3	42.8	85.3
Black	11.5	19.6	0.0	1.7	3.3	19.2	4.0	5.2
Black brown mosaic	0.0	0.0	0.0	0.1	0.2	0.1	0.0	0.0
Dark brown	1.3	1.1	0.0	4.1	0.6	0.0	0.5	0.0
Green	1.3	0.4	0.0	1.2	0.1	0.2	0.2	0.0
Greyish brown	0.0	0.0	0.0	0.4	0.0	0.0	0.2	0.0
Grey	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
Ivory	0.0	0.1	0.0	0.1	0.1	0.0	0.2	0.0
Light brown	1.3	4.2	1.6	10.3	4.7	11.3	22.1	1.7
Light green	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.0
Light orange	5.1	0.0	0.0	0.6	1.0	0.1	0.2	0.9
Light yellow	1.3	0.6	0.8	0.8	2.3	3.0	2.6	0.9
Variegated	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Orange	1.3	0.1	0.0	1.5	0.3	0.3	0.3	0.0
Orange brown	0.6	0.1	0.0	0.6	0.2	0.0	0.0	0.9
Reddish brown	0.6	0.2	0.0	0.3	0.1	0.0	0.3	0.0
Salmon brown	0.0	1.6	0.0	0.1	0.6	0.3	0.2	0.0
Yellow	1.9	8.2	0.0	11.0	0.6	3.4	2.9	0.0
Yellow brown	4.5	6.4	86.8	32.7	4.4	41.5	17.4	3.4
Yellow beige	0.6	1.2	0.8	0.9	0.2	0.7	0.2	0.0
Dots on seed testa								
Present	81.4	69.5	7.0	16.3	79.5	29.8	48.9	93.1
Absent	18.6	30.5	93.0	83.7	20.3	70.2	51.1	6.9
Seed shape								
Angular	32.7	64.8	93.0	90.8	27.1	91.7	55.6	12.9
Owl's head	51.9	31.5	7.0	5.5	68.2	4.9	42.8	83.6
Pea-shaped	15.4	3.7	0.0	3.7	4.7	3.4	1.6	3.5
Seed surface								
Rough	34.0	67.6	93.8	88.8	31.4	92.3	55.6	12.9
Smooth	66.0	31.7	6.2	6.6	68.5	7.8	42.2	87.1
Tuberculated	0.0	0.7	0.0	4.6	0.2	0.0	2.3	0.0
Reaction to wilt								
Moderately resistant	6.8	17.4	25.0	23.1	9.6	11.1	8.6	0.0
Resistant	2.3	10.0	0.0	9.9	3.5	5.4	2.7	3.8
Susceptible	90.9	72.6	75.0	67.0	86.9	83.5	88.7	96.2

Table 3. Means for agronomic traits for different regions in chickpea germplasm

Character	East Asia	West Asia	Southeast Asia	South Asia	Mediterr-anean	Africa	Ameri-cas	Europe
Days to 50% flowering	70.1a[1]	64.1c	56.9e	61.5d	65.6b	54.4f	66.4b	62.0d
Plant height (cm)	45.8b	38.0e	30.0h	37.0f	39.5d	33.9g	40.6c	47.7a
Plant width (cm)	41.6b	40.0c	35.6d	41.1b	38.9c	41.6b	39.1c	45.5a
Basal primary branches (No.)	2.8b	2.7cd	2.4g	2.8b	2.6e	2.6f	2.7ed	3.2a
Apical primary branches (No.)	1.0c	1.5b	0.7d	1.4b	1.1c	1.6a	1.0c	1.4b
Basal secondary branches (No.)	3.4b	3.0c	2.7d	3.1c	3.1c	3.1c	3.1c	4.3a
Apical secondary branches (No.)	4.4d	4.3d	4.5dc	4.7c	4.4d	5.7b	4.3d	6.9a
Tertiary branches (No.)	0.9bc	1.0a	0.2f	0.6d	0.8c	0.6d	1.0ba	0.4e
Days to maturity	123.6ba	117.0d	109.7f	114.2e	120.8c	110.5f	122.6b	124.6a
Pods per plant (No.)	38.6ed	38.5ed	34.1f	41.4c	37.4e	47.9b	39.8d	53.2a
Seeds per pod (No.)	1.21b	1.22b	1.15d	1.23b	1.19c	1.28a	1.22b	1.15d
Yield per plot (kg ha^{-1})	1065.0c	1241.0b	925.0d	1251.0b	1106.1c	1100.0c	1212.2b	1469.0a
100-seed weight (g)	20.9c	16.4e	16.9d	15.9e	22.6b	14.8f	21.1c	25.7a

[1] Differences between means of different regions were tested by the Newman-Keuls test. Means followed by the same letter are not significantly different at p= 0.05.

Table 4. Range of variation for agronomic traits for different regions in chickpea germplasm

Character	East Asia	West Asia	Southeast Asia	South Asia	Mediterr-anean	Africa	Americas	Europe
Days to 50% flowering	38.1–100.0	37.0–94.0	40.6–83.3	33.1–107.0	35.3–97.2	36.0–91.0	37.1–89.0	42.2–94.3
Plant height (cm)	27.5–92.2	18.6–76.7	24.0–45.6	18.8–99.5	18.4–103.8	19.2–55.8	24.1–67.0	26.6–93.7
Plant width (cm)	27.9–61.4	24.0–64.6	29.4–48.3	26.2–60.8	25.3–65.3	26.5–58.5	26.4–53.5	29.2–64.6
Basal primary branches (No.)	1.8–4.3	1.5–4.7	2.3–3.2	1.5–4.9	1.8–4.9	1.5–4.7	1.8–3.9	2.1–4.4
Apical primary branches (No.)	0.4–2.2	0.0–4.2	0.4–1.8	0.0–4.9	0.3–3.1	0.3–3.6	0.0–3.3	0.3–2.1
Basal secondary branches (No.)	2.1–5.4	1.1–7.6	2.3–5.7	0.7–8.0	1.8–7.7	1.7–6.4	1.1–5.2	2.5–6.6
Apical secondary branches (No.)	2.7–9.2	2.5–12.4	3.0–6.1	2.5–13.4	2.7–11.3	2.9–11.0	2.7–9.4	3.1–9.6
Tertiary branches (No.)	0.0–3.2	0.0–4.2	0.0–2.5	0.0–4.2	0.0–4.2	0.0–3.4	0.0–4.0	0.0–2.4
Days to maturity	97.6–158.4	92.2–157.6	103.0–132.6	93.0–156.8	92.8–154.6	94.0–153.2	95.8–152.3	100.1–153.8
Pods per plant (No.)	19.3–70.8	17.3–127.6	24.7–62.6	16.0–137.4	14.8–98.1	23.0–127.3	20.7–80.5	24.5–71.3
Seeds per pod (No.)	1.0–1.5	1.0–2.1	1.0–1.5	1.0–2.1	1.0–2.0	1.0–1.8	1.0–1.7	1.0–1.5
Yield per plot (kg ha^{-1})	422.6–1988.0	361.8–2325.0	494.2–1866.0	347.5–2834.0	401.7–2006.9	450.1–2330.0	321.2–2721.8	547.2–2202.0
100-seed weight (g)	9.5–34.7	6.0–52.6	10.9–23.1	4.1–47.4	8.5–50.7	6.5–47.5	9.8–63.4	9.6–40.5

represented 95.9% range in the entire collection compared to 88.0% range in the West Asia, 62.5% in East Asia, 81.8% in the Mediterranean region, 69.8% in the Americas, 60.7% in Europe, 73.7% in Africa, and 39.9% in Southeast Asia. Over all the seven morphological descriptors, reaction to wilt, and 13 agronomic traits, South Asia represented the highest average range (97.5%) and Southeast Asia the lowest range (48.7%). The variances were heterogeneous (p = <0.0001) for all the 13 agronomic traits (Table 5). East Asia had the highest variances for four traits, days to 50% flowering, plant height, plant width, and days to maturity, and Africa had highest variances for apical primary branches, pods per plant, and seeds per pod and Europe for basal primary branches, basal secondary branches, apical secondary branches, and plot yield (Table 5).

The Shannon-Weaver diversity index (H') was calculated to compare phenotypic diversity among characters and regions. The index is used as a measure of allelic richness and allelic evenness: a low H' indicates an extremely unbalanced frequency class for an

Table 5. Variance for agronomic traits for different regions in chickpea germplasm

Character	East Asia	West Asia	Southeast Asia	South Asia	Mediter-ranean	Africa	Ameri-cas	Europe	F value	Probability
Days to 50% flowering	146.20[1]	69.98	22.95	76.98	98.92	33.27	108.99	102.34	44.55	<0.0001
Plant height (cm)	119.80	15.38	18.32	25.02	53.52	20.17	29.68	70.56	70.19	<0.0001
Plant width (cm)	64.39	40.45	13.05	33.72	42.42	26.93	29.68	29.44	41.63	<0.0001
Basal primary branches (No.)	0.14	0.12	0.10	0.11	0.14	0.07	0.06	0.21	15.60	<0.0001
Apical primary branches (No.)	0.27	0.21	0.04	0.29	0.26	0.34	0.30	0.21	21.53	<0.0001
Basal secondary branches (No.)	0.41	0.37	0.41	0.59	0.40	0.31	0.26	0.61	28.66	<0.0001
Apical secondary branches (No.)	1.76	1.22	0.12	1.35	1.61	4.29	0.88	2.89	101.01	<0.0001
Tertiary branches (No.)	0.68	0.92	0.09	0.66	0.80	0.39	0.62	0.32	75.43	<0.0001
Days to maturity	158.70	119.82	17.31	71.69	145.39	89.77	144.12	48.57	51.07	<0.0001
Pods per plant (No.)	115.37	76.68	18.73	97.05	85.31	233.52	56.85	101.78	44.84	<0.0001
Seeds per pod (No.)	0.007	0.010	0.016	0.011	0.007	0.018	0.006	0.010	21.24	<0.0001
Yield per plot (kg ha^{-1})	103875.00	72780.00	35966.00	84163.00	70359.01	79241.00	66656.91	188064.00	23.20	<0.0001
100-seed weight (g)	29.52	22.77	4.41	7.25	54.73	9.23	75.12	35.44	131.67	<0.0001

[1] Variances were tested using Levene's test.

Table 6. Shannon-Weaver diversity index for agronomic traits in different regions for chickpea germplasm

Character	East Asia	West Asia	Southeast Asia	South Asia	Mediter-ranean	Africa	Americas	Europe	Mean
Flower color	0.41	0.45	0.11	0.20	0.33	0.15	0.33	0.20	0.27± 0.044
Plant color	0.27	0.31	0.14	0.18	0.23	0.31	0.31	0.14	0.24± 0.027
Growth habit	0.37	0.27	0.21	0.32	0.24	0.27	0.20	0.23	0.27± 0.021
Seed color	0.69	0.86	0.24	0.84	0.55	0.75	0.71	0.30	0.62± 0.083
Dots on seed testa	0.21	0.27	0.11	0.19	0.22	0.27	0.30	0.11	0.21± 0.025
Seed shape	0.43	0.33	0.11	0.16	0.33	0.15	0.33	0.23	0.26± 0.040
Seed surface	0.28	0.29	0.10	0.19	0.28	0.12	0.34	0.17	0.22± 0.031
Reaction to wilt	0.16	0.33	0.24	0.36	0.20	0.24	0.19	0.07	0.22± 0.033
Days to 50% flowering	0.62	0.61	0.52	0.62	0.62	0.60	0.60	0.43	0.58± 0.025
Plant height (cm)	0.55	0.59	0.48	0.59	0.57	0.59	0.61	0.39	0.55± 0.027
Plant width (cm)	0.57	0.61	0.45	0.56	0.61	0.48	0.58	0.48	0.54± 0.022
Basal primary branches (No.)	0.58	0.61	0.32	0.58	0.58	0.60	0.59	0.62	0.56± 0.034
Apical primary branches (No.)	0.48	0.62	0.33	0.61	0.55	0.61	0.60	0.56	0.54± 0.035
Basal secondary branches (No.)	0.59	0.60	0.29	0.61	0.60	0.59	0.60	0.58	0.56± 0.038
Apical secondary branches (No.)	0.49	0.58	0.55	0.61	0.44	0.49	0.53	0.42	0.51± 0.024
Tertiary branches (No.)	0.47	0.49	0.14	0.40	0.47	0.42	0.52	0.31	0.40± 0.043
Days to maturity	0.57	0.50	0.35	0.57	0.57	0.53	0.58	0.46	0.52± 0.028
Pods per plant (No.)	0.58	0.53	0.29	0.56	0.63	0.50	0.53	0.48	0.51± 0.036
Seeds per pod (No.)	0.62	0.57	0.53	0.60	0.58	0.60	0.57	0.44	0.57± 0.022
Yield per plot (kg ha^{-1})	0.60	0.56	0.40	0.48	0.56	0.59	0.59	0.55	0.54± 0.024
100-seed weight (g)	0.61	0.58	0.58	0.57	0.58	0.52	0.51	0.59	0.57± 0.012
Mean	0.48± 0.033	0.50± 0.033	0.31± 0.035	0.47± 0.042	0.46± 0.034	0.45± 0.040	0.48± 0.033	0.37± 0.037	0.44

individual trait and a lack of genetic diversity. Estimates were made for each character and pooled across characters and regions for morphological descriptor traits, reaction to fusarium wilt, and for agronomic traits (Table 6). The West Asia region had highest pooled H' for morphological descriptor traits (0.39 ± 0.070) and agronomic traits (0.57 ± 0.012). Seed colour (0.62 ± 0.083) among morphological traits and days to 50% flowering (0.58 ± 0.025) among agronomic traits had highest pooled H' (Table 6). Over all the 21 traits, West Asia (0.50 ± 0.033) had the highest H' and Southeast Asia least pooled H' (0.31 ± 0.035). This may be because the southwest Asia, which is one of the primary centers of diversity, is located in the West Asia and the region is represented by 33.1% of collection whereas Southeast Asia is represented by only 0.8% collection from Myanmar.

The PCA was used to provide a reduced dimension model that would indicate measured differences among groups. PC 1, which is first and the most important component accounted for 55.7% of total variation. The second PC accounted for 26.5%, and third for the 8.7%. A hierarchical cluster analysis conducted on the first three PC scores (total variation accounted 90.9%) resulted in two clusters (Figure 1). Africa, South Asia, and Southeast Asia grouped together to form Cluster 1 and the Americas, Europe, West Asia, Mediterranean region, and East Asia formed Cluster 2. This clustering is not surprising considering the trade of chickpea from the Mediterranean region to the countries in West Asia, and between Europe and Americas, and the preference for light coloured large-seeded cultivars. These links facilitate a flow of particular chickpea types between regions. The accessions from all the member regions of Cluster 1, South Asia (90.8%), Southeast Asia (93.0%) and Africa (91.7%) were predominantly of desi type with low 100-seed weight whereas most members of Cluster 2 were predominantly of kabuli type with high 100-seed weight (Tables 2, 3).

The accessions in Cluster 1 had predominantly low-anthocyanin plants, pink flowers, angular shaped brown or yellow brown seeds with rough seed surface and dots on the seed testa, whereas in Cluster 2 accessions were predominantly non-anthocyanin plants, beige coloured seeds, with smooth seed surface and without dots on seed testa (data not shown). Both clusters differed significantly for all the 13 agronomic traits. Accessions in Cluster 2 took more days to flower and maturity, had taller plants and more tertiary branches, and higher 100-seed weight than the accessions in Cluster 1 (Table 7). Accessions in Cluster 1 had wider plants, more basal primary branches, apical primary branches, basal secondary branches, apical secondary branches, pods per plant, seeds per pod and higher plot yield than in Cluster 2. Variances of the two regional clusters were heterogeneous (p = 0.0001–0.0156) for all the traits except plant height (Table 7).

The geographic origins of ICRISAT chickpea accessions indicated significant differences for range of variation for various morphological and agronomic traits. Chickpea most probably originated in an area of present-day Southwestern Turkey and Northern Syria around the upper reaches of the Tigris and Euphrates rivers (Lev-Yadun et al., 2000). Chickpea spread with human movement toward west to the Mediterranean basin and south toward Indian subcontinent via the Silk Route. In chickpea, like other grain legumes, large-seeded cultivars were common around the Mediterranean basin, whereas the small-seeded predominated eastward. There are linguistic indications that the large-seeded, beige chickpea reached India only two centuries ago, apparently through Afghanistan, as its Hindi name is *Kabuli chana* (*chana* = chickpea), an allusion to the Afghanistan capital Kabul. The mean 100-seed weight was highest in the accessions from Europe followed by the Mediterranean region and Americas indicating importance of large seed size in these regions, whereas in the South Asian countries the small-sized desi chickpea are used. Similarly, tall plant types are required for mechanical harvesting in Europe (47.7 cm) and East Asia (45.8 cm) and the accessions from these regions were tallest. This is in contrast with South Asia, Southeast Asia, and Africa where crop is hand harvested and tall plants are not required. The accessions from these regions had the low plant heights (30.0–37.0 cm).

The levels of diversity found for the morphological and agronomic traits indicate that West Asia region in which southwest Asia, one of the primary centers of diversity is located, was adequately represented by 5564 (33.1%) accessions in the ICRISAT genebank. This was also demonstrated by the highest diversity for the morphological descriptors (pooled H' = 0.389 ± 0.070) and agronomic traits (pooled H' = 0.57 ± 0.012) observed in this region. The Mediterranean region (1240 accessions, 7.4%), which is another primary center of diversity and Africa (1123 accessions, 6.7%), which has Ethiopia, the secondary center of diversity, were not adequately represented numerically in ICRISAT collections. Accessions from

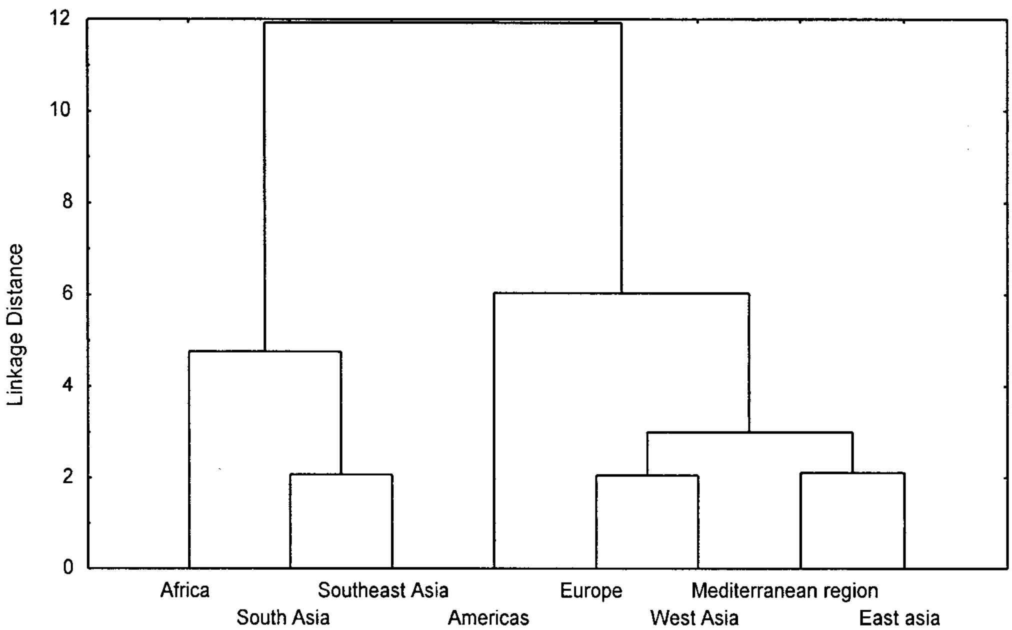

Figure 1. Dendogram of eight regions in the entire chickpea germplasm based on first three principal components.

Table 7. Means and variances for agronomic traits for different clusters in the chickpea germplasm

Character	Mean[1]		Variance[2]			
	Cluster 1	Cluster 2	Cluster 1	Cluster 2	F value	Probability
Days to 50% flowering	60.5b	64.6a	76.4	81.1	5.85	0.0156
Plant height (cm)	36.5b	38.7a	26.0	28.4	3.10	0.0784
Plant width (cm)	40.1a	39.8b	33.1	41.0	15.63	<0.0001
Basal primary branches (No.)	2.8a	2.7b	0.1	0.1	339.40	0.0003
Apical primary branches (No.)	1.4a	1.4b	0.3	0.3	13.40	<0.0001
Basal secondary branches (No.)	3.1a	3.0b	0.6	0.4	30.86	<0.0001
Apical secondary branches (No.)	4.8a	4.4b	1.8	1.4	85.32	<0.0001
Tertiary branches (No.)	0.6b	1.0a	0.6	0.9	40.05	<0.0001
Days to maturity	113.7b	118.3a	74.8	130.4	295.84	<0.0001
Pods per plant (No.)	42.1a	38.7b	118.2	81.2	66.55	<0.0001
Seeds per pod (No.)	1.2a	1.2b	0.01	0.01	52.86	<0.0001
Yield per plot (kg ha^{-1})	1227.6a	1216.5b	86641.4	78016.8	21.89	<0.0001
100-seed weight (g)	15.7b	18.0a	16.2	39.5	422.26	<0.0001

[1] Differences between means of different regions were tested by the Newman-Keuls test. Means followed by the same letter are not significantly different at $p = 0.05$.
[2] Variances were tested using Levene's test.

some of these countries are available in the International Center for Agricultural Research in the Dry Areas (ICARDA), where the genebank holds 9717 accessions of chickpea of which 5521 are unique and not duplicated in the ICRISAT genebank. However, there is need to explore useful crop diversity for special purposes such as resistance to diseases and other biotic stresses for utilization in chickpea improvement programs.

References

Food and Agriculture Organization, 2001. `http: //www/FAO.ORG` FAOSTAT database.

IBPGR, ICRISAT & ICARDA, 1993. Descriptors for Chickpea (*Cicer arietinum* L.). International Board for Plant Genetic Resources, Rome, Italy; International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India and International Center for Agriculture Research in the Dry Areas, Aleppo, Syria.

Keuls, M., 1952. The use of the 'Studentized range' in connection with an analysis of variance. Euphytica 1: 112–122.

Levene, H., 1960. Robust tests for equality of variances. In: I. Olkin (Ed.), Contributions to Probability and Statistics: Essays in Honour of Harold Hotelling, pp. 278–292. Stanford University Press, Stanford.

Lev-Yadun, S., A. Gopher & S. Abbo, 2000. The cradle of agriculture. Science 288: 1602–1603.

Moreno, M.-T. & J.I. Cubero, 1978. Variation in *Cicer arietinum* L. Euphytica 27: 465–485.

Murty, B.R., 1975. Biology of adaptation in chickpea. In: International Workshop on Grain Legumes (Pigeonpeas and Chickpeas). International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad, India, pp. 239–251.

Narayan, R.K.J. & A.J. Macefield, 1976. Adaptive responses and genetic divergence in world germplasm collection of chick pea (*Cicer arietinum* L.). Theor Appl Genet 47: 179–187.

Nene, Y.L. & M.V. Reddy, 1987. Chickpea diseases and their control. In: M.C. Saxena & K.B. Singh (Eds.), The Chickpea, pp. 233–270. C.A.B. International Wallingford, UK.

Nene, Y.L., M.V. Reddy, M.P. Haware, A.M. Ghanekar & K.S. Amin, 1991. Field diagnosis of chickpea diseases and their control. Information Bulletin no. 28. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India.

Newman, D., 1939. The distribution of range in samples from a normal population expressed in terms of an independent estimate of standard deviation. Biometrika 31: 20–30.

Robertson, L.D., B. Ocampo & K.B. Singh, 1997. Morphological variation in wild annual *Cicer* species in comparison to the cultigen. Euphytica 95: 309–319.

Ryan, J.G., 1997. A global perspective on pigeonpea and chickpea sustainable production systems: Present status and future potential. In: A.N. Asthana & Masood Ali (Eds.), Recent Advances in Pulses Research, pp. 1–31. Indian Society of Pulses Research and Development, Indian Institute of Pulses Research (IIPR), Kanpur, India.

Shannon, C.E. & W. Weaver, 1949. The Mathematical Theory of Communication. Univ. of Illinois Press, Urbana.

Singh, K.B., 1987. Chickpea breeding. In: M.C. Saxena and K.B. Singh (Eds.), The Chickpea, pp. 127–162. C.A.B. International Wallingford, UK.

Ward, J., 1963. Hierarchical grouping to optimize an objective function. J Am Stat Assoc 38: 236–244.

Williams, P.C. & U. Singh, 1987. Nutritional quality and the evaluation of quality in breeding programmes. In: M.C. Saxena and K.B. Singh (Eds.), The Chickpea, pp. 329–356. C.A.B. International Wallingford, UK.