Euphytica **128:** 191–204, 2002.

Geographical patterns of diversity for morphological and agronomic traits in the groundnut germplasm collection

Hari D. Upadhyaya, Paula J. Bramel, Rodomiro Ortiz & Sube Singh
Genetic Resources and Enhancement Program, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, 502 324, India

Received 23 August 2001; accepted 1 April 2002

Key words: agronomic traits, *Arachis hypogaea*, diversity, geographical regions, groundnut, morphological descriptors, peanut

Summary

The characterization of diversity in germplasm collection is important to plant breeders to utilize and to the genebank curators to manage the collection efficiently and effectively. The objective of our study was to describe the phenotypic diversity in the 13342 accessions of groundnut (*Arachis hypogaea* L.) germplasm contained in the ICRISAT genebank. The germplasm accessions were characteized for 16 morphological descriptors, 10 agronomic traits in two seasons, and for reaction to early leaf spot and groundut rosette virus disease, to determine the phenotypic variation in different geographical regions. The phenotypic variation was found for most traits in all the regions. The means for different agronomic traits differed significantly among regions. The variances for all the traits among regions were heterogeneous. South America which showed 100% range variation for 12 of the 16 morphological descriptors and on average showed highest range variation. The Shannon-Weaver diversity index was variable in different regions for different traits. South America among regions, primary seed colour among morphological traits, and leaflet length among agronomic traits showed highest pooled diversity index. Three of the six botanical varieties, *aequatoriana*, *hirsuta*, and *peruviana* were poorly represented and need to be collected. Principal component analysis (PCA) using 38 traits and clustering on first seven PC scores delineated three regional clusters; consisting North America, Middle East, and East Asia in the first cluster, South America in the second cluster, and West Africa, Europe, Central Africa, South Asia, Oceania, Southern Africa, Eastern Africa, Southeast Asia, Central Asia, and Caribbean in the third cluster.

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 2000 (FAO, 2000). The world productivity of 1.45 t ha^{-1} is rather low. Of the world production, 68.57% is produced in Asia on 56.32% area and 23.74% in Africa on 38.89% area compared to North and Central America which produces 5.04% on 2.92%. This is because average productivity in Asia (1.76 t ha^{-1}) and Africa (0. 88 t ha^{-1}) is lower than in the North and Central America (2.53 t ha^{-1}). India, the largest groundnut growing country in world with 7.10 million ha (52.89% of Asia, 29.78% of world area) produces only 6.1 million t (25.77% of Asia, 17.67% of world) with average productivity of 0.86 t ha^{-1}. To enhance groundnut productivity, breeding of groundnut cultivars with high yield potential and resistance to various biotic and abiotic constraints is the main objective in most groundnut improvement programs in the world.

Groundnut improvement has made significant progress in the last two decades resulting in enhanced productivity worldwide. The importance of increased use of genetic resources in enhancing genetic potential of crop, alleviating biotic and abiotic stresses, and broadening genetic base of crop has been very well recognized (Banks, 1976; Hammons, 1976). The emphasis on preservation of crop germplasm for its use in the crop improvement led to assembling and main-

taining a very large number of germplasm collections. At ICRISAT, the genebank contains 14 889 accessions from 93 countries belonging to *A. hypogaea* subsp. *fastigiata* var. *aequatoriana*, *fastigiata*, *peruviana*, and *vulgaris* and subsp. *hypogaea* var. *hypogaea* and *hirsuta*. Of these, 2636 accessions were obtained from 60 collection missions in 26 countries and 12 253 accessions obtained from donations by 60 countries.

The germplasm accessions have been characterized for morphological and agronomic traits. However, the extent of variation in collections from different geographical regions for various traits has not been described. The objective of present research was to describe phenotypic variation found in the ICRISAT groundnut collection from different geographical regions of world and to determine the similarities between regions.

Materials and methods

A total of 13342 accessions originating from 92 countries and contained in the ICRISAT genebank were used for this study. A total of 1547 accessions were excluded from this study- for lack of seed stock or due to lack of information on origin. The accessions consisted of predominantly var. *fastigiata* (2121, 15.90%), var. *vulgaris* (4743, 35.55%) and var. *hypogaea* (6194, 46.42%). The number of var. *peruviana* (249, 1.87%), var. *aequatoriana* (15, 0.11%), and var. *hirsuta* (20, 0.15%) accessions was very low. The 92 countries were grouped into 14 regions based on geographical proximity, and origin and distribution of groundnut. The regions are North America, South America, Caribbean, Central Asia, East Asia, Middle East, Southeast Asia, South Asia, Central Africa, Eastern Africa, Southern Africa, West Africa, Europe and Oceania. (Table 1). Data on 16 morphological descriptors, growth habit, stem pigmentation, stem surface, branching pattern, leaflet shape, colour and surface, standard petal colour, colour of markings on standard petal, peg pigmentation, number of seeds per pod, pod beak, constriction and reticulation, seed colour pattern, and primary seed colour were recorded on the plot basis on all the 13 342 accessions (IBPGR & ICRISAT, 1992). The data on 10 agronomic traits, days to emergence (days from sowing to emergence), leaflet length and width, days to 50% flowering (days from emergence to the stage when 50% plants have begun flowering), pod length and width, shelling percentage, and 100-seed weight, seed length and width were recorded each in the rainy and postrainy seasons. Five competitive plants were selected to record observation on leaflet length and width at 60 days after sowing (DAS) in the rainy season and 75 DAS in the postrainy season, and average value was used. 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. The reaction of 12 477 accessions to the early leaf spots (ELS) (caused by *Cercospora arachidicola* Hori) was recorded following (Subrahmanyam et al., 1995) and groundnut rosette virus disease (GRVD) on 12 479 accession was assessed on 1–9 scale (1 = 0–10% diseased plants), 2 (11–21% diseased plants, and 9 (81–100% diseased plants).

Phenotypic proportions of 16 morphological descriptors and reaction to the ELS and GRVD were calculated in each region. 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 diversity of the regions and characters within populations.

Principal component analysis (PCA) of data was performed. The mean observations of traits for each region 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. Cluster analysis (Ward, 1963) was performed using scores of first seven principal components.

Results and discussion

South Asia was represented by the largest number of accessions (3737 accessions, 28.01% of the total) followed by South America (2143, 16.06%) in the

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

Country/Region	Number of accessions	Country/Region	Number of accessions	Country/Region	Number of accessions
North America	1847 (13.84)[1]	South Asia	3737 (28.01)	South Africa	141 (9.55)
Mexico	31 (1.68)	Pakistan	3 (0.08)	Mozambique	148 (10.03)
USA	1816 (98.32)	Sri Lanka	23 (0.62)	Malawi	149 (10.09)
		Nepal	32 (0.86)	Zambia	272 (18.43)
South America	2143 (16.06)	India	3679 (98.45)	Zimbabwe	654 (44.31)
Colombia	1 (0.05)	Southeast Asia	478 (3.58)		
Chile	12 (0.56)	Cambodia	1 (0.21)	West Africa	1512 (11.33)
Ecuador	15 (0.70)	Thailand	6 (1.26)	Liberia	13 (0.86)
Venezuela	17 (0.79)	Philippines	43 (9.00)	Benin	14 (0.93)
Uruguay	99 (4.62)	Malaysia	54 (11.30)	Morocco	21 (1.39)
Paraguay	148 (6.91)	Vietnam	65 (13.60)	Guinea	22 (1.46)
Peru	344 (16.05)	Myanmar	105 (21.97)	Sierra Leone	24 (1.59)
Argentina	359 (16.75)	Indonesia	204 (42.68)	Gambia	29 (1.92)
Bolivia	427 (19.93)			Togo	46 (3.04)
Brazil	721 (33.64)	Central Africa	427 (3.20)	Ghana	52 (3.44)
		Libyan Arab Jamahiriya	1 (0.23)	Burkina Faso	60 (3.97)
Caribbean	89 (0.67)	Congo	6 (1.41)	Cote d'Ivoire	81 (5.36)
Barbados	4 (4.49)	Equatorial Guinea	13 (3.04)	Mali	207 (13.69)
Honduras	4 (4.49)	Chad	84 (19.67)	Niger	241 (15.94)
Jamaica	4 (4.49)	Cameroon	104 (24.36)	Senegal	285 (18.85)
Puerto Rico	4 (4.49)	Central African Republic	109 (25.53)	Nigeria	417 (27.58)
Trinidad and Tobago	5 (5.62)	Zaire	110 (25.76)		
Martinique	6 (6.74)			Europe	71 (0.53)
Costa Rica	22 (24.72)	Eastern Africa	948 (7.11)	Hungary	2 (5.30)
Cuba	40 (44.94)	Burundi	1 (0.11)	Bulgaria	4 (10.59)
		Rwanda	1 (0.11)	Spain	4 (10.59)
Central Asia	61 (0.46)	Somalia	9 (0.95)	Belgium	5 (13.24)
Russia & CISs	61 (100.00)	Egypt	16 (1.69)	Portugal	6 (15.89)
		Kenya	46 (4.85)	Turkey	6 (15.89)
East Asia	391 (2.93)	Sudan	216 (22.78)	Greece	7 (18.54)
Japan	38 (9.72)	Uganda	242 (25.53)	United Kingdom	37 (97.97)
Taiwan, Province of China	46 (11.76)	Tanzania	417 (43.99)		
Korea, Republic of	93 (23.79)			Oceania	60 (0.45)
China	214 (54.73)	Southern Africa	1476 (11.06)	Fiji	2 (3.33)
		Botswana	1 (0.07)	Australia	58 (96.67)
Middle East	102 (0.76)	Comoros	1 (0.07)		
Syria	1 (0.98)	Angola	7 (0.47)		
Yemen, Republic of	1 (0.98)	Swaziland	8 (0.54)		
Iran	9 (8.82)	Namibia	24 (1.63)		
Cyprus	10 (9.80)	Mauritius	26 (1.76)		
Israel	81 (79.41)	Madagascar	45 (3.05)		

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

Table 2. Means of agronomic traits for different regions for groundnut germplasm in the rainy and postriany seasons

Character	North America	South America	Caribbean	Central Asia	East Asia	Middle East	South Asia	Southeast Asia	Central Africa	Eastern Africa	Southern Africa	West Africa	Europe	Oceania
Rainy season														
Days to emergence	8.86bac[1]	8.1de	7.83fe	8.8bac	7.7f	8.43bdc	8.75bac	7.64f	8.5bdac	8.9ba	8.46bdac	8.83bac	8.94a	8.39dc
Days to 50% flowering	25.95ba	22.98e	22.99e	23.52de	25.27bc	25.27bc	25.29bc	24.22dc	23.27de	24.69c	24.91c	26.57a	23.41de	24.42c
Leaflet length (mm)	50.99dc	54.77ba	54.86ba	55.72a	50.38cd	53.19bac	52.4bdc	52.3bdc	52.3bdc	53.94da	54.01ba	48.89e	53.66da	55.63a
Leaflet width (mm)	22.96gef	23.46cefd	24.14cbd	25.61a	22.67gf	24.01cebd	23.68cefd	23.18gcefd	23.02gefd	24.2cb	24.12cbd	22.24g	23.65cefd	24.83b
Pod length (mm)	29.54b	31.51a	28.39cbd	26.93d	29.53b	28.96cb	27.17d	26.96d	28.46cbd	28.79cb	28.35cbd	27.43cd	28.9cb	27.8cd
Pod width (mm)	12.73a	12.71a	11.97bc	11.91bc	12.56a	12.53a	11.84bc	11.77c	11.83bc	12.15bc	12.31ba	11.93bc	12bc	11.97bc
Shelling percentage	66.64bc	67.18bac	67.27bac	69.04ba	65.43c	66.87bc	68.59ba	68.81ba	69.47a	68.83ba	67.71bac	67.05bac	67.05bac	69.47a
100-Seed weight (g)	48.85a	41.99dc	40.97dc	41.55dc	46.78ba	47.82a	42.91dc	39.62de	37.44fe	44.29bc	44.49bc	42.89dc	35.89f	43.49c
Seed length (mm)	14.35a	13.14dc	12.75dfce	12.42fe	13.84b	13.92b	12.99dce	12.51dfe	12.67dfce	13.05dc	13.21c	13.2c	12.19f	13.1dc
Seed width (mm)	7.98a	7.73bac	7.7bac	7.68bc	7.73bac	7.89ba	7.92ba	7.42d	7.6c	7.85bac	7.85bac	7.77bac	7.38d	7.85ba c
Postrainy season														
Days to emergence	12.07ba	11.96bac	11.46dc	11.23d	11.55bdc	11.75bac	12.29a	11.95bac	12.27a	11.92bac	11.99bac	11.91bac	12.12ba	11.75bac
Days to 50% flowering	38.2b	35.76cd	35.21ed	34.18e	36.44cbd	35.89cd	37.32cb	36.76cbd	37.44cb	36.7cbd	36.94cb	39.45a	37.03cb	37.2cb
Leaflet length (mm)	52.65c	55bac	55.61bac	57.66a	53.6bc	54.91bac	53.14bc	56.01ba	50.16d	54.7bac	55.54bac	49.45d	53.56bc	57.08a
Leaflet width (mm)	24.82ed	24.67ed	25.56bedc	27.31a	24.92edc	25.9bdc	25.05bedc	26.3bac	23f	25.48bedc	25.85bdc	23.26f	24.31e	26.38ba
Pod length (mm)	31.8bc	33.14a	29.16ef	28.77f	32.12ba	31.08bc	28.94f	28.97f	29.34efd	30.59ecd	30.73bcd	29.29efd	30.7bcd	29.55efd
Pod width (mm)	13.8ba	13.77ba	12.86gef	12.95gefd	13.95a	13.43bc	12.66gf	12.87gef	12.61g	13.04gefcd	13.34ecd	12.89gef	13.39bcd	13.13efcd
Shelling percentage	67.83c	69.22bac	71.50a	70.29ba	67.88c	67.89c	69.81bac	71.38a	70.02bac	69.95bac	69.50bac	68.63bc	70.86ba	70.17bac
100-seed weight (g)	58.2a	50.62dc	49.22de	47.69de	57.8a	55.07ba	48.37de	50.23dc	45.76e	51.03dc	53.7bc	50.6dc	48.12de	50.52dc
Seed length (mm)	15.37a	14.11dc	13.48de	13.2e	15.43a	14.79b	13.66dce	13.57dce	13.28e	13.77dce	14.18c	13.98dc	14.22c	13.73dce
Seed width (mm)	8.81a	8.63ba	8.39bc	8.63ba	8.84a	8.65ba	8.65ba	8.61ba	8.31c	8.59ba	8.73a	8.64ba	8.78a	8.72a

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 3. Variances for agronomic traits for different regions for groundnut germplasm in the rainy and postrainy seasons

Character	North America	South America	Caribbean	Central Asia	East Asia	Middle East	South Asia	Southeast Asia	Central Africa	Eastern Africa	Southern Africa	West Africa	Europe	Oceania	F value	Prob>F
Rainy season																
Days to emergence	2.14	2.51	2.19	3.82	2.44	2.33	2.21	2.08	1.54	2.48	2.31	2.2	1.57	1.45	3.3164	0.0001
Days to 50% flowering	9.95	13.95	15.15	10.49	9.63	10.34	10.92	12.51	15.13	14.78	11.17	20.06	13.87	10.01	19.939	0.0001
Leaflet length (mm)	66.88	60.61	57.66	36.9	37.45	67.99	83.25	37.41	48.61	53.48	56.84	57.51	60.91	69.93	20.866	0.0001
Leaflet width (mm)	12.22	10.93	9.36	7.61	9.25	13.24	16.43	9.03	10.09	10.59	10.93	11.17	12.15	11.97	18.516	0.0001
Pod length (mm)	24.66	38.74	16.47	14.1	20.72	22.12	16.81	15.06	25.05	23.61	25.27	19.48	26.42	21.16	30.716	0.0001
Pod width (mm)	2.9	2.13	1.8	2.05	2.07	2.95	1.76	1.78	1.85	1.79	2.44	1.48	2.68	2.17	15.124	0.0001
Shelling percentage	48.28	44.56	40.95	52.45	51.00	68.22	45.23	45.66	34.33	42.69	48.55	52.18	44.38	35.29	3.825	0.0001
100-seed weight (g)	173.78	155.43	65.32	60.05	157.14	185.03	93.41	99.21	96.4	112.23	143.89	107.06	134.36	90.77	17.43	0.0001
Seed length (mm)	6.45	3.57	3.06	2.5	5.86	6.43	3.44	2.37	2.75	3.71	4.41	3.36	4.77	4.63	41.106	0.0001
Seed width (mm)	0.71	0.68	0.46	0.58	0.79	0.66	0.62	0.61	0.77	0.6	0.65	0.63	0.89	0.37	1.6121	0.074
Postrainy season																
Days to emergence	2.4	3.34	1.48	1.68	1.84	3.55	3.43	4.68	3.66	2.34	2.92	2.88	1.6	2.22	9.4239	0.0001
Days to 50% flowering	27.25	27.22	17.63	21.45	23.43	27	25.49	27.73	41.56	24.72	29.28	40.8	14.26	24.67	13.151	0.0001
Leaflet length (mm)	84.11	101.92	60.12	54.76	86.24	99.82	103.95	103.23	79.97	75.1	91.27	81.69	90.83	94.04	7.4836	0.0001
Leaflet width (mm)	16.09	21.04	13.26	11.28	23.11	22.07	23.76	26.43	16.26	16.33	18.84	17.15	22.48	23.22	12.608	0.0001
Pod length (mm)	26.58	36.89	18.02	20.93	24.5	28.35	17.14	15.47	22.19	21.42	28.01	19.18	23.7	26.62	30.514	0.0001
Pod width (mm)	3.27	2.62	1.93	3.23	2.59	3.16	1.76	2.08	2.02	2.07	2.93	1.86	2.6	2.73	21.705	0.0001
Shelling percentage	49.51	43.52	27.60	33.10	36.92	69.13	39.85	34.82	37.40	39.80	41.26	41.24	29.58	49.97	3.773	0.0001
100-seed weight (g)	244.14	196.69	60.38	80.82	184.15	245.17	102.5	109.95	105.74	118.21	188.5	110.58	107.07	132.93	33.214	0.0001
Seed length (mm)	7.38	4.59	2.69	3.45	8.04	7.21	3.4	2.99	3.31	4.03	4.65	3.56	5.1	5.05	55.777	0.0001
Seed width (mm)	0.71	0.88	0.45	0.51	0.7	0.79	0.58	0.51	0.8	0.6	0.69	0.69	0.81	0.58	6.7379	0.0001

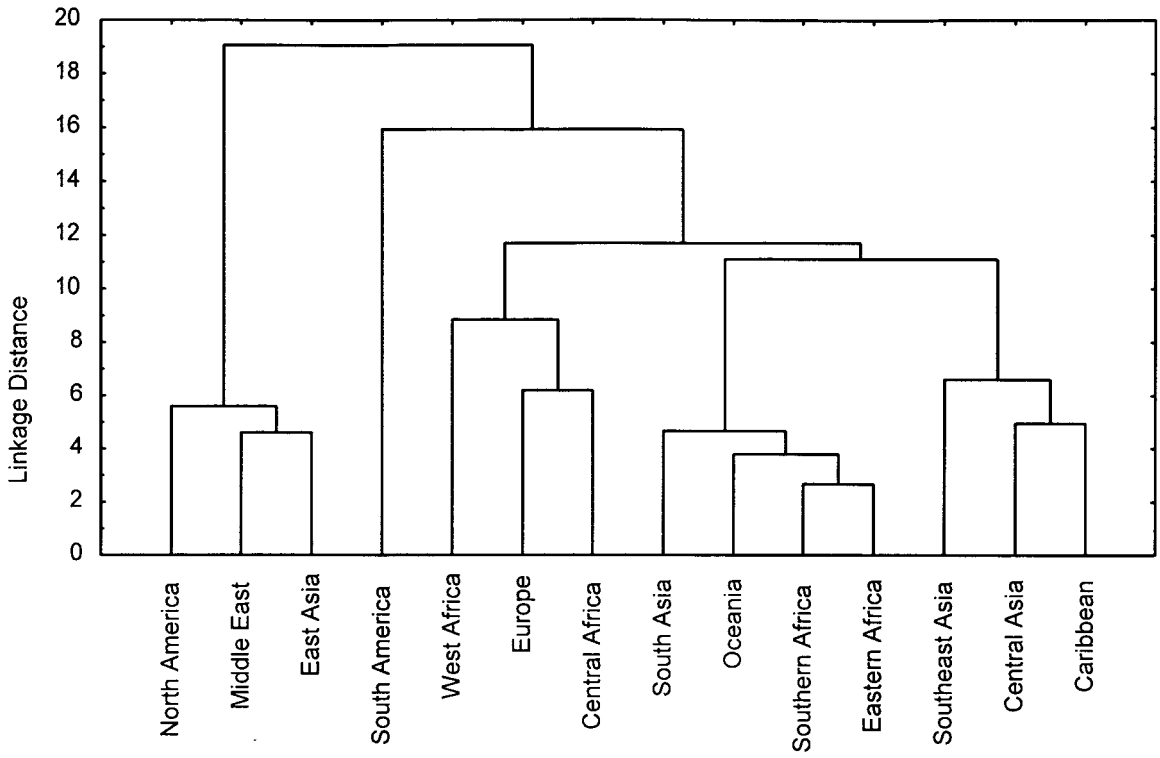

Figure 1. Dendogram of 14 regions in entire groundnut germplasm based on scores of first seven principal components.

ICRISAT genebank. India in South Asia with 3679 accessions (98.45% of the region) and The United States of America (USA) with 1816 accessions (98.32% of the region) in North America were two dominant germplasm contributing countries (Table 1). The South America where primary center of diversity (Chaco region between southern Bolivia and northwestern Argentina) (Gregory & Gregory, 1976) and seven secondary centers of diversity are located, contributed only 2143 accessions (16.06%) and was underrepresented. Africa which can be considered a tertiary center of diversity (Stalker & Simpson, 1995) was adequately represented by a total of 4363 accessions (32.70%). China, which along with India, is considered as other important center of diversity was represented by only 214 accessions due to difficulty in collection/acquisition of germplasm.

The 16 morphological descriptors showed differences among geographical regions in their distribution and range of variation (Appendix 1). Six morphological descriptors, leaflet shape, leaflet surface, colour of standard petal, colour of markings on standard petal, peg pigmentation, and seed colour pattern were monomorphic in most regions. Most accessions have elliptic leaflet shape, almost glabrous on both surfaces of leaflet, orange colour petal, dark orange markings on standard petal, presence of peg pigmentation, and one primary seed colour in most regions (Appendix 1). The remaining 10 morphological descriptors showed at least two classes. Primary seed colour showed maximum variability with 19 classes however the number of classes differed in different regions. South America had maximum classes (12) for this trait followed by Middle East (11) and North America and Eastern Africa (10). Caribbean, East Asia, Southeast Asia, and West Africa had 7 classes each. Overall, tan seed colour was most prominent in all the regions. More than 80% accessions from Central Asia, Southeast Asia, and Europe have erect growth habit, from North America, East Asia, Middle East, South Asia, Southeast Asia, Southern Africa, West Africa, and Oceania do not have pigmented stem. All the regions except South America and Southern Africa have more than 80% accessions which have sub-glabrous stem surface (Appendix 1).

ELS is one of the most important and widely occurring disease of groundnut (Bunting et al., 1985). GRVD is a major constraint to groundnut production in sub-Saharan Africa and its offshore islands (Naidu et al., 1999). Levels of resistance against ELS available in the cultivated species of groundnut are very low and only 1 accession out of 1963 accessions from South America showed a score of 4 on a 1–9 scale. In case of GRVD, 2 accessions from North America (out of 1695), 1 from central Asia (out of 60), 3 from East Asia (out of 364), 13 from South Asia (3630), 6 from Central Africa (397), 13 from Southern Africa (1383), 88 from West Africa (1428) and 1 from Europe (57) showed resistance to disease (Appendix 1). A possible explanation for the occurrence of GRVD resistance in the accessions from the areas where disease has never existed (Reddy, 1991) is that the resistance was present as a constituent trait in the ancestors of groundnut and was only expressed in the new encounter situation. During the course of evolution, as these genes did not possess any survival value in the absence of disease, they may have been altered in the majority of the genotypes.

There were significant differences among regions for means of all 10 agronomic traits in the rainy and postrainy seasons (Table 2). Accessions from South America (22.98 days) and Caribbean (22.99 days) took the least number of days to 50% flowering in the rainy season and those from Central Asia (34.18 days) took least days in the postrainy season whereas accessions from West Africa took the highest number of days to flowering in the rainy (26.57 days) and postrainy (39.45 days) seasons. The accessions from North America had highest 100-seed weight in both rainy (48.85 g) and postrainy (58.2 g) seasons.

All 14 regions showed 100% range variation of the entire collection for growth habit and stem pigmentation (data not given). South America showed 100% range variation for all the morphological descriptors except stem surface, branching pattern and standard petal colour whereas South Asia showed 100% range variation for all except stem surface, leaflet surface, and number of seeds per pod. On average South America showed 93.85% range variation of entire collection followed by South Asia (92.41%) and North America (88.65%). Only South America for reaction to ELS and nine regions, North America, Central Asia, East Asia, South Asia, Central Africa, Eastern Africa, Southern Africa, West Africa, and Europe for reaction to GRVD showed 100% range variation.

The 10 agronomic traits showed a large range variation in different regions in the rainy and postrainy seasons. South America for pod length and seed length and South Asia for days to 50% flowering, pod width, seed length, and shelling percentage in the rainy season and South America for pod length and width and North America for shelling percentage in the postrainy season showed 100% range variation (data not given). On average South America represented 86.31% range variation of entire collection compared to 83.16% range variation in the South Asia, 77.91% in North America, and 78.24% in West Africa. Caribbean represented only 47.49% range variation. Over all the 16 morphological descriptors, reaction to ELS and GRVD, and 10 agronomic traits in the rainy and postrainy seasons, South America (89.88%), South Asia (86.89%), and North America (82.54%) were three regions which represented more than 80% average range variation (data not given).

The variances were heterogeneous for all the 10 agronomic traits in the rainy ($p = 0.0001$–0.074) and postrainy ($p = 0.0001$) seasons (Table 3). Middle East for five traits and South America and South Asia for three traits each had highest variances. The traits were pod width in the rainy season and shelling percentage and 100-seed weight in the rainy and postrainy seasons for Middle East, pod length in the rainy and postrainy season and seed width in the postrainy season for South America, and leaflet length and width in the rainy and leaflet length in the postrainy season for South Asia (Table 3).

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 classes for an 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 ELS and GRVD, and for agronomic traits in the rainy and postrainy seasons (Table 4). South America region had highest H' for all the morphological descriptor traits except growth habit, branching pattern, leaflet colour and shape, and pod beak (Table 4). North America for growth habit, South Asia for branching pattern, Caribbean for leaflet colour, and Central Africa for pod beak had highest H'. South America had highest pooled H' for morphological descriptors (0.336 ± 0.051) and North America for the 10 agronomic traits in the rainy and postrainy seasons (0.608 ± 0.007). Primary seed colour (0.480 ± 0.027)

Table 4. Shannon-Weaver diversity index for morphological and agronomic traits for different regions for groundnut germplasm

Character	North America	South America	Caribbean	Central Asia	East Asia	Middle East	South Asia	Southeast Asia	Central Africa	Eastern Africa	Southern Africa	West Africa	Europe	Oceania	Mean
Growth habit	0.632	0.372	0.335	0.244	0.533	0.556	0.500	0.258	0.408	0.509	0.552	0.614	0.279	0.452	0.446 ±0.035
Stem pigmentation	0.149	0.298	0.253	0.250	0.141	0.196	0.182	0.205	0.230	0.247	0.207	0.151	0.274	0.196	0.213 ±0.013
Stem surface	0.229	0.386	0.197	0.085	0.176	0.202	0.152	0.160	0.212	0.200	0.295	0.196	0.216	0.161	0.205 ±0.019
Branching pattern	0.249	0.243	0.219	0.169	0.301	0.300	0.304	0.178	0.269	0.295	0.303	0.287	0.187	0.271	0.255 ±0.013
Leaflet colour	0.321	0.292	0.417	0.215	0.301	0.299	0.308	0.189	0.271	0.303	0.303	0.293	0.232	0.276	0.287 ±0.014
Leaflet shape	0.010	0.020			0.008	0.024	0.004			0.007	0.006	0.002	0.032		0.012 ±0.003
Leaflet surface	0.126	0.183	0.080	0.036	0.034	0.072	0.109	0.029	0.063	0.083	0.088	0.068	0.056	0.037	0.076 ±0.011
Standard petal colour	0.116	0.202	0.158	0.105	0.030	0.097	0.066	0.104	0.052	0.110	0.114	0.054	0.032	0.064	0.093 ±0.013
Colour of standard petal markings	0.069	0.176	0.054		0.008		0.015	0.007	0.020	0.035	0.022	0.005			0.041 ±0.016
Peg pigmentation	0.033	0.130	0.027		0.014	0.024	0.016	0.017	0.018	0.030	0.039	0.006			0.032 ±0.010
Pod beak	0.458	0.458	0.417	0.376	0.388	0.392	0.420	0.398	0.489	0.404	0.441	0.467	0.353	0.470	0.424 ±0.011
Pod Constriction	0.387	0.466	0.338	0.383	0.239	0.394	0.304	0.348	0.372	0.382	0.402	0.389	0.450	0.420	0.377 ±0.015
Pod reticulation	0.443	0.626	0.516	0.427	0.334	0.430	0.382	0.393	0.438	0.400	0.411	0.420	0.408	0.456	0.434 ±0.018
Primary seed colour	0.487	0.732	0.434	0.353	0.350	0.564	0.446	0.356	0.499	0.524	0.552	0.519	0.411	0.493	0.480 ±0.027
Seed colour	0.022	0.149			0.008	0.024	0.017		0.023	0.007	0.065	0.047			0.040 ±0.015
Number of seeds per pod	0.346	0.645	0.409	0.387	0.332	0.336	0.401	0.381	0.612	0.547	0.479	0.393	0.578	0.469	0.451 ±0.028
Mean (16 traits)	0.255 ±0.048	0.336 ±0.051	0.275 ±0.039	0.253 ±0.033	0.2002 ±0.042	0.261 ±0.047	0.227 ±0.044	0.216 ±0.036	0.265 ±0.050	0.255 ±0.048	0.267 ±0.048	0.244 ±0.051	0.270 ±0.042	0.314 ±0.042	0.242
Reaction to early leaf spot	0.523	0.463	0.430	0.308	0.425	0.399	0.440	0.255	0.260	0.374	0.375	0.303	0.372	0.532	0.390 ±0.023
Reaction to rosette	0.037	0.021	0.049	0.037	0.045		0.034	0.016	0.066	0.015	0.038	0.144	0.038	0.037	0.044 ±0.009
Rainy season															
Days to emergence	0.570	0.577	0.556	0.565	0.580	0.546	0.554	0.604	0.583	0.594	0.556	0.576	0.562	0.589	0.572 ±0.004
Days to 50% flowering	0.643	0.585	0.580	0.648	0.637	0.614	0.605	0.601	0.598	0.600	0.624	0.586	0.504	0.612	0.603 ±0.009
Leaflet length (mm)	0.637	0.617	0.593	0.569	0.641	0.618	0.630	0.623	0.625	0.627	0.631	0.629	0.584	0.596	0.616 ±0.006
Leaflet width (mm)	0.614	0.615	0.622	0.584	0.589	0.630	0.625	0.617	0.641	0.626	0.610	0.616	0.564	0.602	0.611 ±0.005
Pod length (mm)	0.610	0.626	0.601	0.543	0.617	0.592	0.624	0.594	0.619	0.610	0.619	0.611	0.575	0.585	0.602 ±0.006
Pod width (mm)	0.625	0.605	0.539	0.591	0.575	0.587	0.583	0.550	0.611	0.560	0.628	0.621	0.567	0.577	0.587 ±0.008
Shelling percentage	0.611	0.615	0.607	0.612	0.620	0.600	0.614	0.627	0.620	0.613	0.626	0.605	0.610	0.567	0.610 ±0.004
100-seed weight (g)	0.629	0.602	0.615	0.627	0.608	0.600	0.615	0.610	0.606	0.612	0.613	0.615	0.568	0.596	0.608 ±0.004
Seed length (mm)	0.600	0.588	0.539	0.492	0.580	0.566	0.593	0.602	0.610	0.590	0.629	0.588	0.629	0.540	0.582 ±0.010
Seed width (mm)	0.531	0.524	0.439	0.481	0.503	0.520	0.508	0.500	0.546	0.496	0.521	0.500	0.583	0.391	0.503 ±0.012

Table 4. Continued

Character	North America	South America	Caribbean	Central Asia	East Asia	Middle East	South Asia	Southeast Asia	Central Africa	Eastern Africa	Southern Africa	West Africa	Europe	Oceania	Mean
Postrainy season															
Days to emergence	0.613	0.522	0.584	0.576	0.587	0.500	0.560	0.604	0.556	0.567	0.544	0.552	0.609	0.478	0.561 ±0.011
Days to 50% flowering	0.612	0.592	0.555	0.580	0.589	0.581	0.629	0.595	0.582	0.630	0.600	0.624	0.566	0.583	0.594 ±0.006
Leaflet length (mm)	0.637	0.620	0.617	0.594	0.615	0.630	0.629	0.622	0.632	0.629	0.630	0.624	0.559	0.578	0.615 ±0.006
Leaflet width (mm)	0.628	0.635	0.555	0.591	0.602	0.608	0.617	0.605	0.621	0.630	0.632	0.637	0.574	0.571	0.608 ±0.007
Pod length (mm)	0.633	0.623	0.556	0.569	0.611	0.599	0.636	0.617	0.606	0.611	0.620	0.609	0.572	0.596	0.604 ±0.006
Pod width (mm)	0.581	0.586	0.593	0.585	0.596	0.557	0.590	0.590	0.578	0.584	0.618	0.631	0.594	0.556	0.588 ±0.005
Shelling percentage	0.620	0.619	0.628	0.603	0.618	0.604	0.615	0.617	0.640	0.639	0.634	0.632	0.620	0.597	0.620 ±0.004
100-seed weight (g)	0.609	0.600	0.599	0.614	0.629	0.606	0.619	0.623	0.616	0.611	0.603	0.623	0.601	0.491	0.603 ±0.009
Seed length (mm)	0.618	0.633	0.602	0.570	0.583	0.568	0.584	0.565	0.581	0.603	0.650	0.600	0.535	0.486	0.584 ±0.011
Seed width (mm)	0.539	0.584	0.419	0.440	0.532	0.561	0.493	0.469	0.562	0.502	0.534	0.516	0.545	0.490	0.513 ±0.013
Mean (20 traits)	0.608	0.598	0.570	0.572	0.596	0.584	0.596	0.592	0.602	0.597	0.606	0.600	0.576	0.554	0.589
	±0.007	±0.007	±0.012	±0.011	±0.007	±0.008	±0.009	±0.009	±0.006	±0.009	±0.008	±0.008	±0.007	±0.013	
Mean (38 traits)	0.442	0.469	0.437	0.436	0.410	0.444	0.422	0.420	0.442	0.432	0.442	0.430	0.441	0.453	0.423
	±0.036	±0.032	±0.031	±0.031	±0.0038	±0.033	±0.036	±0.035	±0.036	±0.036	±0.036	±0.037	±0.031	±0.028	

among morphological traits and leaflet length in the rainy season (0.616 ± 0.006) and shelling percentage in the postrainy season (0.620 ± 0.006) among agronomic traits had highest pooled H' (Table 4). Over all the 38 traits, South America (0.469 ± 0.032) had the highest H' indicating that the diversity for different traits from region consisting of primary and secondary centers of diversity has been conserved in the ICRISAT collection.

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 33.23% of total variation. The second PC accounted for 24.83%, third for the 15.51%, and fourth for the 9.97%. The seventh PC accounted for 2.54% variation. A hierarchical cluster analysis conducted on the first seven PC scores (total variation accounted 95.58%) resulted in three clusters (Figure 1). North America Middle East, and East Asia grouped together to form Cluster 1, South America alone formed Cluster 2, and West Africa, Europe, Central Africa, South Asia, Oceania, Southern Africa, Eastern Africa, Southeast Asia, Central Asia, and Caribbean formed Cluster 3. This clustering is not surprising considering the dispersion of groundnut from South America to different parts of world. Most authorities believe that the Portuguese carried two-seeded groundnut varieties from the east coast of South America (Brazil) to Africa, to the Malabar coast of southeastern India and possibly to the far east in the late 15th century. The Spaniards took 3-seeded Peruvian types (including *hirsuta*) to Indonesia and China up to Madagascar from the west coast of South America via the western Pacific in the early 16th century. Groundnut made its way to the North America from Africa as well as from Caribbean islands, Central America, and Mexico and was distributed worldwide by the middle of 16th century and became an important crop in West Africa, India, China, and USA by the 19th century. Groundnut at present is cultivated as an important crop in 96 countries of world. The long histories of its cultivation under diverse agroclimatic condition has resulted in accumulation of changes required for adaptation and thus in wide diversity for phenotypic traits in different regions. South America forming of a separate cluster is in accordance with the region's importance in housing the primary center of diversity and all the secondary center of diversity.

The accessions in Cluster 1 were predominantly alternate branching pattern, green leaflet colour, moderate pod beak, constriction, and reticulation whereas

Table 5. Means of agronomic traits for different clusters for groundnut germplasm in the rainy and postrainy seasons

Character	Cluster 1	Cluster 2	Cluster 3
Rainy season			
Days to emergence	8.65a[1]	8.10b	8.65a
Days to 50% flowering	25.81a	22.98c	25.16b
Leaflet length (mm)	50.99c	54.78a	52.30b
Leaflet width (mm)	22.96b	23.46a	23.53a
Pod length (mm)	29.52b	31.51a	27.68c
Pod width (mm)	12.70a	12.71a	11.97b
Shelling percentage	48.49a	41.99c	42.78b
100-seed weight (g)	66.34c	67.26b	68.65a
Seed length (mm)	14.26a	13.14b	13.01c
Seed width (mm)	7.94a	7.74c	7.82b
Postrainy season			
Days to emergence	11.97b	11.96b	12.10a
Days to 50% flowering	37.80a	35.75c	37.48b
Leaflet length (mm)	52.91b	54.99a	53.17b
Leaflet width (mm)	24.88a	24.67a	24.92a
Pod length (mm)	31.83b	33.14a	29.51c
Pod width (mm)	13.81a	13.77a	12.87b
Shelling percentage	58.00a	50.62b	49.92c
100-seed weight (g)	68.78c	70.00b	70.81a
Seed length (mm)	15.36a	14.11b	13.79c
Seed width (mm)	8.81a	8.63b	8.64b

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

in Clusters 2 the accessions were predominantly with sequential branching pattern, light green leaflet, slight pod beak, constriction and reticulation. (data not given). All the three clusters differed significantly for days to 50% flowering, pod length, seed length, 100-seed weight, and shelling percentage in both the rainy and postrainy seasons and leaflet length and seed width in the rainy season (Table 5). Of the remaining three traits in the rainy season and five traits in the postrainy season, Clusters 1 and 2 did not differ significantly from each other but were significantly different from Cluster 3 for days to emergence in the postrainy season and pod width in both the seasons (Table 5).

The geographic regions of origin of ICRISAT groundnut collections indicated significant differences for range of variation for various morphological and agronomic traits. Among the regions, though South America which houses the primary center of diversity and all the seven secondary centers of diversity was under represented in terms of number of accessions (2143, 16.06% of total accessions), contained adequate diversity for the morphological and agronomic traits. This was clearly demonstrated by the highest H' the 12 of 16 morphological descriptors and highest pooled H' over all the descriptors (0.336 ± 0.051) and over all the 38 traits (0.469 ± 0.032) in this region. Africa which is considered a tertiary center of diversity was represented by 4363 (32.70%) accessions (Table 1) and all the four regions in Africa, Central, Eastern, Southern, and West showed high diversity for the morphological and agronomic traits (Table 4). China seems under represented (214 accessions) due to difficulties in collection and acquisition of germplasm. Botanical varieties wise the collection at ICRISAT is highly skewed and we have only 20 accessions of *hirsuta*, 15 accessions of *aequatoriana*, and 249 accessions of *peruviana*, which together represent only 2.13% of the total collection. Therefore, there is need to explore from both primary and secondary centers of diversity to collect these botanical varieties and conserve useful diversity of crop for utilization in crop improvement programs.

Appendix 1. Phenotypic proportions (%) of morphological descriptor traits for different regions for groundnut germplasm

Character	North America	South America	Caribbean	Central Asia	East Asia	Middle East	South Asia	Southeast Asia	Central Africa	Eastern Africa	Southern Africa	West Africa	Europe	Oceania
Growth habit														
Procumbent-1	19	10	10	5	16	21	34	7	7	15	18	13	10	10
Decumbent-1	2	1	1	2	1	0	1	3	1	1	2	3	3	3
Decumbent-2	25	7	6	3	25	17	1	13	19	14	14	25	1	8
Decumbent-3	28	6	4	3	8	16	5	2	5	12	14	23	3	11
Erect	26	76	79	87	50	46	49	85	68	58	52	36	83	68
Stem pigmentation														
Absent	89	56	73	74	90	83	85	82	78	74	82	89	68	83
Present	11	44	27	26	10	17	15	18	22	26	18	11	32	17
Stem surface														
Sub-Glabrous	83	60	83	95	86	82	89	88	81	84	72	84	80	90
Moderately hairy	15	33	17	5	14	18	11	12	19	16	26	16	20	8
Very hairy	2	5	0	0	0	0	0	0	0	0	2	0	0	2
Wooly	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Branching pattern														
Alternate	74	24	20	13	50	54	51	14	31	42	48	64	15	32
Sequential	26	76	80	87	50	46	49	86	69	58	52	36	85	68
Leaflet colour														
Yellow/yellow green	0	0	17	0	0	0	0	0	0	0	0	0	0	0
Light green	27	69	58	80	49	45	47	84	68	57	51	35	77	67
Green	70	30	25	20	51	55	53	16	32	43	49	65	23	33
Dark Green	3	1	0	0	0	0	0	0	0	0	0	0	0	0
Leaflet shape														
Obcuneate	0	1	0	0	0	1	0	0	0	0	0	0	0	0
Elliptic	100	99	100	100	100	99	100	100	100	100	100	100	99	100
Oblong-elliptic	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Leaflet surface														
Almost glabrous on both surfaces	93	88	96	98	98	96	94	99	97	95	95	96	97	98
Almost glabrous above, hairs below	6	12	4	2	2	4	6	1	3	5	5	4	3	2
Hairs on both surfaces, without bristles	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Standard petal colour														
Orange-yellow/yellow orange	4	13	9	7	1	6	3	6	3	6	7	3	1	3
Orange	94	86	90	93	99	94	97	94	97	94	93	97	99	97
Dark orange	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Garnet/brick red	2	1	1	0	0	0	0	0	0	0	0	0	0	0

Appendix 1. Continued

Character	North America	South America	Caribbean	Central Asia	East Asia	Middle East	South Asia	Southeast Asia	Central Africa	Eastern Africa	Southern Africa	West Africa	Europe	Oceania
Colour of standard petal markings														
Orange-yellow/ yellow orange	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Orange	1	8	1	0	0	0	0	0	0	1	1	0	0	0
Dark orange	96	90	98	100	100	100	100	100	99	99	99	100	100	100
Garnet/brick red	2	1	1	0	0	0	0	0	1	0	0	0	0	0
Peg pigmentation														
Absent	1	9	1	0	1	1	1	1	1	1	2	0	0	0
Present	99	91	99	100	99	99	99	99	99	99	98	100	100	100
Pod beak														
Absent	7	6	6	3	2	1	5	5	9	4	5	10	1	8
Slight	38	49	44	57	30	46	45	23	42	50	45	40	55	45
Moderate	50	40	48	38	62	48	47	66	43	43	45	46	43	42
Prominent	5	5	2	2	6	5	3	6	6	3	5	4	1	5
Pod constriction														
None	1	6	1	0	0	1	2	2	2	2	3	5	1	3
Slight	18	45	27	18	8	17	18	26	44	29	28	28	52	20
Moderate	69	43	69	69	85	71	77	69	52	64	63	64	37	65
Deep	11	6	3	11	6	9	3	3	2	5	5	3	8	12
Very deep	1	0	0	2	1	3	0	0	0	0	1	0	1	0
Pod reticulation														
None	2	10	2	3	0	4	3	3	1	3	4	2	3	8
Slight	31	37	31	34	18	23	36	18	33	37	27	28	32	32
Moderate	58	31	48	56	73	65	59	69	54	57	64	63	59	55
Prominent	8	10	17	7	9	5	2	10	12	3	5	5	6	5
Very prominent	1	12	2	0	0	3	0	0	0	0	0	2	0	0
Seed colour pattern														
One colour	99	89	100	100	100	99	99	100	99	100	97	98	100	100
Variegated	1	11	0	0	0	1	1	0	1	0	3	2	0	0
Primary seed colour														
White	1	1	0	2	0	1	0	0	0	0	1	0	0	2
Off-white	1	1	1	0	0	2	1	0	1	1	0	0	0	0
Very pale tan	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Light tan	1	1	1	0	1	0	2	5	2	1	1	1	0	2
Tan	73	37	67	72	79	67	77	79	59	64	65	69	69	68

Appendix 1. Continued

Dark tan	9	1	0	0	1	8	3	2	3	3	11	9	1	0
Greyed orange	1	0	0	0	0	4	4	0	0	0	0	0	0	0
Rose	3	1	0	2	13	5	2	1	1	2	1	4	3	0
Salmon	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Light red	0	2	0	0	0	0	0	0	1	1	0	3	0	0
Red	6	37	24	21	4	6	8	11	28	23	15	12	21	12
Dark red	2	5	2	3	1	2	2	1	4	3	4	2	3	2
Purplish Red/Reddish purple	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Light purple	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Purple	3	9	3	0	1	3	1	1	1	1	1	0	3	3
Dark Purple	0	3	0	0	0	1	0	0	0	1	1	0	0	7
Other	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Number of seeds per pod														
2-1	76	34	65	72	76	78	68	65	44	54	62	71	44	63
2-3/2-1-3	14	14	7	10	17	9	21	29	28	19	18	17	34	18
3-2-1/3-1-2	5	14	4	7	2	2	6	2	7	11	10	6	6	7
2-3-4-1/2-4-3-1/2-3-1-4/2-4-1-3/2-1-3-4	1	4	0	0	1	2	1	1	5	2	1	1	4	2
2-1-4-3-5/3-2-4-1/3-2-1-4	4	33	24	11	4	9	3	3	13	14	9	4	11	10
3-4-1/3-4-1-2	0	0	0	0	0	0	0	0	2	0	0	0	1	0
4-3-2-1/4-2-3-1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Early leaf spot score														
4	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00
6	10.50	2.45	4.76	0.00	2.48	1.09	2.43	0.00	0.00	1.69	1.96	0.70	3.57	10.17
7	11.92	9.93	9.52	5.00	8.82	9.78	8.19	3.37	0.25	2.13	2.10	0.56	7.14	16.95
8	29.85	35.10	19.05	21.67	29.75	26.09	42.32	16.32	26.77	45.51	47.79	31.93	17.86	23.73
9	47.73	51.96	66.67	73.33	58.95	63.04	47.06	80.31	72.98	50.56	48.15	66.81	71.43	49.15
Rosette score														
1	0.12	0.00	0.00	1.67	0.82	0.00	0.36	0.00	1.51	0.11	0.94	6.16	1.75	0.00
2	0.24	0.10	0.00	0.00	0.00	0.00	0.17	0.26	1.01	0.00	0.00	0.98	0.00	0.00
3	0.06	0.05	0.00	0.00	0.27	0.00	0.19	0.00	0.25	0.22	0.00	0.28	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.07	0.14	0.00	0.00
5	0.18	0.05	0.00	0.00	0.27	0.00	0.08	0.00	0.00	0.00	0.14	0.14	0.00	1.69
6	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.00	0.00	0.14	0.00	0.00	0.00
7	0.06	0.05	0.00	0.00	0.27	0.00	0.06	0.00	0.00	0.11	0.00	0.07	0.00	0.00
8	0.41	0.41	2.38	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.07	0.00	0.00	0.00
9	98.82	99.33	97.62	98.33	98.35	100.00	98.95	99.48	97.23	99.55	98.63	92.23	98.25	98.31

References

Banks, D.J., 1976. Peanuts: Germplasm resources. Crop Sci 16: 499–502.

Bunting, A.H., R.W. Gibbons & J.C. Wynne, 1985. Groundnut (Arachis hypogaea L.). In: R.J. Summerfield & E.H. Roberts (Eds.), Grain Legume Crops, pp. 747–800. Collins, London.

FAO, 2000. FAOSTAT database. http: //www/FAO.ORG

Gregory, W.C.& M. P. Gregory, 1976. Groundnut. In: N.W. Simmonds (Ed.), Evolution of Crop Plants, pp. 151–154. Longman Group Ltd., London.

Hammons, R.O., 1976. Peanuts: Genetic vulnerability and breeding strategy. Crop Sci 16: 527–530.

IBPGR & ICRISAT, 1992. Descriptors for groundnut. International Board for Plant Genetic Resources, Rome, Italy; International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India.

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.

Naidu, R.A., F.M. Kimmins, C.M. Deom, P. Subrahmanyam, A.J. Chiyembekeza & P.J.A. van der Merwe. 1999. Groundnut rosette: a virus disease affecting groundnut production in sub-Saharan Africa. Plant Disease 83: 700–709.

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

Reddy, D.V.R., 1991. Groundnut virus and virus diseases: distribution, identification and control. Rev Plant Pathol 70: 665–678.

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

Stalker, H.T. & C.E. Simpson, 1995. Germplasm resources in *Arachis*. In: H.E. Pattee & H.T. Stalker (Eds.), Advances in Peanut Science, pp. 14–53. American Peanut Research and Education Society, Inc. Stillwater, OK.

Subrahmanyam, P.S., D. McDonald, F. Waliyar, L.J. Reddy, S.N. Nigam, R.W. Gibbons, V. Ramanatha Rao, A.K. Singh, S. Pande, P.M. Reddy & P.V. Subba Rao, 1995. Screening methods and sources of resistance to rust and late leaf spot of groundnut. Information Bulletin no. 47. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India, pp. 24.

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