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Identification of diverse groundnut germplasm: Sources of early maturity in a core collection

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Abstract

A groundnut core collection was evaluated in two seasons to identify 21 early maturing landraces. Phenotypic diversity of these 21 early maturing landraces was assessed in three rainy and five post-rainy seasons, along with the three known sources of early maturity (Chico, Gangapuri, and JL 24). The new sources differed in 8 of 14 morphological traits studied. Of the 14 agronomic and 2 quality traits studied, 8 yield and yield-component traits were evaluated at two harvest dates. The landraces matured in 80–90 days after sowing (DAS), similar to Chico and Gangapuri (80–90 DAS) and earlier than JL 24 (90–95 DAS). Four new early maturing landraces [ICG 4558 (India); ICG 4890 (Argentina); ICG 9930 (Zimbabwe); ICG 11605 (Bolivia)], with predominantly three to four seeds per pod, were identified as additional sources for breeding confectionery groundnut varieties. Correlation coefficients between the observations made at the two harvest dates for the seven yield traits were ≥ 0.71, indicating a single observation is sufficient at 75 DAS or 90 DAS in initial characterization. Correlation between pod yield and 100-seed weight was significant in all the eight seasons individually and overall at 90 DAS. Presence of additional phenotypic diversity in the new early maturity landraces was detected. Principal component analysis (PCA) using the first 10 PC scores delineated the 21 landraces into three clusters. The formation of these clusters could neither be explained on the basis of geographic areas of landraces collection nor on the basis of botanical varieties. This might reflect the nascent variation acquired by the landraces in their secondary habitats, under ecologically similar conditions, independent of their countries of origin. Landraces in clusters 2 and 3 showed a wide range for several agronomic traits, indicating their usefulness in breeding programs for developing early maturing high yielding broad based cultivars.

Keywords: Core collection; Diversity assessment; Early maturity; Groundnut landraces; Principal component analysis

1. Introduction

Groundnut (*Arachis hypogaea* L.) is an annual legume, grown primarily for high quality edible oil and easily digestible protein in its seeds. It is cultivated in 109 countries, in tropical, sub-tropical, and warm temperate regions of the world. During 2003 it was grown on 26.46 million ha with an estimated total production of 35.66 million t (groundnuts in shell) and an average productivity of 1.35 t ha^{-1} (FAO, 2004). Over two-thirds of global groundnut production occurs in seasonally dry regions, where drought is a potential constraint for crop production (Smartt, 1994). Average groundnut yield is about 0.8 t ha^{-1} in the Semi-Arid Tropical (SAT) countries, which is lower than the world average (1.35 t ha^{-1} during 2003). Besides the occurrence of pests and diseases and poor socioeconomic conditions of SAT farmers, lack of adapted varieties matching the available crop duration, contribute towards poor yields in the SAT.

Early maturing groundnut cultivars with improved yield are required for several agro-ecological situations. Such situations include short growing seasons, necessitated by end-of-season droughts, cooler temperatures, and early frosts. Early maturing cultivars also form an important component of high intensity multiple cropping systems in South and Southeast Asia (Gibbons, 1980). Such cropping systems involving early maturing cultivars, either as inter or

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as sequence crops provide opportunities to the resource-poor farmers to minimize the risk of crop failures and problems of soil health. They also allow cultivation of more crops, resulting in higher per day productivity, and gainful employment to farm labor for an extended period. Short growing seasons, such as those that occur in the semi-arid regions prevent groundnut from maturing properly. Immature pods lower groundnut quality and yield, and enhance the growth of toxin-producing molds during storage (N'Doye and Smith, 1993). Hence, breeding early maturing high yielding groundnut varieties is an important objective in many breeding programs in the world.

Most groundnut improvement programs have so far used only a few germplasm sources for early maturity. They include Chico, Gangapuri, and JL 24 (Upadhyaya et al., 2001b). Chico is an early maturing Spanish (subsp. *fastigiata* var. *vulgaris*) germplasm line (Bailey and Hammons, 1975). Gangapuri (Ramamurthy, 1974) and JL 24 (Patil et al., 1980) are early maturing cultivars grown in India. The former belongs to subsp. *fastigiata* var. *fastigiata* and the latter belongs to subsp. *fastigiata* var. *vulgaris*. Chico is the most extensively used source of earliness in several breeding programs. It has been used 1180 times as a parent in developing early maturity lines at ICRISAT from 1976 to 2002 (Upadhyaya, unpublished). This has resulted in a narrow base of cultivars developed in these programs. The currently used early maturity sources have some defects, Chico with short stature, low biomass, and very small pods (Bailey and Hammons, 1975), and Gangapuri with low shelling percentage and low harvest index (Ramachandran et al., 1980). Hence, there is a need to identify additional sources of early maturity for use in breeding programs. In the past, global groundnut germplasm has not been systematically evaluated for the identification of early maturing genotypes due to the requirement of huge resources for testing the large number of accessions. To overcome this problem in groundnut, Upadhyaya et al. (2003) developed a representative core collection consisting of 1704 accessions from 14,310 accessions in the ICRISAT genebank. The core collections in groundnut have previously been used successfully in identification of resistance sources to various diseases (Anderson et al., 1996; Franke et al., 1999; Holbrook and Anderson, 1995; Isleib et al., 1995), drought tolerance traits (Upadhyaya, 2005) and other traits such as high oil content (Holbrook et al., 1998), and cold tolerance (Upadhyaya et al., 2001a). The main objectives of this study were to identify new early maturing germplasm sources in a groundnut core collection and assess their diversity in various traits at two harvest dates based on the cumulative thermal time (measured as degree days, °Cd).

2. Materials and methods

A groundnut core collection comprising 1704 germplasm accessions was planted in an augmented design using four control cultivars, ICGS 44, ICGS 76, M 13, and Gangapuri to identify early maturing sources in the 1999 rainy season. Each entry was planted on a 4 m long ridge in a ridge–furrow system. The spacing was 60 cm between ridges and 10 cm between plants in subsp. *fastigiata* and 15 cm in subsp. *hypogaea* on a ridge. Botanical variety-specific control cultivars were repeated after every nine test entries. These include ICGS 44 (PI 537112), a Spanish cultivar, released from ICRISAT; ICGS 76 (PI 546372), a Virginia cultivar (subsp. *hypogaea* var. *hypogaea*), released from ICRISAT; M 13, an old Virginia runner cultivar released in India and Gangapuri an early maturing (80–90 DAS) Valencia (*fastigiata*) cultivar from India (Ramamurthy, 1974). At 1470 °Cd (equivalent to 90 DAS in the rainy season at ICRISAT Center, Patancheru) (Rao et al., 1992), half of the plot was harvested to assess maturity. None of the genotypes belonging to subspecies *hypogaea* showed early maturity and only 14 *vulgaris* and 5 *fastigiata* landraces from 13 countries showed maturity similar to Gangapuri. We selected these landraces and evaluated them in a preliminary trail in the 1999–2000 post-rainy season at two harvest dates 1240 °Cd (equivalent to 75 DAS in the rainy season at ICRISAT Center, Patancheru) and at 1470 °Cd at ICRISAT Center, Patancheru, India. In the 1999–2000 post-rainy season, we selected additional 17 *vulgaris* and 5 *fastigiata* early maturing landraces of 15 countries from the groundnut core collection. We evaluated them separately in another trial at 1240 °Cd and 1470 °Cd during the 2000 rainy season at ICRISAT Center, Patancheru. Considering pod yield, shelling percentage, and 100-seed weight at both harvests, 21 (17 *vulgaris* and 4 *fastigiata*) promising landraces (14 from first trial and 7 from second trial), were selected for further evaluation.

The 21 chosen landraces were evaluated during three rainy and five post-rainy seasons. The details on the origin and botanical type of the landraces studied are given in Table 1. All the 21 landraces and the three controls belong to the subspecies *fastigiata* (Krapovickas and Gregory, 1994). Four accessions (ICG 4558, ICG 4890, ICG 9930, and ICG 11605) belong to the variety *fastigiata* and the remaining belong to variety *vulgaris*. Information on number of replications, plot size, and the details of traits recorded in different seasons is given in Table 2. In all seasons, we adopted a plot size of 6 m^2 (4 m × 1.5 m broad bed comprising four rows), a row to row spacing of 30 cm and a plant to plant spacing of 10 cm within a row, and normal plant protection and irrigation practices. For each harvesting date half of the plot (2 m × 1.5 m broad bed comprising four rows) was used to record various observations. The performance of the landraces was assessed by using cumulative thermal time expressed as °Cd (Rao et al., 1992) and were harvested when the crops were exposed to 1240 °Cd and 1470 °Cd in randomized complete block design using two or three replications (Table 2). Fourteen morphological traits were recorded on plot basis on all the 21 landraces and 3 control cultivars, following IBPGR/

Table 1
Information on origin and botanical type of early maturity groundnut landraces used in the study

Genotype	Synonym	Botanical variety	Origin
ICG 3200	EC 16669	*Vulgaris*	China
ICG 3540	You ka Ich	*Vulgaris*	China
ICG 3631	EC 109276	*Vulgaris*	Zaire
ICG 4558	IC 22942	*Fastigiata*	India
ICG 4729	Worte sutuei	*Vulgaris*	China
ICG 4890	AH 7081	*Fastigiata*	Argentina
ICG 5512	AH 7778	*Vulgaris*	India
ICG 5560	AH 7844	*Vulgaris*	India
ICG 5881	VRR 115	*Vulgaris*	India
ICG 9427	63-111	*Vulgaris*	Senegal
ICG 9930	RV 5	*Fastigiata*	Zimbabwe
ICG 9968	57-386-1	*Vulgaris*	Sudan
ICG 11605	PI 475919	*Fastigiata*	Bolivia
ICG 11914	RS 44-3	*Vulgaris*	Mali
ICG 13585	SSI 5	*Vulgaris*	Indonesia
ICG 13606	SSI 33	*Vulgaris*	Indonesia
ICG 13647	SSI 20	*Vulgaris*	Indonesia
ICG 14390	SNW 47	*Vulgaris*	Myanmar
ICG 14788	SKN 2	*Vulgaris*	Vietnam
ICG 14814	SKN 29	*Vulgaris*	Vietnam
ICG 14815	SKN 30	*Vulgaris*	Vietnam
Controls			
ICG 7827	JL 24	*Vulgaris*	India
ICG 476	Chico	*Vulgaris*	USSR
ICG 2738	Gangapuri	*Fastigiata*	India

Table 2
Details of replicated experiments conducted to evaluate early maturity groundnut landraces at ICRISAT Center, Patancheru, India

Season	Number of replications	Plot size (m^2)	Quantitative traits[a]
1999–2000 post-rainy	2	6	EMR, DF, LLN, LWD, PLHT, PRBR, PPP[b], PLN[b], PWD[b], SLN[b], SWD[b], PYKGH[b], SH%[b], SDWT
2000 rainy	3	6	EMR, DF, LLN, LWD, PLHT, PRBR, PPP, PLN, PWD, SLN, SWD, PYKGH, SH%, SDWT
2000–2001 post-rainy	3	6	EMR, DF, LLN, LWD, PLHT, PRBR, PPP, PLN, PWD, SLN, SWD, PYKGH, SH%, SDWT
2001 rainy	2	6	DF, PYKGH, SH%, SDWT
2001–2002 post-rainy	2	6	DF, PYKGH, SH%, SDWT, OIL%, PROT%
2002–2003 post-rainy	2	6	DF, PYKGH, SH%, SDWT, OIL%
2003 rainy	2	6	DF, PYKGH, SH%, SDWT
2003–2004 post-rainy	2	6	DF, PYKGH, SH%, SDWT, OIL%

[a] EMR: days to 50% emergence, DF: days to 50% flowering, LLN: leaflet length (mm), LWD: leaflet width (mm), PLHT: plant height (cm), PRBR: primary branch (no.), PPP: pod per plant (no.), PLN: pod length (mm), PWD: pod width (mm), SLN: seed length (mm), SWD: seed width (mm), PYKGH: pod yield (kg ha^{-1}), SH%: shelling percentage, SDWT: 100-seed weight (g), OIL%: oil content (%), and PROT: protein content (%).
[b] Data recorded at both harvest dates (1240 °Cd and 1470 °Cd).

ICRISAT (1992). Observations were also recorded for 14 agronomic traits and for oil and protein content in seeds either on plant or plot basis both in rainy and post-rainy seasons. However, observations on all the traits were not recorded in all the seasons.

Days to emergence (the stage when 50% seedlings have emerged), days to 50% flowering (days from emergence to the stage when 50% plants have begun flowering) were recorded on plot basis. Plant height, leaflet length, and width on five competitive plants were recorded at 60 days from sowing in the rainy seasons and at an equivalent cumulative thermal time (1000 °Cd) in the post-rainy seasons. Pods per plant, pod length and width, seed length and width, 100-seed weight, and shelling percentage, were recorded at 75 DAS (1240 °Cd) and 90 DAS (1470 °Cd). Pods per plant were calculated from five competitive plants. Pod length and width were recorded on 10 mature pods and seed length and width on 10 mature seeds. Two-hundred-gram sound mature pods were used to calculate shelling percentage. Sound seeds were used to record 100-seed weight and for oil and protein estimates. Oil content was measured with a commercial nuclear magnetic resonance spectrometer following the procedure described by Jambunathan et al. (1985) and protein content was estimated with a Technicon Autoanalyser (Pulse Instrumentation Ltd., Saskatoon, SK; Singh and Jambunathan, 1980). Pod yields were uniformly converted to kg ha^{-1} for comparison across the seasons.

Data were analyzed following residual maximum likelihood (REML) analysis using seasons as fixed and entries as random on GENSTAT 6.1. The season component was divided into rainy and post-rainy and their interactions with genotypes were determined. In all the subsequent analyses, genotype × season interaction was considered and if it was significant for a trait the separate values were considered for each season and if it was non-significant, then mean values over seasons were used. The correlations for yield and yield related traits were calculated separately for the two harvest dates using best linear unbiased predictors (BLUPs) for all the agronomic traits studied. The component of phenotypic variance ($\delta^2 p$) due to genotype ($\delta^2 g$), genotype × environ-environment ($\delta^2 ge$), and residual and their standard errors were calculated.

Principal component analysis (PCA) was carried out using standardized data. The mean observations of all traits for each season were standardized by subtracting from each observation the mean value of the character and subsequently dividing by its respective standard deviation. The resulting standardized values for each trait had an average of 0 and standard deviation of 1 or less. The PCA was performed using GENSTAT 6.1. Cluster analysis according to Ward (1963) was performed using scores of first 10 principal components, resulting in three clusters. The means of each trait in different clusters were compared using Newman–Keuls test (Newman, 1939; Keuls, 1952). The homogeneity of variances among the clusters was tested using Levene's test (Levene, 1960).

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).

3. Results and discussion

All of the 21 early maturity landraces studied were similar in their erect growth habit, sequential branching pattern, almost with glabrous surface on both sides of leaflet, flowers with dark orange streak color, presence of peg color, and one seed color pattern (data not shown). The landraces differed, however, in their plant pigmentation, stem hairiness, leaf color, pod beak, pod constriction and reticulation, seeds per pod, and primary seed color (Table 3). For stem hairiness, they were sub-glabrous to moderately hairy. All the landraces had light green leaflets, except ICG 11914, with green leaflets. Pod beaks varied from prominent to slight, pod constriction from slight to none, and pod reticulation from prominent to slight. Seeds per pod varied from 1 to 4. While, most landraces had predominantly two-seeded pods, four of them ICG 4558 (India), ICG 4890 (Argentina), ICG 9930 (Zimbabwe), and ICG 11605 (Bolivia) in addition to the control variety, Gangapuri (ICG 2738), had predominantly three-seeded pods and some four-seeded pods. Gangapuri is the most preferred variety for in-shell boiled and roasted nuts in India because it produces more seeds per pod. Similar to Gangapuri, all the four new early maturity sources belong to the botanical variety *fastigiata*. However, they differ among themselves and with Gangapuri in stem hairiness, pod constriction, and primary seed color (Table 3). These four newly identified landraces, which originated in different countries, may provide useful genetic variability in breeding programs aimed at developing short-duration groundnut varieties.

Estimates of variance due to genotype, season × genotype, and their standard error and Wald statistics and Chi-square probability for various traits during three rainy and five post-rainy seasons at ICRISAT Center, Patancheru, India, are given in Table 4.

Table 3
Morphological variation[a] in the newly identified early maturity sources in groundnut

Genotype	Plant pigmentation	Stem hairiness	Pod beak	Pod constriction	Pod reticulation	Seeds per pod	Primary seed color
ICG 3200	Absent	Sub-glabrous, hairs in 1 or 2 rows along main axis	Moderate	Moderate	Prominent	2-1	Tan
ICG 3540	Absent	Sub-glabrous, hairs in 1 or 2 rows along main axis	Slight	Moderate	Moderate	2-1	Tan
ICG 3631	Present	Sub-glabrous, hairs in 1 or 2 rows along main axis	Slight	Slight	Moderate	2-1	Red
ICG 4558	Present	Moderately hairy, hairs in 3 or 4 rows along main axis	Slight	Slight	Slight	3-2-4-1/3-2-1-4/3-4-2-1	Red
ICG 4729	Absent	Sub-glabrous, hairs in 1 or 2 rows along main axis	Slight	Moderate	Slight	2-1	Tan
ICG 4890	Absent	Sub-glabrous, hairs in 1 or 2 rows along main axis	Slight	Slight	Slight	3-2-4-1/3-2-1-4/3-4-2-1	Dark purple
ICG 5512	Absent	Sub-glabrous, hairs in 1 or 2 rows along main axis	Slight	Moderate	Slight	2-1	Tan
ICG 5560	Absent	Sub-glabrous, hairs in 1 or 2 rows along main axis	Slight	Moderate	Slight	2-1	Tan
ICG 5881	Absent	Sub-glabrous, hairs in 1 or 2 rows along main axis	Slight	Moderate	Slight	2-1	Tan
ICG 9427	Absent	Sub-glabrous, hairs in 1 or 2 rows along main axis	Moderate	Slight	Slight	2-1	Dark tan
ICG 9930	Present	Moderately hairy, hairs in 3 or 4 rows along main axis	Slight	Slight	Slight	3-2-4-1/3-2-1-4/3-4-2-1	Red
ICG 9968	Present	Sub-glabrous, hairs in 1 or 2 rows along main axis	Moderate	Moderate	Moderate	2-1	Red
ICG 11605	Present	Moderately hairy, hairs in 3 or 4 rows along main axis	Slight	None	Slight	3-2-4-1/3-2-1-4/3-4-2-1	Purplish-red/reddish-purple
ICG 11914[b]	Present	Moderately hairy, hairs in 3 or 4 rows along main axis	Slight	Moderate	Moderate	2-1	Tan
ICG 13585	Present	Sub-glabrous, hairs in 1 or 2 rows along main axis	Moderate	Moderate	Slight	2-1	Tan
ICG 13606	Present	Sub-glabrous, hairs in 1 or 2 rows along main axis	Slight	Moderate	Moderate	2-1	Tan
ICG 13647	Present	Moderately hairy, hairs in 3 or 4 rows along main axis	Moderate	Moderate	Moderate	2-3-1/2-1-3	Tan
ICG 14390	Absent	Sub-glabrous, hairs in 1 or 2 rows along main axis	Slight	Slight	Moderate	2-1	Tan
ICG 14788	Absent	Sub-glabrous, hairs in 1 or 2 rows along main axis	Moderate	Slight	Moderate	2-1	Light tan
ICG 14814	Absent	Sub-glabrous, hairs in 1 or 2 rows along main axis	Moderate	Slight	Moderate	2-1	Tan
ICG 14815	Absent	Sub-glabrous, hairs in 1 or 2 rows along main axis	Moderate	Moderate	Moderate	2-3-1/2-1-3	Tan
Controls							
JL 24	Absent	Sub-glabrous, hairs in 1 or 2 rows along main axis	Moderate	Moderate	None	2-1	Dark tan
Chico	Absent	Sub-glabrous, hairs in 1 or 2 rows along main axis	Prominent	Moderate	Slight	2-1	Tan
Gangapuri	Present	Sub-glabrous, hairs in 1 or 2 rows along main axis	Slight	Slight	Slight	3-2-4-1/3-2-1-4/3-4-2-1	Red

[a] No variation was observed among the early maturity landraces for growth habit, branching pattern, leaflet surface hairiness, color of standard petal markings, peg color, and seed color pattern.

[b] Except ICG 11914 with green leaf color, the rest of the landraces have light green leaves.

Table 4
Estimates of variance due to genotype, genotype × season, standard error Wald statistic, and χ^2 probability for groundnut landraces evaluated during three rainy and five post-rainy seasons in two harvests at ICRISAT Center, Patancheru, India

Trait	Variance									Wald statistic							
	Number of seasons	Genotype	S.E.	Genotype × season	S.E.	Genotype × post-rainy	S.E.	Genotype × rainy	S.E.	Seasons	χ^2 prob.	Post-rainy season	χ^2 prob.	Rainy season	χ^2 prob.	Rainy vs. post-rainy	χ^2 prob.
Days to 50% emergence (number)	3[a]	0.06	0.04	0.08	0.05	0.02	0.06	0.07	0.07	6.66	0.04	11.43	<0.001	0.00	+	0.97	0.33
Days to 50% flowering (number)	8[b]	0.68**	0.22	0.24	0.13	0.2	0.13	0.00	+	7694.5	<0.001	2322.63	<0.001	1260.57	<0.001	8985.78	<0.001
Leaflet length (mm)	3	6.18**	2.15	1.2	0.99	1.17	0.99	0.00	+	558.68	<0.001	0.06	0.81	0.00	+	617.64	<0.001
Leaflet width (mm)	3	1.55**	0.56	0.6*	0.28	0.46	0.35	0.18	0.36	169.22	<0.001	0.5	0.48	0.00	+	162.64	<0.001
Plant height (cm)	3	1.22*	0.53	0.66	0.37	0.07	0.42	0.71	0.57	2222.54	<0.001	14.68	<0.001	0.00	+	1848.73	<0.001
Primary branch (number)	3	0.00	0.02	0.09**	0.03	0.09**	0.03	0.00	+	1.9	0.39	0.57	0.45	0.00	+	1.35	0.25
Pods per plant (number) at 1240 °Cd[c]	3	2.16*	0.98	1.38	0.74	1.39	0.74	0.00	+	48.9	<0.001	33.93	<0.001	0.00	+	15.44	<0.001
Pod length (mm) at 1240 °Cd	3	13.02**	3.9	1.03	0.75	0.9	+	0.13	0.79	1.81	0.18	0.00	+	0.00	+	1.81	0.18
Pod width (mm) at 1240 °Cd	3	0.69**	0.22	0.11	0.06	0.08	+	0.03	0.06	5.48	0.02	0.00	+	0.00	+	5.48	0.02
Seed length (mm) at 1240 °Cd	3	0.96**	0.31	0.16	0.09	0.16	+	0.00	+	2.97	0.09	0.00	+	0.00	+	2.96	0.09
Seed width (mm) at 1240 °Cd	3	0.09*	0.04	0.04	0.03	0.04	+	0.00	+	44.75	<0.001	0.00	+	0.00	+	44.28	<0.001
Pod yield (kg ha^{-1}) at 1240 °Cd	8	10233*	4336	21937**	4227	13861**	3986	13964**	4819	673	<0.001	561	<0.001	310	<0.001	39	<0.001
100-Seed weight (g) at 1240 °Cd	8	10.53**	3.03	3.01**	0.74	2.07**	0.8	1.78*	0.78	114.1	<0.001	132.17	<0.001	11.81	0.003	6.62	0.01
Shelling percentage at 1240 °Cd	8	9.47**	3.31	12.96**	2.23	12.77**	2.75	4.74**	1.71	348.52	<0.001	405.42	<0.001	200.60	<0.001	7.68	0.01
Pods per plant (number) at 1470 °Cd[d]	3	4.14*	1.85	1.87	1.12	1.87	+	0.00	+	5.88	0.02	0.00	+	0.00	+	5.87	0.02
Pod length (mm) at 1470 °Cd	3	11.64**	3.36	0.84	0.43	0.00	+	1.55*	0.69	5.19	0.08	11.13	<0.001	0.00	+	0.31	0.58
Pod width (mm) at 1470 °Cd	3	0.80**	0.24	0.13**	0.05	0.02	0.04	0.15	0.08	4.73	0.09	0.05	0.83	0.00	+	3.4	0.07
Seed length (mm) at 1470 °Cd	3	0.69**	0.22	0.05	0.07	0.00	+	0.05	0.07	22.53	<0.001	8.71	0.003	0.00	+	26.19	<0.001
Seed width (mm) at 1470 °Cd	3	0.01	0.02	0.00	+	0.00	+	0.00	+	74.87	<0.001	20.68	<0.001	0.00	+	54.19	<0.001
Pod yield (kg ha^{-1}) at 1470 °Cd	8	9919	5371	40938**	7216	35686**	7924	14628**	6869	556	<0.001	548	<0.001	272	<0.001	139	<0.001
100-Seed weight (g) at 1470 °Cd	8	13.63**	3.8	2.2**	0.67	0.51	0.69	1.48*	0.74	84.22	<0.001	45.45	<0.001	95.83	<0.001	44.23	<0.001
Shelling percentage at 1470 °Cd	8	8.06**	2.51	3.37**	1.16	0.00	+	4.93**	1.57	33.4	<0.001	66.17	<0.001	117.85	<0.001	5.96	0.02

(+) Not calculated due to low/non-significant value.
[a] Recorded in two post-rainy and one rainy season.
[b] Recorded in five post-rainy and three rainy seasons.
[c] 1240 °Cd (degree days) is equivalent to 75 days after sowing (DAS) to harvest in the rainy season at ICRISAT, Patancheru, India.
[d] 1470 °Cd (degree days) is equivalent to 90 DAS to harvest in the rainy season at ICRISAT, Patancheru, India.
* Significant at $p \leq 0.05$.
** Significant at $p \leq 0.01$.

REML analysis indicated that the variance component due to genotype was significant for all the traits in all the seasons. The combined analysis indicated that the genotypic variance was significant for all the traits except days to emergence and number of primary branches per plant and seed width and pod yield at 1470 °Cd.

Seasons were significant for all the traits except number of primary branches, pod and seed length at 1240 °Cd, and pod length and width at 1470 °Cd. The differences between the rainy seasons were significant for days to flower, and at both the harvests (1240 °Cd and 1470 °Cd) for pod yield, shelling percentage, and 100-seed weight. Post-rainy seasons were significant for days to emergence and flowering, plant height, number of pods per plant, pod yield, shelling percentage, and 100-seed weight at 1240 °Cd and for pod length, seed length and width, pod yield, shelling percentage, and 100-seed weight at 1470 °Cd. The rainy versus post-rainy season component was significant for all the traits except emergence, primary branch number, pod length and seed length at 1240 °Cd, and for pod length and width at 1470 °Cd. The genotype × season interactions were significant for leaflet width, number of primary branches, pod yield, shelling percentage, and 100-seed weight at both the harvests and for pod width at 1470 °Cd (Table 4). The genotype × rainy season interactions were significant for pod yield, 100-seed weight, and shelling percentage at both the harvests; and for pod length at 1470 °Cd only. The genotype × post-rainy season interactions were significant for primary branches, and pod yield at both the harvests; and for shelling percentage and 100-seed weight at 1240 °Cd only.

For the seven yield and yield-component traits, significance of the harvest date was determined. Several traits were significant at the both the harvest dates. They include days to 50% flowering ($p < 0.001$), pods per plant at 1240 °Cd ($p < 0.001$) and at 1470 °Cd ($p = 0.015$), pod width at 1240 °Cd ($p = 0.019$), seed width at 1240 °Cd ($p < 0.001$) and at 1470 °Cd ($p < 0.001$), pod yield (kg ha^{-1}) at 1240 °Cd ($p < 0.001$) and at 1470 °Cd ($p < 0.001$), 100-seed weight at 1240 °Cd ($p < 0.001$) and at 1470 °Cd ($p < 0.001$), shelling percentage at 1240 °Cd ($p = 0.006$) and at 1470 °Cd ($p = 0.015$).

The mean pod yield, shelling percentage, and 100-seed weight averaged over three rainy and five post-rainy seasons are presented separately at two harvesting dates (1240 °Cd and 1470 °Cd), along with oil and protein contents in seed (Table 5). All the landraces showed higher values for all the three traits at 1470 °Cd compared to those at 1240 °Cd. The

Table 5
Mean values for yield and yield components and quality characteristics in early maturity groundnut landraces at two harvesting dates averaged over three rainy and five post-rainy seasons at ICRISAT Center, Patancheru, India

Landrace	1240 °Cd			1470 °Cd				
	Pod yield (kg ha^{-1})	Shelling%	100-Seed weight (g)	Pod yield (kg ha^{-1})	Shelling%	100-Seed weight (g)	Oil%[a]	Protein%[b]
ICG 3200	1131.6	52.1	33.5	1570.8	64.3	42.2	48.6	25.0
ICG 3540	1262.8	59.2	27.3	1455.7	68.7	31.3	48.6	24.0
ICG 3631	1188.9	59.8	30.0	1496.7	67.5	33.0	47.8	24.0
ICG 4558	1192.5	61.5	35.5	1380.4	66.0	40.5	47.1	24.0
ICG 4729	1099.0	54.1	25.4	1429.7	67.6	29.6	47.0	23.0
ICG 4890	1040.7	55.6	29.5	1499.5	67.0	36.4	48.7	23.0
ICG 5512	1036.7	56.8	27.2	1410.3	67.6	32.7	48.4	23.0
ICG 5560	1146.3	57.5	27.0	1491.9	69.2	32.6	47.9	23.0
ICG 5881	1026.2	58.8	25.0	1442.8	68.4	30.2	48.7	23.0
ICG 9427	1184.5	57.9	33.2	1645.1	69.3	40.6	47.4	24.0
ICG 9930	1125.1	57.2	33.5	1419.5	65.8	37.4	47.2	23.0
ICG 9968	847.3	51.8	25.5	1313.5	62.4	33.5	48.5	23.0
ICG 11605	979.7	50.1	27.4	1223.6	59.4	34.6	46.6	25.0
ICG 11914	1037.9	50.5	28.5	1409.0	63.3	37.1	46.8	23.0
ICG 13585	1072.5	56.4	30.3	1530.9	68.0	36.5	47.2	24.0
ICG 13606	914.0	61.4	26.0	1379.0	71.2	29.8	46.8	23.0
ICG 13647	1022.7	57.6	29.6	1479.9	67.8	35.1	47.8	23.0
ICG 14390	1005.5	57.0	25.2	1391.8	68.8	31.2	48.5	22.0
ICG 14788	1063.6	58.8	31.7	1493.9	69.0	37.9	47.3	23.0
ICG 14814	1148.3	62.6	32.0	1460.8	71.7	36.8	47.2	24.0
ICG 14815	1203.9	53.1	36.5	1627.7	61.0	45.2	45.3	26.0
Controls								
Chico	1031.2	62.9	28.5	1315.9	71.3	33.4	46.4	25.0
JL 24	987.2	54.0	30.6	1400.2	64.5	38.1	46.4	26.0
Gangapuri	975.8	56.6	35.9	1161.0	66.1	38.3	46.9	24.0
Grand mean	1071.8	56.8	29.8	1434.6	66.9	35.6	47.5	23.8

[a] Mean of three seasons data.
[b] One season data (2001–2002 post-rainy).

Table 6
Significant correlation coefficients observed in three seasons in the early maturing groundnut landraces at ICRISAT Center, Patancheru, India

Traits	1999–2000 post-rainy	2000 rainy	2000–2001 post-rainy	Combined analysis
Leaflet length–leaflet width	0.890	0.560	0.770	0.760
Pod length at 1240 °Cd–pod width at 1240 °Cd	0.800	0.770	0.710	0.250
Pod length at 1240 °Cd–seed length at 1240 °Cd	0.850	0.810	0.790	0.800
Pod width at 1240 °Cd–100-seed weight (g) at 1240 °Cd	0.610	0.530	0.570	0.560
Pod width at 1240 °Cd–seed length at 1240 °Cd	0.640	0.590	0.740	0.650
100-Seed weight (g) at 1240 °Cd–seed length at 1240 °Cd	0.630	0.650	0.740	0.680
Seed width (g) at 1240 °Cd–seed length at 1240 °Cd	0.620	0.650	0.550	0.620
Seed width (g) at 1240 °Cd–100-seed weight (g) at 1240 °Cd	0.630	0.670	0.730	0.670
Pod length at 1470 °Cd–pod per plant at 1470 °Cd	−0.650	−0.820	−0.750	−0.750
Pod length at 1470 °Cd–pod width at 1470 °Cd	0.680	0.705	0.750	0.430
Pod length at 1470 °Cd–seed length at 1470 °Cd	0.690	0.640	0.610	0.640
Pod width at 1470 °Cd–pod per plant at 1470 °Cd	−0.570	−0.690	−0.540	−0.610
Pod width at 1470 °Cd–seed length at 1470 °Cd	0.620	0.510	0.730	0.620
100-Seed weight (g) at 1470 °Cd–seed length at 1470 °Cd	0.590	0.610	0.550	0.570
Pod yield (kg ha^{-1}) at 1470 °Cd–100-seed weight (g) at 1470 °Cd	0.827	0.876	0.824	0.890

trial mean pod yield at 1470 °Cd was higher (1435 kg ha^{-1}) compared to that at 1240 °Cd (1072 kg ha^{-1}). The test entries produced an average pod yield of 1082 kg ha^{-1}, 8.4% more than the average yield of three control cultivars (998 kg ha^{-1}) across the eight seasons at 1240 °Cd. At 1470 °Cd, they produced 1455 kg ha^{-1}, 12.6% more pod yield than the average of three controls (1292 kg ha^{-1}). The mean pod yields at 1240 °Cd, ranged from 847 kg ha^{-1} to 1263 kg ha^{-1}. Among the controls, Chico gave highest pod yield (1031 kg ha^{-1}) and shelling percentage (62.9%) at 1240 °Cd. Two new early maturity sources, ICG 3540 with 1263 kg ha^{-1} (22.5% higher over Chico), and ICG 14815 with 1204 kg ha^{-1} (16.8% higher over Chico) had superior pod yields, but their shelling percentage was lower compared to that of Chico. However, two other new sources, ICG 4558 with 1193 kg ha^{-1} pod yield (15.7% higher over Chico) and ICG 14814 with 1148 kg ha^{-1} (11.4% higher over Chico) had higher pod yield and similar shelling percentage to that of Chico. Two new sources, ICG 14815 and ICG 4558, were similar in their 100-seed weight to that of the superior control, Gangapuri. The mean pod yields harvested at 1470 °Cd, ranged across the landraces from 1224 kg ha^{-1} to 1645 kg ha^{-1}. Among the controls, JL 24 gave the highest pod yield (1400 kg ha^{-1}). Several new germplasm landraces gave better pod yield than JL 24. They include, ICG 9427 and ICG 14815, with 17.5% and 16.3% increased pod yield, respectively, over JL 24. ICG 14814 and ICG 13606, with 71.7% and 71.2% shelling percentage, respectively, were similar to the best control, Chico (71.3%). ICG 14815 and ICG 3200 showed 18.0% and 10.2% higher 100-seed weight, respectively, over the best control, Gangapuri (38.3 g 100 $seed^{-1}$). Oil and protein contents were similar in the landraces and control varieties.

Correlation coefficients were calculated for all the traits from the observations made in all the seasons separately, on combined data for three rainy, five post-rainy seasons, and on all the eight seasons. A large number of correlations were significant. Of the 276 correlations, studied for various traits, 70 and 37 correlations during 1999–2000 post-rainy season, 98 and 56 correlations during 2000 rainy season, 105 and 52 correlations during 2000–2001 post-rainy season were significant at 5% and 1% probability, respectively. Fifteen correlations were significant in the 2000 rainy, 1999–2000 post-rainy, and 2000–2001 post-rainy seasons, and overall (Table 6). Correlation between pod yield and 100-seed weight was significant in all the eight seasons separately, over three rainy seasons, five post-rainy seasons, and over eight seasons at 1470 °Cd.

We have considered correlation coefficients values ≥0.71 or ≤−0.71 to be biologically meaningful ($R^2 = 0.50$) (Skinner et al., 1999) for selected traits at both the harvesting dates, with the main purpose of minimizing the observations to be recorded, without sacrificing the required information. For almost all the yield traits meaningful correlations with the R^2 values higher than 50% were found between the two dates of harvest. However, for pod yield the R^2 was only 46% (data not shown). The relationship for 100-seed weight at both the harvesting dates was consistent across both rainy and post-rainy seasons.

The grouping of similar genotypes depends on the dissimilarity among them, which can be determined by a phenotypic diversity index. The average phenotypic diversity index in the early maturity landraces was 0.2941 (Table 7). The closest genotypes with minimum phenotypic diversity in the study were ICG 5512 and ICG 5560 and the farthest genotypes with maximum phenotypic diversity were ICG 13606 (from Indonesia) and ICG 14815 (from

Table 7
Phenotypic diversity index in the early maturity groundnut landraces at ICRISAT Center, Patancheru, India

Mean phenotypic diversity index	0.2941
Minimum phenotypic diversity index	0.1255
Between	ICG 5512 and ICG 5560
Maximum phenotypic diversity index	0.5291
Between	ICG 13606 and ICG 14815

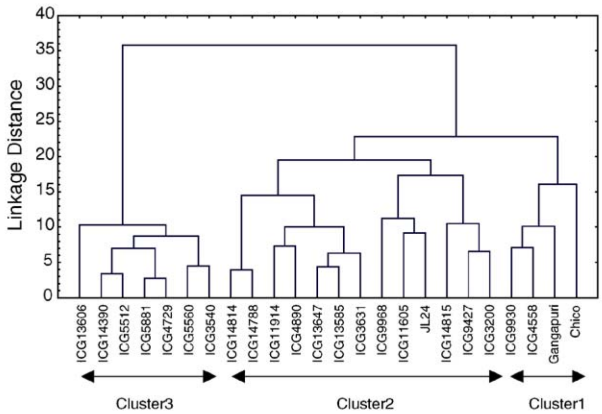

Fig. 1. Dendogram of 21 early maturing groundnut landraces with three control varieties based on the first 10 principal components.

Vietnam). None of the three early maturity controls are captured in either of the minimum or maximum diversity groups. These observations corroborate the presence of additional diversity in the newly identified sources, which is not apparent in the currently used early maturity sources in the breeding programs. It will be interesting to involve the two new genotypes with maximum phenotypic diversity index in the hybridization and selection programs for various traits.

A hierarchical cluster analysis conducted on the first 10 principal component scores (total variation accounted 85.55%) resulted in three clusters (Fig. 1). The first cluster comprised two landraces (ICG 9930 and ICG 4558) and the two controls (Gangapuri and Chico). Except for Chico, which belongs to variety *vulgaris*, the other three belong to variety *fastigiata*. ICG 4558 is from India and ICG 9930 from Zimbabwe. The second cluster comprised 12 landraces and the control variety, JL 24 from India. Of the 12 landraces, 10 belong to variety *vulgaris*, with their origins in Vietnam (3), Indonesia (2), Mali, Zaire, Senegal, Sudan, and China (1) accession from each. The remaining two landraces belong to variety *fastigiata*, one each from Bolivia and Argentina. The third cluster comprised seven landraces of variety *vulgaris*, three from India, two from China, and one each from Myanmar and Indonesia. The apparent non-relationship of the origins of these landraces with the diversity available among them is not surprising, if we look at dissemination routes from the center of origin of groundnut to the old world countries. According to Dubard (1906) primarily two distinct groundnut types, the two-seeded Brazilian and the three-seeded Peruvian types, were distributed over the world from South America. Based on the morphology and configuration of pod samples collected from these places and the groundnut samples found in the tombs at Ancon, Peru, Dubard (1906) concluded that the three-seeded Peruvian type (*hirsuta*) was transported from Peru to the Western Pacific, to China, Java (Indonesia) and to Madagascar (Malagasy Republic, East Africa). Further, Krapovickas (1968) concluded that the Peruvian type reached India from the west coast of South America to Mexico and then across the Pacific to the Philippines, from where it has spread to China, India, Malaysia, and Indonesia. The Portuguese probably brought groundnut to Africa from Brazil in the sixteenth century (Higgins, 1951) and again the reformed varieties from the Old World have been brought to Africa (Krapovickas, 1968).

At a macro-level, involving 13,342 groundnut accessions from 92 countries (grouped into 14 broad geographic regions), a study of 16 morphological and 10 agronomic traits resulted in distinct clusters in tandem with each geographic region (Upadhyaya et al., 2002). In the present study at a micro-level, involving germplasm from few countries, no distinct relationship was observed between country of origin and cluster formation. At the micro-level, the diversity observed in the landraces appears to be small and of nascent origin in the agro-ecologically similar habitats. The adaptation of cultivars can vary with the different environments within a country, and the distribution of local cultivars may to some extent represent their adaptation to the areas in which they are grown (Gibbons, 1978). For example, Harkness et al. (1976) have surveyed the range of local cultivars in northern Nigeria, while others have correlated this with the vegetation, soil, and rainfall (Kowal and Knabe, 1972). Hence, the clustering in the present study could not have captured the country-based landraces due to the possible adaptation of early maturity genotypes in similar ecological niches across the geographical boundaries of their secondary homes.

The means and variances of the three clusters were compared for different traits (Table 8). The clusters did not differ significantly for days to emergence, plant height, primary branches, and seed width, pod yield and shelling percentage at 1240 °Cd. Also, the clusters did not differ for seed width, shelling percentage, oil, and protein content at 1470 °Cd. Clusters 1 and 2 were similar for days to flowering, leaflet length and width and pods per plant, but greater than those in cluster 3. Cluster 1 had more pods per plant at 1470 °Cd than cluster 2 or 3. Clusters 2 and 3 were similar, but were greater than cluster 1 for pod width at 1240 °Cd and for pod width and seed length at 1470 °Cd. Cluster 3 had greater pod length and seed length at 1240 °Cd and pod length at 1470 °Cd than cluster 1 or 2. The variances of all the three clusters were homogeneous for all the traits, except pods per plant at 1240 °Cd and 1470 °Cd and pod width at 1470 °Cd. Cluster 3 had maximum variance for these three traits (Table 8). Cluster 2 represented highest range of entire set for 18 traits, whereas cluster 3 represented the highest range for the remaining 6 traits. The landraces in cluster 2, with a wider range for several traits (such as days to flowering, number of primary branches, pod and seed length at 1240 °Cd and 1470 °Cd, seed width and pod yield at 1470 °Cd), can be selectively deployed in breeding programs aimed at improving either one or more of these traits. Similarly, the landraces in cluster 3 can be used to improve early flowering, pod width, pod length, seed length,

Table 8
Range, mean, and variance of three clusters of groundnut landraces at ICRISAT Center, Patancheru, India

Character	Range			Mean[1]			Variance				
	Cluster 1	Cluster 2	Cluster 3	Cluster 1	Cluster 2	Cluster 3	Cluster 1	Cluster 2	Cluster 3	*F* value	Prob > *F*
Days to 50% emergence (number)	8.78–8.99	8.42–9.14	8.49–8.90	8.86a	8.82a	8.61a	0.01	0.05	0.04	1.95	0.167
Days to 50% flowering (number)	39.17–40.86	39.14–41.13	38.25–38.67	40.06a	40.24a	38.49b	0.30	0.34	0.03	1.12	0.345
Leaflet length (mm)	48.61–53.37	48.11–53.11	45.85–50.56	51.23a	50.75ba	48.73b	2.66	3.03	4.12	0.12	0.884
Leaflet width (mm)	22.01–24.53	21.32–25.26	20.93–22.06	23.26a	23.31a	21.57b	0.63	1.02	0.26	0.83	0.449
Plant height (cm)	16.34–17.96	14.66–18.86	15.49–17.96	17.16a	16.62a	17.07a	0.28	1.19	1.19	0.97	0.396
Primary branch (number)	4.08–4.23	4.04–4.28	4.03–4.14	4.14a	4.11a	4.08a	0.00	0.00	0.00	0.24	0.785
Pods per plant (number) at 1240 °Cd	10.59–13.07	9.50–12.12	8.84–12.63	12.02a	10.84ba	10.39b	0.71	0.81	3.06	4.53	0.023
Pod length (mm) at 1240 °Cd	21.43–23.33	21.23–30.47	26.56–33.69	22.55c	26.03b	30.66a	0.43	7.13	8.97	2.45	0.111
Pod width (mm) at 1240 °Cd	10.33–11.57	11.00–12.91	10.24–12.62	10.88b	11.90a	11.92a	0.22	0.37	1.27	2.71	0.090
Seed length (mm) at 1240 °Cd	9.46–10.49	9.68–12.43	11.62–12.97	10.07c	11.40b	12.33a	0.12	0.52	0.47	0.85	0.442
Seed width (mm) at 1240 °Cd	6.77–7.08	6.58–7.47	6.52–7.44	6.91a	7.17a	7.14a	0.01	0.06	0.18	2.03	0.156
Pod yield (kg ha^{-1}) at 1240 °Cd	914.02–1262.81	847.27–1203.95	975.84–1192.53	1070.09a	1069.91a	1081.16a	12557.36	10326.00	9309.69	0.11	0.8955
100-Seed weight (g) at 1240 °Cd	25.01–27.30	25.50–36.51	28.54–35.92	26.17b	30.63a	33.36a	1.00	8.05	11.43	1.43	0.2622
Shelling percentage at 1240 °Cd	54.08–61.42	50.14–62.65	56.60–62.92	57.84a	55.41a	59.53a	5.25	14.80	9.83	1.56	0.2345
Pods per plant (number) at 1470 °Cd	11.91–14.36	9.59–13.10	8.46–14.11	13.03a	11.36b	10.37b	0.65	1.13	6.60	4.5	0.024
Pod length (mm) at 1470 °Cd	21.57–23.64	23.71–30.47	26.84–34.51	22.93c	26.44b	31.37a	0.41	4.71	10.45	3.3	0.070
Pod width (mm) at 1470 °Cd	10.69–11.53	11.37–13.57	10.29–13.00	11.23b	12.35a	12.16a	0.08	0.48	1.62	3.65	0.044
Seed length (mm) at 1470 °Cd	10.04–11.06	10.55–12.95	11.71–12.78	10.69b	11.56a	12.25a	0.14	0.59	0.25	2.71	0.090
Seed width (mm) at 1470 °Cd	7.44–7.50	7.40–7.55	7.39–7.50	7.47a	7.48a	7.46a	0.00	0.00	0.00	1.58	0.230
Pod yield (kg ha^{-1}) at 1470 °Cd	1379.04–1491.86	1223.60–1645.08	1160.99–1419.51	1428.75ba	1473.21a	1319.21b	1513.03	13784.07	12950.77	1.43	0.2624
100-Seed weight (g) at 1470 °Cd	29.63–32.74	33.01–45.20	33.36–40.45	31.07b	37.45a	37.38a	1.62	12.03	8.78	1.3	0.2945
Shelling percentage at 1470 °Cd	67.56–71.16	59.43–71.74	65.78–71.26	68.77a	65.79a	67.28a	1.47	13.05	7.05	2.67	0.0929
Oil% at 1470 °Cd	46.78–48.65	45.33–48.68	46.38–47.23	47.97a	47.34a	46.90a	0.61	0.90	0.14	1.04	0.3722
Protein% at 1470 °Cd	22.00–24.00	23.00–26.00	23.00–25.00	23.00a	24.08a	24.00a	0.33	1.24	0.67	1.91	0.1735

[1] For cluster mean followed by same letter indicates no significant difference at $p \leq 0.05$.

and shelling percentage at 1240 °Cd and pod length at 1470 °Cd.

With the predicted changes in global temperature and rainfall patterns, it may become necessary to select and match the genotype more carefully to the length of growing season. For instance, groundnut production in Nigeria was reduced over the past few years because of severe droughts. The isohyet movement towards the south has resulted in the shortening of the period of useful rains in the northern Nigeria. This has necessitated the shift from growing longer season groundnut genotypes to shorter season genotypes of 75–90 days duration (Gibbons, 1978). Agroclimatological analysis of major rainfed groundnut environments in the SAT indicate that growing areas in the SAT are characterized by short growing seasons, i.e. 75–110 days (Virmani and Singh, 1986). Hence, the demand for diverse early maturity groundnut varieties suitable for various agroclimatic conditions will be increasingly felt.

From the long-term studies of changes in adaptedness in a number of experimental populations of annual plants that developed under predominant selfing, Allard (1988) found patterns of ecogenetic differentiation characterized by fine-scaled overlays of environmental heterogeneity. The picture of evolutionary change that emerges from this study is one in which the incorporation of increasing number of favorably interacting alleles into large synergistic complexes in the inbreeding populations. Hence, use of germplasm sources that originated under different agro-ecologies provides better opportunities to improve the complex traits such as early maturity in autogamous crops (e.g. groundnut) through recombination breeding. The diverse early maturity sources identified from different countries in the present study are agronomically superior and therefore likely to provide better opportunities in developing early maturity cultivars suitable for different geographic regions. While selecting the exotic germplasm lines for inclusion in the breeding programs, it is important to consider the genetic background and agronomic performance of the lines as it will be useful in predicting their behavior in hybrid combinations with the adapted genotypes. The less divergent the germplasm lines and adapted lines, the more likely it will be that additive gene effects will play a primary role in inheritance of quantitative traits (Isleib and Wynne, 1983). As the diversity between the parents increases, dominance effects and epistatic variations have significant roles in the inheritance of quantitative traits (Halward and Wynne, 1991). In groundnut, a self-pollinated crop, this would have implications in choosing an appropriate selection strategy.

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