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Phenotypic diversity in groundnut (*Arachis hypogaea* L.) core collection assessed by morphological and agronomical evaluations

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Abstract

The groundnut (*Arachis hypogaea* L.) core collection consists of 1704 accessions of which 910 belong to subsp. *fastigiata* (var. *fastigiata*, *vulgaris*, *aequatoriana*, *peruviana*) and 794 to subsp. *hypogaea* (var. *hypogaea*, *hirsuta*). This core collection was evaluated for 16 morphological descriptors and for 32 agronomic characteristics, 15 in the 1999 rainy season and 17 in the 1999/2000 postrainy season, to estimate phenotypic diversity and determine importance of different descriptor traits. The two groups differed significantly for all the traits except leaflet surface and oil content. The *hypogaea* group showed significantly greater mean pod length, pod width, seed length, seed width, yield per plant, and 100-seed weight than the *fastigiata* group in both seasons whereas it is opposite for plant height, leaflet length, leaflet width and shelling percentage. There were significant phenotypic correlations among the various characteristics. Four of these, days to 50% flowering (r = 0.752), leaflet length (r = 0.743), pod length (r = 0.758), and seed length (r = 0.759) in the rainy explained more than 50% variation in the postrainy season. Principal coordinate and principal component analyses showed that 12 morphological descriptors and 15 agronomic traits, respectively, were important in explaining multivariate polymorphism. Leaflet shape and surface, colour of standard petal markings, seed colour pattern, seed width, and protein content did not significantly account for variation in the first five principal coordinates or components of *fastigiata* and *hypogaea* types as well as for the entire core collection. This indicates their relatively low importance as groundnut descriptors. The average phenotypic diversity index was similar in both subspecies groups. The Shannon-Weaver diversity index varied among traits between the two groups, and the diversity within a group depended upon the season and traits recorded.

Introduction

Groundnut is an important oilseed crop cultivated in 96 countries of world with an annual production of 34.52 million t on 23.84 million ha in year 2000 (FAO 2000). Groundnut is a native of South America. The cultivated species, was described by Linnaeus in 1753 as *Arachis* (derived from the Greek ''arachos '' meaning a weed) *hypogaea* (meaning an underground chamber) or in botanical terms, a weed with fruits produced below the soil. In South America, where the greatest diversity is found, Krapovickas (1969), Gregory and Gregory (1976) recognised the Chaco region between southern Bolivia and northwestern Argentina as the primary center of diversity, and other regions as secondary centers of diversity of cultivated groundnut. Recent evidences indicate a seventh secondary center of diversity in Ecuador (Simpson et al. 1992). Following the subspecies nomenclature and varietal associations proposed by Krapovickas and Gregory (1994), two subspecies and six botanical varieties are recognised. *A. hypogaea* is divided into two subspecies, *fastigiata* Waldron and *hypogaea* Krap. et Rig. Subsp. *fastigiata* is subdivided into four botanical varieties, *fastigiata*, *peruviana* Krapov. & W.C. Gregory, *aequatoriana* Krapov. & W.C. Gregory, and *vulgaris* Harz. The two botanical varieties in subsp. *hypogaea* are *hypogaea* and *hirsuta* Kohler.

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 and Bennett 1970), the accessibility and usefulness of a collection is inversely related to its size (Frankel and Soulé 1981). The ICRISAT genebank contains 14,310 germplasm accessions of groundnut from 92 countries.

These accessions were acquired mainly by donations from different countries, and supplemented by conducting a total of 57 collecting missions (30 in Asia and 27 in Africa). Of the 14,310 accessions, 2,561 are from collecting missions, 1,302 from 19 African countries and 1,259 from seven Asian countries. The remaining 11,749 accessions have been acquired by donations from Asia, Africa, the Americas, 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 1,704 entries using data of taxonomical, geographical, and morphological descriptors to enhance the use of genetic resources in improvement programs. The main objectives of this study were to assess phenotypic diversity for various morphological descriptors and agronomic traits in the rainy and postrainy seasons, determine the importance of different descriptor traits, and associations among them in the core subset and most diverse genotypes.

Materials and methods

The experimental materials for this study comprised 1,704 accessions of groundnut core collection, consisting of 910 accessions belonging to subsp. *fastigiata* (var. *vulgaris*, *fastigiata*, *peruviana*, and *aequatoriana*) and 794 to subsp. *hypogaea* (var. *hypogaea* and *hirsuta*). These 1,704 and four control cultivars, Gangapuri (*fastigiata*), ICGS 44 (*vulgaris*), ICGS 76 (*hypogaea*) and M 13 (*hypogaea*) were evaluated in an augmented design in the 1999 rainy and 1999/2000 postrainy seasons. Four control cultivars were repeated after every 10 entries. The accessions were sown by hand in an alfisol- Patancheru Soil Series (Udic Rhodustolf) field. Each treatment consisted of a 4-m row on a ridge. The distance between rows was 60 cm and between plants within a row 15 cm. Care was taken to ensure uniform depth of planting. Seeds of accessions belonging to var. *hypogaea* and var. *hirsuta* were treated with ethrel (2-chloroethylphosphonic acid) before sowing to overcome the possible effects postharvest seed dormancy. The experiments received 60 kg P_2O_5 ha^{-1}, 400 kg gypsum ha^{-1}, full irrigation (four irrigations in the rainy and 10 irrigations in postrainy, each irrigation with 5 cm water) and protection against diseases and insect pests, and weeds. In each accession five representative plants were selected at random to record leaflet length and width (mm) at 60 days after planting (DAP) in the rainy season and 75 DAP in the postrainy season, and plant height (cm), number of primary branches per plant, pods per plant, and yield per plant (g) at harvest. Data on days to emergence (days from sowing to emergence), 50% flowering (days from emergence to the stage when 50% plants have begun flowering), pod length and width, seed length and width, plot yield (kg ha^{-1}), shelling percentage and 100-seed weight (g) were recorded on plot basis. Entire plot was harvested and pods were striped, dried and weighed. Yield of five plants was added to determine total plot yield. A 200-g mature pod sample was used to estimate shelling percentage. Pod length and width was recorded on 10 mature pods and seed length and width on 10 mature seeds, 100 mature seeds were used to record weight. Oil content was measured with a commercial nuclear magnetic resonance spectrometer following the procedure described by Jambunathan et al. (1985) in the 1999/2000 postrainy season. All the readings were taken on oven dried (110 °C, 16 h) samples and values were expressed on a uniform 50 g kg^{-1} seed moisture. Protein content was estimated with a Technicon Autoanalyser (Pulse Instrumentation Ltd., Saskatoon, SK) (Singh and Jambunathan 1980). Morphological descriptors (growth habit, branching pattern, stem pigmentation and surface, leaflet colour, shape and surface, peg pigmentation, colour of standard petal, colour of streak markings on standard petal, pod beak, constriction, and reticulation, seeds per pod, primary seed colour and seed colour pattern) were recorded according to a descriptor list (IBPGR and ICRISAT 1992) on whole plot basis.

Means of the two subspecies *fastigiata* (consisting *fastigiata*, *aequatoriana*, *peruviana*, and *vulgaris* botanical varieties; referred as *fastigiata* type or group) and *hypogaea* (consisting *hypogaea* and *hirsuta* botanical varieties; referred as *hypogaea* type or group) were compared using Newman-Keuls procedure (Newman 1939; Keuls 1952) for all traits in the rainy and postrainy seasons. The homogeneity of variances of these groups was tested using Levene's test (Levene 1960). Phenotypic correlations were calculated among all traits in the core collection and in the two subspecies in both the seasons. Principal coordinate analysis (PCoA) of data on morphological (qualitative) traits and principal component analysis (PCA) of data on agronomical (quantitative) traits were performed to know the importance of different traits in explaining multivariate polymorphism. The mean observations of agronomic traits for each accession were standardized by substracting 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.

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 and 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 the two groups.

Results and discussion

Morphological characteristics

The frequency distribution of the core collection entries for all the morphological descriptors, except leaflet shape, revealed a large degree of variation.

Growth habit

Five of the six growth habit based on angle of primary branches at the podding stage (IBPGR and ICRISAT 1992) were found. Erect was the most predominant growth habit (911 accessions) followed by procumbent 1 (320 accessions), decumbent 2 (285), and decumbent 3 (169). Decumbent 1 was observed in only 19 accessions and procumbent 2 in none of the accessions.

Branching pattern

Sequential branching which is characteristic of subsp. *fastigiata* was observed in 910 accessions followed by alternate pattern of *hypogaea* in 794 accessions.

Stem pigmentation

Pigmentation on stem of mature plants was absent in 1,420 accessions and present in the remaining 284 accessions.

Stem surface

All five types of stem surface were observed. Subglabrous, hairs in one or two rows along the main stem, was observed in 1,289 accessions, moderately hairy, three to four rows of hairs on main stem, in 388 accessions, and very hairy, most of stem surface covered with hairs, in 17 accessions, glabrous in 7 accessions and wooly, most of the stem surface covered with long hairs, in only 3 accessions.

Leaflet colour

Four of the five leaflet colours were observed in the core subset. Light green leaflet colour was most frequent (906 accessions) followed by green (779 accessions) and dark green (18 accesions). Yellow/yellow green was observed in only one accession and bluish green in none of the accessions.

Leaflet shape

Elliptic leaf shape was observed in all the 1,704 accessions of core collection. In the entire collection of 14,310 accessions, 14,271 accessions have elliptic leaf shape. The other two types were obcuneate (27 accessions) and oblong-elliptic (12 accessions).

Leaflet surface

Only four of eight types of leaflet surface were observed. Almost glabrous on both surfaces of leaflet was most predominant with 1,686 accessions. Other three types were almost glabrous above and hairs below (14 accessions), hairs on both surfaces without bristles (1 accessions) and hairs on both surfaces with bristles at least on one surface (3 accessions). Four leaflet surface types, almost glabrous above hairs and/or bristles below, almost glabrous below and hairs above, almost glabrous below hairs and/or bristles above, and wooly without bristles were not found in any of the accessions.

Standard petal colour

The 1,656 accessions had orange standard petal of fresh, fully opened flowers, 40 accessions have garnet or brick red standard petal and only 8 had orange-yellow (IBPGR and ICRISAT 1992). White, lemon yellow, yellow and dark orange were not observed in any of the accessions.

Colour of standard petal markings

Colour of markings (crescent) on the front face of the standard petal revealed predominance of dark orange markings (1597 accessions). Orange marking was observed only in 67 accessions and garnet or brick red in the 40 accessions. White, lemon yellow, yellow and orange-yellow were not observed in any of the accessions.

Peg pigmentation

Pigmentation on peg was present in 1,663 accessions and absent in the remaining 41 accessions.

Number of seeds per pod

Most accessions have 2-1 seeded pods (2-seed pods most frequent, 1-seed pods less frequent IBPGR and ICRISAT (1992)) (1,084 accessions), followed by 3-2-1 or 3-1-2 seeded (3-seed pods most frequent followed by 2- or 1-seed pods) (293 accessions), and 2-3-1/2-1-3 seeded (2-seed pods most frequent followed by 3- or 1-seed pods) (251 accessions). The number of 2-3-4-1/2-4-3-1/2-3-1-4 seeded pod accessions was 67 and 3-2-4-1/3-2-1-4 seeded pod only 9 accessions.

Pod beak

Beak in mature pods was absent in 105 accessions, slight in 727 accessions, moderate in 740 accessions, prominent in 124 accessions, and very prominent in only 8 accessions.

Pod constriction

Slight constriction in mature pods was present in 1,041 accessions, moderate in 592 accessions, deep in 36, absent in 35 accessions, and very deep in none of the accessions.

Pod reticulation

Reticulation in pod surface was moderate in a maximum of accessions (1,256) followed by slight in 214 accessions, prominent in 185 accessions, very prominent in 44 accessions, and absent in only 5 accessions.

Primary Seed colour

Of the 15 classes of seed colour observed in the core subset, tan was the most common represented (1,225 accessions) followed by red (265 accessions). Very pale tan was seen in only one accession. Dark tan, salmon, purplish red/reddish purple and dark purple were observed in none of the accessions.

Seed colour pattern

Mature seeds of 1,655 accessions had single colour and only 49 accessions had variegated seeds.

The mean scores for all the morphological descriptors, except leaflet shape and surface, were significantly different for *fastigiata* and *hypogaea* types (data not shown). Variances for all morphological descriptors, except branching pattern ($p = 0.3941$), leaflet surface ($p = 0.8454$), colour of standard petal markings ($p = 0.2767$), and pod constriction ($p = 0.2110$) were heterogeneous ($p = 0.0001$–0.0046) (data not shown)

The percentage variation explained by the first five principal coordinates (PCo) was 66.69% in the entire core subset, 70.23% in *fastigiata* group, and 58.03% in *hypogaea* group. PCo 1 which is first and the most important coordinate accounted for 39.09% variation in *fastigiata* group, 17.25% in *hypogaea* group, and 30.30% in the total core collection (data not shown). Considering the analyses of *fastigiata* and *hypogaea* groups and the total core subset all together, 12 morphological showed high correlation with the PCo scores and occurred at least one time out of three, indicating their importance in explaining variation. These morphological descriptors are growth habit, stem pigmentation, stem surface, branching pattern, leaflet colour, standard petal colour, peg pigmentation, and pod beak, constriction and reticulation, primary seed colour, and seeds per pod.

Agronomic characteristics

All the traits except pod width showed genotype x season interactions. The differences between mean values for all the 15 traits in the rainy and postrainy seasons were significantly different in the *fastigiata* and *hypogaea* groups and in the total core subset (data not shown). The means in the postrainy season were significantly greater than in the rainy season for days to emergence and 50% flowering, pod length and width, seed length and width, pods per plant, yield per plant, yield per plot, shelling percentage, and 100-seed weight. The number of primary branches, plant height, leaflet length and width were greater in the rainy season than in the postrainy season (Table 1). The means of *fastigiata* and *hypogaea* types were significantly different from each other for all the traits, except oil content in the postrainy season (Table 1). The *hypogaea* type took more days to emerge and 50% flowering, have higher number of primary branches, pod length and width, seed length and width, yield per plant, and 100-seed weight in both the seasons. The *fastigiata* type have more plant height, leaflet length and width, and higher shelling percentage than *hypogaea* type in both seasons (Table 1). The range for most of the traits was different in two types. The *fastigiata* type represented 100% range variation of total core collection for five traits (days to 50% flowering, plant height, seed width, yield per plant, and yield per plot) in the rainy season and four traits (days to emergence, seed length, pods per plant, and oil content) in the postrainy season. The *hypogaea* type represented 100% range of total core collection for days to emergence, pod length, yield per plant, and shelling percentage in the rainy season and days to emergence and 50% flowering, pod and seed width, plot yield and protein content in the postrainy season. Overall, *fastigiata* group captured 86.29% range variation of total core collection as compared with 91.53% by *hypogaea* group. The variances between the *fastigiata* and *hypogaea* types were homogeneous for eight traits in the rainy season (days to emergence and 50% flowering, plant height, leaflet length, pod width, seed width, yield per plant, and yield per plot) and for two traits in the postrainy season (days to emergence and shelling percentage) (Table 1).

The percentage of variation explained by the first five principal components (PC) and the vector loadings for each agronomic character and PC are given in Table 2. The first five PCs explained 58.74% variation in the core collection of groundnut and reduced the original 32 characters to 19 characters. The first five PCs explained 51.35% variation in *fastigiata* and 47.08% in *hypogaea* type and reduced the 32 characters to 18 and 15 characters, respectively. PC 1 which is first and the most important component accounted for 20.48% in *fastigiata* type, 18.34% in *hypogaea* type and 26.10% in the total core collection. The eigen values of PC1 were 6.55 in *fastigiata* and 5.87 in *hypogaea* type as compared to 8.35 in the total core collection.

The PC 1 separates accessions on three traits in the rainy season (pod length and width, and seed length) and four traits (pod length and width, seed length, and 100-seed weight) in the postrainy season in the *fastigiata* group, three traits each in the rainy season (leaflet length, pod width, and seed length) and postrainy (pod length and width, and seed length) in *hypogaea* group. However, in the entire core collection primary branches in the rainy season, leaflet length in the postrainy season and days to flower, leaflet width, and seed length in both seasons separated the accessions. Interestingly, seed length which had positive loadings in the *fastigiata* and *hypogaea* types in both the rainy and postrainy seasons, showed negative loadings in the entire core collection in both seasons (Table 2). Considering the analyses of *fastigiata* and *hypogaea* groups and the total core subset all together, 15 agronomic traits had high loadings and occurred at least one time out of three, in the first five PCs, indicating their importance for groundnut as descriptors. The agronomic traits are days to emergence and 50% flowering, primary branches, plant height, leaflet length and width, pod length and width, seed length, pods per plant, yield per plant, yield per plot, shelling percentage, 100-seed weight, and oil content. Seed width in both the rainy and postrainy seasons and protein content in the postrainy season had no contribution in explaining variation in the first five PCs of *fastigiata* and *hypogaea* groups and total core collection, indicating their low importance as groundnut descriptors. However, protein content is an important quality trait and should be used as a descriptor.

Phenotypic correlations were conducted between all 47 traits (leaflet shape excluded) in the entire core subset, *fastigiata* and *hypogaea* groups independently. Correlation between 32 traits in the entire core collection are presented in (Table 3). Any correlation coefficient with more than 1700 degrees of freedom (e.g. for entire core collection) with an absolute value

Table 1. Mean, range, and variance of 17 quantitative characters for two subspecies of groundnut (Patancheru, India, 1999 rainy and 1999/2000 postrainy seasons).

	Mean[1]			Range		Variance[2]			
Character	*fastigiata* (910)[3]	*hypogaea* (794)[3]	Significance	*fastigiata* (910)[3]	*hypogaea* (794)[3]	*fastigiata* (910)[3]	*hypogaea* (794)[3]	F value	*p*
Rainy season									
Days to emergence	8.2	8.6	*	6–11	6–12	1.0677	0.9844	1.494	0.2218
Days to 50% flowering	20.3	26.8	*	15–31	17–31	5.4611	4.8153	1.938	0.164
Primary branches (No.)	4.2	5.5	*	3–6	4–8	0.2320	0.4913	78.211	0.0001
Plant height (cm)	35.0	26.4	*	6.6–63.4	10.4–50.2	32.9180	35.2987	0.568	0.4512
Leaflet length (mm)	53.8	46.4	*	31.6–75.4	24.8–72	29.2603	27.4054	0.556	0.4558
Leaflet width (mm)	23.5	20.1	*	16.6–30.8	7–30.4	5.7256	3.8745	19.463	0.0001
Pod length (mm)	26.6	29.8	*	15.5–54.5	12.6–55.7	35.8604	18.1264	47.995	0.0001
Pod width (mm)	11.5	12.5	*	8–17.5	5.7–17	1.5668	1.5272	0.106	0.7447
Seed length (mm)	10.8	13.6	*	7.2–16.5	7.4–19.5	1.7244	3.1023	53.684	0.0001
Seed width (mm)	6.9	7.1	*	4.8–9.5	5.5–9.5	0.3596	0.4107	3.208	0.0735
Pods per plant (No.)	9.4	8.2	*	2–28	1–21	15.0606	10.3059	21.173	0.0001
Yield per plant (g)	5.3	5.6	*	0.4–18	0.4–18	6.5727	6.4728	0.033	0.8565
Plot yield (kg ha^{-1})	588.4	624.4	*	29.17–1875.02	33.33–1737.51	74599.9474	69351.4211	0.775	0.3787
Shelling percentage	64.3	62.4	*	41.6–77	40–78.7	39.8016	24.7686	32.208	0.0001
100-seed weight (g)	27.5	33.0	*	16.8–42.2	18.5–68	22.4934	32.6393	19.745	0.0001
Postrainy season									
Days to emergence	10.1	10.9	*	9–13	9–13	0.7801	0.7499	0.396	0.5293
Days to 50% flowering	36.8	46.6	*	34–56	29–56	4.3189	24.9535	218.9	0.0001
Primary branches (No.)	4.0	5.1	*	2.2–6.4	2.8–8.4	0.1776	0.7961	212.8	0.0001
Plant height (cm)	14.1	11.9	*	3.6–26.8	6.2–29.9	13.5242	11.2321	4.469	0.0347
Leaflet length (mm)	48.5	37.6	*	24.8–75	23.4–65.2	32.3201	20.5103	21.666	0.0001
Leaflet width (mm)	21.4	17.4	*	13.8–58.8	8.6–28	7.4893	2.6894	8.163	0.0043
Pod length (mm)	28.7	30.7	*	19–58	14–53	30.2621	20.5549	15.917	0.0001
Pod width (mm)	12.6	12.8	*	9–19	7–19	1.7245	2.4541	17.997	0.0001
Seed length (mm)	12.4	15.5	*	9–22	10–22	3.4334	4.3303	7.581	0.006
Seed width (mm)	8.3	9.2	*	6–12	6–13	0.5746	1.0004	46.599	0.0001
Pods per plant (No.)	12.0	13.8	*	2–34.8	2–33.4	21.3299	25.6887	4.858	0.0277
Yield per plant (g)	9.9	14.6	*	0.38–26.58	1–37.88	12.8825	29.2109	75.000	0.0001
Plot yield (kg ha^{-1})	1233.4	1112.1	*	153.34–2315.85	65.00–2697.94	133386.7	165666.4	9.684	0.0019
Shelling percentage	71.6	70.2	*	51.3–83.5	42–81.2	21.3287	23.1020	0.584	0.4448
100–seed weight (g)	44.9	53.7	*	25.6–80	25–78	51.5073	88.5781	47.031	0.0001
Oil content (%)	49.3	49.5	NS	41–55.3	41.8–54.9	5.4165	4.0477	16.820	0.0001
Protein content (%)	23.8	21.7	*	18.2–28.7	15.5–29.1	3.6236	4.7708	17.257	0.0001

1. Differences between means of *fastigiata* and *hypogaea* types tested by the Newman-Keuls test. NS and * indicate nonsignificant and significant differences at $p = 0.05$, respectively.
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. Vector loadings and percentage of variation explained by the first five principal components after assessing agronomic characteristics in subsets of groundnut core collection.

Characteristics	Principal components				
	1	2	3	4	5
Entire core collection					
Variation explained (%)	26.10	14.24	7.78	5.90	4.72
Latent root	8.35	4.56	2.49	1.89	1.51
Rainy season					
Days to emergence	−0.069	0.056	0.039	−0.074	−0.263
Days to 50% flowering	−0.255	0.134	0.022	−0.192	−0.014
Primary branches (No.)	−0.241	0.125	−0.080	−0.052	−0.111
Plant height (cm)	0.202	−0.25	−0.046	−0.018	−0.086
Leaflet length (mm)	0.194	−0.241	−0.037	−0.299	−0.118
Leaflet width (mm)	0.230	−0.117	−0.061	−0.318	−0.122
Pod length (mm)	−0.172	−0.290	0.021	0.161	−0.067
Pod width (mm)	−0.210	−0.271	−0.004	0.072	−0.023
Seed length (mm)	−0.279	−0.139	−0.023	−0.047	−0.063
Seed width (mm)	−0.078	−0.052	−0.145	−0.144	0.070
Pods per plant (No.)	0.070	0.146	−0.406	0.200	−0.249
Yield per plant (g)	−0.046	0.030	−0.484	0.240	−0.268
Plot yield (kg ha^{-1})	−0.033	0.063	−0.459	0.149	−0.086
Shelling percentage	0.095	0.230	−0.226	−0.027	0.135
100-seed weight (g)	−0.213	−0.109	−0.229	0.013	−0.063
Postrainy season					
Days to emergence	−0.174	0.059	0.073	−0.049	−0.273
Days to 50% flowering	−0.267	0.107	0.045	−0.129	−0.174
Primary branches (No.)	−0.211	0.124	0.0129	−0.128	−0.065
Plant height (cm)	0.115	−0.222	−0.061	−0.145	−0.275
Leaflet length (mm)	0.244	−0.218	−0.074	−0.179	−0.124
Leaflet width (mm)	0.241	−0.130	−0.115	−0.217	−0.109
Pod length (mm)	−0.141	−0.325	0.0101	0.108	0.038
Pod width (mm)	−0.084	−0.311	−0.053	0.009	0.115
Seed length (mm)	−0.269	−0.176	−0.041	−0.098	0.060
Seed width (mm)	−0.199	−0.111	−0.106	−0.159	0.209
Pods per plant (No.)	−0.036	0.144	−0.084	−0.281	−0.099
Yield per plant (g)	−0.172	−0.024	−0.174	−0.276	0.085
Plot yield (kg ha^{-1})	0.059	−0.030	−0.334	−0.248	0.302
Shelling percentage	0.081	0.143	−0.177	0.025	0.494
100-seed weight (g)	−0.212	−0.201	−0.126	−0.088	0.229
Oil content (%)	0.011	0.201	−0.029	−0.352	0.025
Protein content (%)	0.141	−0.212	−0.082	0.242	0.160
fastigiata group					
Variation explained (%)	20.48	11.52	7.97	6.16	5.22
Latent root	6.55	3.60	2.55	1.97	1.67
Rainy season					
Days to emergence	−0.039	0.024	−0.039	−0.031	−0.248
Days to 50% flowering	−0.131	−0.225	0.008	−0.289	0.090
Primary branches (No.)	−0.090	−0.019	−0.151	−0.008	−0.219
Plant height (cm)	0.156	−0.136	0.180	0.244	0.229
Leaflet length (mm)	0.079	−0.370	0.186	−0.133	0.205
Leaflet width (mm)	−0.060	−0.368	0.135	−0.119	0.138
Pod length (mm)	0.336	0.061	−0.029	0.031	0.116
Pod width (mm)	0.313	0.073	−0.069	−0.026	0.045
Seed length (mm)	0.283	−0.036	−0.13	−0.166	0.050
Seed width (mm)	0.021	−0.079	−0.196	−0.097	0.049
Pods per plant (No.)	−0.147	−0.053	−0.361	0.141	0.143
Yield per plant (g)	−0.010	−0.063	−0.476	0.145	0.233

Table 2. (*continued*)

Characteristics	Principal components				
	1	2	3	4	5
Plot yield (kg ha^{-1})	−0.047	−0.112	−0.421	0.112	0.294
Shelling percentage	−0.251	−0.017	−0.141	0.118	0.075
100-seed weight (g)	0.146	−0.056	−0.352	−0.104	0.153
Postrainy season					
Days to emergence	0.001	0.059	−0.089	−0.206	−0.034
Days to 50% flowering	−0.105	−0.071	−0.047	−0.392	0.014
Primary branches (No.)	−0.083	−0.126	−0.105	0.070	−0.424
Plant height (cm)	0.097	−0.248	0.137	0.344	−0.019
Leaflet length (mm)	0.102	−0.390	0.136	0.068	0.098
Leaflet width (mm)	−0.021	−0.361	0.080	0.106	0.035
Pod length (mm)	0.341	0.030	−0.001	0.011	0.024
Pod width (mm)	0.275	−0.033	−0.050	−0.031	−0.099
Seed length (mm)	0.286	−0.106	−0.099	−0.194	−0.174
Seed width (mm)	0.123	−0.113	−0.143	−0.175	−0.267
Pods per plant (No.)	−0.151	−0.194	−0.075	0.007	−0.192
Yield per plant (g)	0.060	−0.268	−0.113	0.144	−0.350
Plot yield (kg ha^{-1})	−0.058	−0.273	−0.121	0.229	−0.192
Shelling percentage	−0.167	0.065	−0.056	0.156	−0.115
100-seed weight (g)	0.269	−0.097	−0.135	−0.142	−0.188
Oil content (%)	−0.217	−0.137	−0.005	−0.296	0.018
Protein content (%)	0.186	0.086	−0.016	0.313	−0.101
hypogaea group					
Variation explained (%)	18.34	9.89	7.15	6.75	4.95
Latent root	5.87	3.17	2.29	2.16	1.58
Rainy season					
Days to emergence	0.002	−0.081	−0.102	−0.244	0.062
Days to 50% flowering	−0.044	−0.073	−0.245	0.162	−0.232
Primary branches (No.)	−0.016	0.165	−0.100	−0.260	−0.108
Plant height (cm)	0.213	−0.07	0.250	−0.190	0.099
Leaflet length (mm)	0.279	−0.199	0.151	−0.046	−0.177
Leaflet width (mm)	0.168	−0.241	0.164	−0.142	−0.277
Pod length (mm)	0.253	0.062	−0.258	−0.010	−0.009
Pod width (mm)	0.312	0.050	−0.180	0.062	0.075
Seed length (mm)	0.265	0.068	−0.281	0.052	0.025
Seed width (mm)	0.134	0.040	0.024	0.039	−0.107
Pods per plant (No.)	−0.107	0.357	0.034	−0.357	0.035
Yield per plant (g)	0.018	0.394	−0.049	−0.360	0.021
Plot yield (kg ha^{-1})	−0.017	0.372	−0.021	−0.183	−0.073
Shelling percentage	−0.127	0.230	0.038	0.030	−0.286
100-seed weight (g)	0.231	0.210	−0.168	−0.056	−0.001
Postrainy season					
Days to emergence	0.024	−0.108	−0.319	−0.153	−0.140
Days to 50% flowering	0.014	−0.100	−0.383	−0.174	−0.249
Primary branches (No.)	−0.058	0.002	−0.151	−0.006	−0.067
Plant height (cm)	0.201	−0.160	0.061	−0.343	0.062
Leaflet length (mm)	0.237	−0.169	0.172	−0.167	−0.194
Leaflet width (mm)	0.170	−0.150	0.215	−0.192	−0.253
Pod length (mm)	0.267	0.074	−0.131	0.065	−0.022
Pod width (mm)	0.271	0.066	−0.007	0.120	0.101
Seed length (mm)	0.285	0.134	−0.112	0.202	0.093
Seed width (mm)	0.220	0.139	0.094	0.248	0.083
Pods per plant (No.)	−0.061	−0.030	−0.050	−0.068	−0.181
Yield per plant (g)	0.097	0.133	0.065	0.013	−0.337
Plot yield (kg ha^{-1})	0.076	0.242	0.224	0.086	−0.299
Shelling percentage	−0.080	0.255	0.252	0.189	−0.231

Table 2. (*continued*)

Characteristics	Principal components				
	1	2	3	4	5
100-seed weight (g)	0.259	0.176	0.100	0.164	−0.020
Oil content (%)	−0.079	0.000	−0.049	0.210	−0.357
Protein content (%)	0.117	0.100	0.271	−0.096	0.268

greater than 0.1 will be significant at $P = 0.0001$. There were 650 correlations out of total 1080 which were greater than significant at $P = 0.0001$. Of these, 93 correlations were greater than 0.500 or less than −0.500 in the entire core collection. However, the correlation coefficients greater than 0.707 or smaller than −0.707 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 and Cochran 1980). In our study, we found such meaningful relationships between the rainy and postrainy seasons for days to 50% flowering (r = 0.752), leaflet length (r = 0.743), pod length (r = 0.758), and seed length (r = 0.759) in the entire core subset. These results suggested that in future germplasm evaluations, these traits can be evaluated in either of seasons. Further, growth habit, an easily measurable trait, showed correlation more than 0.500 with important but relatively difficult to measure traits like days to 50% flowering (r = −0.672 in rainy, r = −0.557 in postrainy), primary branches (r = −0.557 in rainy, r = −0.533 in postrainy), plant height ((r = 0.653 in rainy), leaflet length (r = 0.621 in postrainy), leaflet width (r = 0.521 in rainy, r = 0.565 in postrainy), seed length (r = −0.526 in rainy), and protein content (r = 0.504 in postrainy). Growth habit can substitute for these traits in the initial evaluation of a large number germplasm accessions.

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 similar in both the groups (Table 4). The range of phenotypic diversity was slightly higher in the *hypogaea* group than in the *fastigiata* group. The closest lines were ICG 5588 and ICG 6021 in the *fastigiata* group (total core subset also) and ICG 1596 and ICG 9712 in the *hypogaea* group. The largest phenotypic diversity index was observed between ICG 13479 and ICG 8422 in the *fastigiata* group and between ICG 13723 and ICG 20016 in the *hypogaea* group (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 an extremely unbalanced frequency classes for an individual trait and a lack of genetic diversity. The estimates of H' were made for each trait and two groups for both seasons and pooled across traits and seasons for each group (Table 5). The diversity values were variable among traits and among types. Thus, the diversity within a group depended upon the traits and seasons. Among the morphological descriptors primary seed colour in *fastigiata* group and pod beak in the *hypogaea* group showed highest H'. The average H' across morphological descriptors was similar (Table 5). Among the agronomic traits in *fastigiata* group 100-seed weight in the rainy season and plot yield in the postrainy season, and in the *hypogaea* group pod width in the rainy season and seed length in the postrainy season had the highest H'. The average H' values across traits were similar between rainy and postrainy seasons in both groups as well as in the entire core collection (data not shown).

The results of this study indicate that there is a significant variation for morphological and agronomic traits in this groundnut core collection. The phenotypic correlations depended upon the subspecies group. The mean pod length, pod width, seed length, seed width, yield per plant, and 100-seed weight was higher in the *hypogea* group than in the *fastigiata* group in both seasons while it is opposite for plant height, leaflet length, leaflet width and shelling percentage. This groundnut core collection should be revised periodically as additional accessions are collected, particularly from botanical varieties *hitsuta* and *aequatoriana* as well as others from locations that are not represented or under represented in the ICRISAT genebank (Upadhyaya et al. 2001). These locations include traditional groundnut areas in sub-

Table 3. Correlation coefficients between 32 characters measured in the entire core collection of groundnut (Patancheru, India).

	EMR	DFR	PRBR	PLHTR	LLNR	LWDR	PLNR	PWDR	SLNR	SWDR	PPPR	YPPR	YKGHR	SHR	SWTR	EMPR	DFPR	PRBPR	PLHTPR	LLNPR	LWDPR	PLNPR	PWDPR	SLNPR	SWDPR	PPPPR	YPPPR	YKGHPR	SHPR	SWTPR	OILPR
DFR	−0.010																														
PRBR	0.215	0.611																													
PLHTR	−0.218	−0.574	−0.461																												
LLNR	−0.133	−0.420	−0.454	0.615																											
LWDR	−0.076	−0.414	−0.444	0.513	0.816																										
PLNR	−0.008	0.123	0.137	0.053	−0.032	−0.243																									
PWDR	0.030	0.232	0.231	−0.045	−0.073	−0.277	0.699																								
SLNR	0.127	0.524	0.469	−0.302	−0.233	−0.402	0.611	0.647																							
SWDR	0.004	0.144	0.138	−0.050	−0.017	−0.009	0.073	0.267	0.262																						
PPPR	0.047	−0.145	0.086	−0.016	−0.051	0.061	−0.279	−0.269	−0.229	−0.039																					
YPPR	0.064	0.009	0.208	−0.053	−0.122	−0.100	0.096	0.094	0.097	0.089	0.673																				
YKGHR	−0.131	0.091	0.095	−0.032	−0.123	−0.088	0.044	−0.004	0.061	0.080	0.389	0.578																			
SHR	−0.088	−0.089	−0.064	−0.061	−0.071	0.090	−0.423	−0.425	−0.305	0.041	0.266	0.118	0.237																		
SWTR	0.083	0.351	0.358	−0.198	−0.167	−0.273	0.428	0.535	0.627	0.246	−0.038	0.288	0.319	−0.002																	
EMPR	0.199	0.396	0.338	−0.323	−0.274	−0.305	0.158	0.237	0.355	0.101	−0.076	0.037	−0.007	−0.075	0.270																
DFPR	0.243	0.752	0.623	−0.549	−0.447	−0.433	0.217	0.320	0.557	0.141	−0.135	0.055	0.062	−0.132	0.391	0.507															
PRBPR	0.186	0.542	0.533	−0.433	−0.407	−0.396	0.119	0.175	0.391	0.068	−0.071	0.038	0.044	−0.058	0.250	0.290	0.526														
PLHTPR	−0.028	−0.281	−0.222	0.587	0.411	0.330	0.070	0.033	−0.108	−0.044	−0.008	−0.020	−0.058	−0.098	−0.084	−0.139	−0.206	−0.194													
LLNPR	−0.158	−0.572	−0.557	0.604	0.743	0.650	−0.100	−0.178	−0.379	−0.066	0.054	−0.062	−0.088	0.011	−0.273	−0.332	−0.583	−0.479	0.517												
LWDPR	−0.130	−0.483	−0.489	0.470	0.585	0.636	−0.224	−0.288	−0.422	−0.038	0.113	−0.038	−0.022	0.125	−0.279	−0.319	−0.513	−0.411	0.450	0.820											
PLNPR	−0.031	0.049	0.075	0.093	0.057	−0.167	0.758	0.579	0.518	0.045	−0.268	0.037	−0.036	−0.420	0.344	0.110	0.133	0.049	0.108	−0.004	−0.141										
PWDPR	−0.018	−0.025	−0.009	0.131	0.158	−0.019	0.373	0.515	0.291	0.148	−0.176	0.030	−0.054	−0.333	0.303	0.005	0.018	−0.044	0.154	0.109	−0.002	0.573									
SLNPR	0.108	0.481	0.435	−0.260	−0.174	−0.372	0.555	0.602	0.759	0.167	−0.246	0.083	0.015	−0.359	0.558	0.278	0.470	0.365	−0.091	−0.333	−0.382	0.552	0.395								
SWDPR	0.083	0.374	0.349	−0.201	−0.133	−0.246	0.241	0.449	0.459	0.261	−0.155	0.065	0.041	−0.180	0.404	0.179	0.320	0.266	−0.110	−0.261	−0.270	0.243	0.337	0.676							
PPPPR	0.084	0.208	0.173	−0.200	−0.100	−0.017	−0.165	−0.123	0.013	0.042	0.058	0.027	0.069	0.153	0.031	0.117	0.199	0.169	−0.024	−0.113	−0.036	−0.174	−0.147	0.015	0.024						
YPPPR	0.108	0.383	0.375	−0.200	−0.160	−0.217	0.213	0.262	0.390	0.128	−0.071	0.113	0.110	−0.105	0.280	0.205	0.375	0.426	−0.006	−0.230	−0.215	0.197	0.125	0.440	0.343	0.158					
YKGHPR	−0.026	−0.108	−0.084	0.101	0.161	0.204	−0.134	−0.147	−0.144	0.049	0.140	0.119	0.221	0.167	−0.039	−0.204	−0.175	−0.081	0.140	0.206	0.246	0.015	0.084	−0.032	0.067	0.091	0.332				
SHPR	−0.090	−0.125	−0.085	−0.019	−0.077	0.043	−0.278	−0.283	−0.268	−0.016	0.163	0.029	0.105	0.391	−0.163	−0.202	−0.201	−0.103	−0.159	−0.024	0.058	−0.234	−0.191	−0.261	−0.087	0.034	−0.042	0.275			
SWTPR	0.036	0.354	0.318	−0.161	−0.077	−0.262	0.457	0.556	0.598	0.209	−0.199	0.096	0.056	−0.297	0.519	0.171	0.321	0.227	−0.045	−0.203	−0.253	0.491	0.475	0.685	0.566	−0.031	0.368	0.091	−0.020		
OILPR	0.029	0.159	0.042	−0.158	0.025	0.111	−0.296	−0.248	−0.078	0.003	0.070	−0.036	0.033	0.189	−0.055	0.021	0.084	0.071	−0.232	−0.066	0.009	−0.296	−0.256	−0.101	−0.030	0.177	0.040	0.084	0.150	−0.096	
PROTPR	−0.137	−0.512	−0.365	0.428	0.281	0.234	0.044	0.006	−0.244	−0.048	0.071	0.017	−0.045	−0.058	−0.117	−0.266	−0.450	−0.364	0.279	0.383	0.312	0.119	0.191	−0.179	−0.083	−0.183	−0.176	0.150	0.107	0.005	−0.469

EM, days to emergence; DF, days to 50% flowering; PRB, number of primary branches per plant; PLHT, plant height (cm); LLN, leaflet length (mm); LWD, leaflet width (mm); PLN, pod length (mm); PWD, pod width (mm); SLN, seed length (mm); SWD, seed width (mm); PPP, number of pods per plant; YPP, yield per plant (g); YKGH, yield per plot (kg ha^{-1}); SH, shelling percentage; SWT, 100-seed weight (g); OIL, oil content (%); PROT, protein content (%); R, rainy season and PR, postrainy season.

Table 4. Phenotypic diversity index in the *fastigiata* and *hypogaea* groups (excluding branching pattern) and in the total core subset (including branching pattern) of groundnut.

	fastigiata group	*hypogaea* group	Total core subset
Mean phenotypic diversity index	0.146	0.141	0.168
Minimum phenotypic diversity index	0.029	0.031	0.024
Between	ICG 5588 and ICG 6021	ICG 1596 and ICG 9712	ICG 5588 and ICG 6021
Maximum phenotypic diversity index	0.425	0.453	0.434
Between	ICG 13479 and ICG 8422	ICG 13723 and ICG 20016	ICG 20004 and ICG 7411

Table 5. Shannon-Weaver diversity index in the *fastigiata* and *hypogaea* groups of groundnut in the rainy and postrainy seasons.

Character	*fastigiata*			*hypogaea*		
	Rainy	Postrainy	Mean ± s.e	Rainy	Postrainy	Mean ± s.e
Days to emergence	0.575	0.494	0.534 ± 0.041	0.595	0.491	0.543 ± 0.052
Days to 50% flowering	0.502	0.437	0.469 ± 0.032	0.560	0.531	0.546 ± 0.015
Primary branches (No.)	0.296	0.274	0.285 ± 0.011	0.457	0.579	0.518 ± 0.061
Plant height (cm)	0.628	0.621	0.624 ± 0.003	0.610	0.587	0.598 ± 0.012
Leaflet length (mm)	0.617	0.628	0.622 ± 0.005	0.613	0.622	0.618 ± 0.005
Leaflet width (mm)	0.605	0.585	0.595 ± 0.010	0.611	0.575	0.593 ± 0.018
Pod length (mm)	0.597	0.589	0.593 ± 0.004	0.611	0.620	0.615 ± 0.005
Pod width (mm)	0.574	0.597	0.585 ± 0.012	0.665	0.582	0.623 ± 0.042
Seed length (mm)	0.570	0.573	0.571 ± 0.002	0.627	0.638	0.632 ± 0.006
Seed width (mm)	0.447	0.490	0.468 ± 0.022	0.453	0.608	0.530 ± 0.078
Pods per plant (No.)	0.603	0.614	0.609 ± 0.005	0.627	0.620	0.624 ± 0.004
Yield per plant (g)	0.602	0.623	0.613 ± 0.011	0.599	0.618	0.608 ± 0.009
Plot yield (kg ha^{-1})	0.611	0.636	0.623 ± 0.012	0.613	0.624	0.618 ± 0.006
Shelling percentage	0.607	0.588	0.598 ± 0.010	0.615	0.585	0.600 ± 0.015
100-seed weight	0.629	0.621	0.625 ± 0.004	0.625	0.621	0.623 ± 0.002
Oil content (%)	–[1]	0.626	0.626	–	0.628	0.628
Protein content (%)	–[1]	0.631	0.631	–	0.629	0.629
Mean ± s.e.	0.564 ± 0.023	0.566 ± 0.023		0.592 ± 0.015	0.598 ± 0.009	
Growth habit[2]	0.040	–		0.536	–	0.288 ± 0.248
Stem pigmentation	0.262	–		0.045	–	0.154 ± 0.109
Stem surface	0.311	–		0.184	–	0.248 ± 0.063
Branching pattern	0.012	–		0.019	–	0.016 ± 0.004
Leaflet colour	0.051	–		0.096	–	0.074 ± 0.022
Leaflet surface	0.033	–		0.022	–	0.028 ± 0.006
Standard petal colour	0.077	–		0.041	–	0.059 ± 0.018
Colour of standard petal markings	0.129	–		0.107	–	0.118 ± 0.011
Peg pigmentation	0.075	–		0.022	–	0.046 ± 0.024
Pod beak	0.445	–		0.491	–	0.468 ± 0.023
Pod Constriction	0.353	–		0.363	–	0.358 ± 0.005
Pod reticulation	0.395	–		0.273	–	0.334 ± 0.061
Primary seed colour	0.461	–		0.343	–	0.402 ± 0.059
Seed colour	0.035	–		0.085	–	0.060 ± 0.025
Seeds per pod (No.)	0.440	–		0.351	–	0.395 ± 0.045
Mean ± s.e.	0.191 ± 0.046			0.188 ± 0.046		

1. Oil and protein contents were estimated only in the 1999/2000 postrainy season.
2. Morphological descriptors were recorded only in the rainy season.

sistence agriculture, areas of early introduction such as Laos, China, Angola, Namibia, and South Africa, or areas of secondary centre of diversity in Peru, Ecuador, Paraguay, and Uruguay. 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 and 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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