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GEOGRAPHICAL DIVERSITY IN RELATION TO GENETIC DIVERGENCE IN CULTIVATED *SORGHUM*

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A knowledge of genetic diversity present among populations and its quantitative assessment usually helps a plant breeder in choosing desirable parents for breeding programmes. The utility of multivariate analysis and the use of generalized distance (D^2) as a quantitative measure of genetic divergence are well illustrated in crop plants and other biological populations (Cassie, 1963; Chandrasekariah, Murty and Arunachalam, 1967).

The genus *Sorghum* possesses a wealth of genetic diversity. It was possible to classify the whole genus into nine major categories by multivariate analysis of genetic divergence using D^2-statistic (Chandrasekariah *et al.*, 1967). Information on the nature of genetic diversity between geographical groups particularly from the African countries may be useful in analysing the evolutionary pattern in this genus. Hence an attempt is made in this investigation to find out the relationship between geographic and genetic diversity and to assess the diversity in some maturity groups in the genus *Sorghum*, since flowering time is a major factor of adaptation in cultivated *Sorghums*.

Materials and Methods

A world collection of about 10,000 genetic stocks of *Sorghum* is maintained at the Division of Genetics, Indian Agricultural Research Institute, Delhi. They are mainly cultivated types collected from 44 countries all over the world. The whole collection was divided into 70 working groups on the basis of panicle opening (Govila, Arunachalam, Saxena and Murty, 1966) and studied for a constellation of qualitative and quantitative characters. The material for this investigation consisted of 80 collections representative of all the groups and 16 countries. It was possible to further divide them into three physiological groups based on days to 50 per cent. flowering, namely, early (up to 75 days), medium (76–99 days) and late (100 days and above).

The 80 stocks were grown in a randomized block design with three replications during 1965–66 at Delhi. Observations on 10 characters, namely, rate of 50 per cent. seedling emergence (X_1), days to 50 per cent. flowering (X_2), number of whorls on rachis (X_3), plant height at maturity in cm. (X_4), number of tillers (X_5), panicle length in cm. (X_6), panicle breadth in cm. (X_7), length

of rachis in cm. (X_8), number of leaves per plant (X_9) and stem diameter in cm. (X_{10}) were recorded on random samples of three plants per plot.

The countrywise distribution of the 80 genetic stocks under different physiological groups is presented in Table 1. The countrywise means for early, medium and late populations (28 in number) were utilized for assessing divergence in the physiological groups—material A, while the means of all the collections from each of the 16 countries irrespective of the physiological groups to which they belonged were made use of to relate geographic and genetic diversity—material B.

TABLE 1

Physiological grouping of 80 lines from a world collection of Sorghum

S. No.	Country	Number of lines			Total
		Early	Medium	Late	
1	India	7	11	9	27
2	Japan	2	4	1	7
3	China	1	—	—	1
4	Maryland (U.S.A.)	4	3	1	8
5	Mexico	2	—	1	3
6	Nebraska (U.S.A.)	6	1	—	7
7	Texas (U.S.A.)	3	1	—	4
8	U.S.A. (others)	1	1	—	2
9	Uganda	—	1	1	2
10	Mali	—	1	—	1
11	Sudan	—	6	1	7
12	Nigeria	—	—	7	7
13	Upper Volta	—	1	—	1
14	S. Africa	—	1	—	1
15	Ethiopia	—	1	—	1
16	Kenya	—	—	1	1
	Total	26	32	22	80

Analyses of variance and covariance of the plot means of the 80 stocks were carried out for all the characters. Using the common error dispersion matrix, the D^2 between all the possible combinations were computed for materials A and B separately (Rao, 1952). Principal component analysis to obtain the first two canonical vectors supplying the best two linear functions serving as major and secondary axes of differentiation was done separately for the two cases (Rao, 1952). The material A and B were grouped into different clusters following Tocher's method (Rao, 1952). The first two canonical roots and

their contribution to the total variation were also worked out. The whole analysis was programmed and carried out on an I.B.M. 1620 computer.

Results

The ANOVA of plot means for ten characters presented in Table 2 revealed highly significant differences among the collections for all the characters excepting rate of 50 per cent. seedling emergence. The 28 physiological and the 16 geographical groups formed ten and six clusters respectively (Table 3). The inter- and intra-cluster divergence for the two cases are presented in Table 4 and the cluster means for the ten characters in Table 6.

Table 2

Analysis of variance for ten characters in 80 genetic stocks of Sorghum

X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
	**	**	**	**	**	**	**	**	**
1·235	869·129	11·215	9210·611	0·368	118·423	30·422	115·365	28·968	0·213
1·288	15·877	1·776	588·182	0·073	7·583	1·722	33·954	2·050	0·043

**Significant at 1 % level.

Top line: due to varieties with 79 d.f., bottom line: due to error with 158 d.f.

PHYSIOLOGICAL GROUPS

The disposition of the ten clusters is illustrated in Figure 1.

The pattern of formation of clusters showed that early, medium and late groups formed two, four and four clusters respectively. It was interesting to note that there was no overlapping of the populations of different physiological groups in the same cluster. However, the medium populations of U.S.A. entered the first cluster which otherwise comprised early types only (Table 3). The early populations of U.S.A. were found in both clusters I and IV while those of Asia were located in the first cluster only from which it could be inferred that the intra-group variation within the early populations of U.S.A. was substantial.

The medium populations of Africa were found in all the three clusters II, V and VI consisting of medium populations only which occupied positions in space almost equidistant from each other (Table 4 and Fig. 1). The medium culture from South Africa formed a separate cluster (Cluster VII) which was quite far from each of the clusters II, V and VI. This again points to the substantial diversity within the populations of medium group from all regions and from Africa, in particular.

TABLE 3

Clusters obtained on the basis of genetic divergence in Sorghum

Cluster	Populations included
	Material A
I	1. India—Early, 2. Japan—Early, 3. China—Early, 5. Mexico—Early, 6. Nebraska—Early, 14. U.S.A.—Medium.
II	9. India—Medium, 10. Japan—Medium, 11. Maryland—Medium 17. Sudan—Medium, 20. Ethiopia—Medium.
III	21. India—Late, 22. Japan—Late, 23. Maryland—Late, 26. Sudan—Late, 27. Nigeria—Late.
IV	4. Maryland—Early, 7. Texas—Early, 8. U.S.A.—Early.
V	13. Texas—Medium, 15. Uganda—Medium, 18. Upper Volta—Medium.
VI	12. Nebraska—Medium, 16. Mali—Medium.
VII	19. South Africa—Medium.
VIII	24. Mexico—Late.
IX	25. Uganda—Late.
X	28. Kenya—Late
	Material B
I	1. India, 2. Japan, 11. Sudan.
II	3. China, 6. Nebraska, 7. Texas, 8. U.S.A.
III	4. Maryland, 5. Mexico, 14. South Africa
IV	9. Uganda, 10. Mali, 12. Nigeria, 13. Upper Volta.
V	15. Ethiopia.
VI	16. Kenya.

The disposition of the late populations in clusters III, VIII, IX and X clearly brought out the uniqueness of other African late cultures from the Uganda and Kenya which formed separate clusters. The Sudan and Nigerian late populations entered the same clusters as the Indian, Japan and Maryland late populations which was unexpected. It was significant that a late population from Mexico formed a separate cluster. The clusters containing late populations were in the same plane far removed from the rest (Fig. 1). The clusters containing early populations were in the lowermost plane while those containing late populations were in the uppermost with those containing medium populations occupying an intermediate position. This obviously supported the choice of preliminary norms made in this study to delineate the different physiological groups.

GEOGRAPHIC DIVERSITY

The 16 categories belonging to 16 different geographic regions in Asia, Africa and America formed six clusters as shown in Figure 2. It was interesting to

TABLE 4

Inter - and intra-cluster divergence (D^2) *in* Sorghum

	I	II	III	IV	V	VI	VII	VIII	IX	X
				Material A						
I	13·77									
II	58·22	12·44								
III	142·41	40·50	16·82							
IV	30·45	88·45	185·90	19·50						
V	74·28	42·19	55·73	94·08	12·68					
VI	92·80	41·93	48·22	105·71	37·30	28·54				
VII	41·70	26·42	99·22	52·22	83·27	77·84	—			
VIII	405·70	200·12	117·89	426·34	250·23	202·38	268·74	—		
IX	143·20	54·98	40·73	161·93	55·16	48·53	108·20	215·02	—	
X	148·75	48·95	39·74	208·21	112·10	102·73	94·49	194·10	67·19	—
				Material B						
I	5·51									
II	47·01	14·20								
III	18·11	31·86	20·66							
IV	35·08	103·72	64·19	24·57						
V	20·38	83·50	37·40	66·33	—					
VI	47·66	149·67	90·56	87·77	47·31	—				

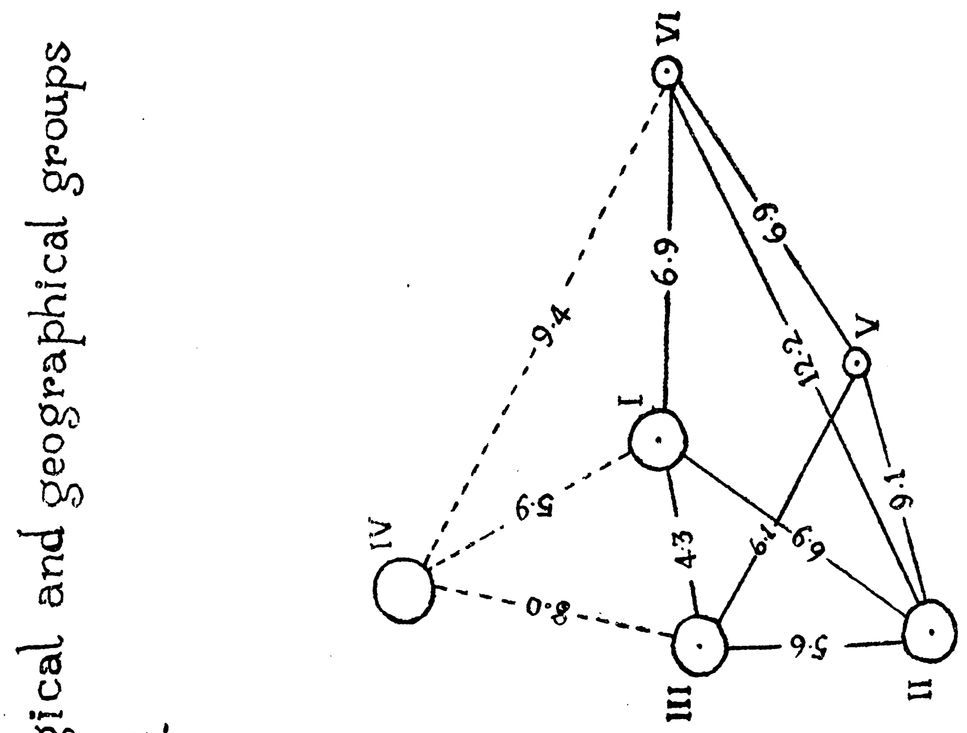

Fig. 2

Genetic Divergence in some physiological and geographical groups of Sorghum

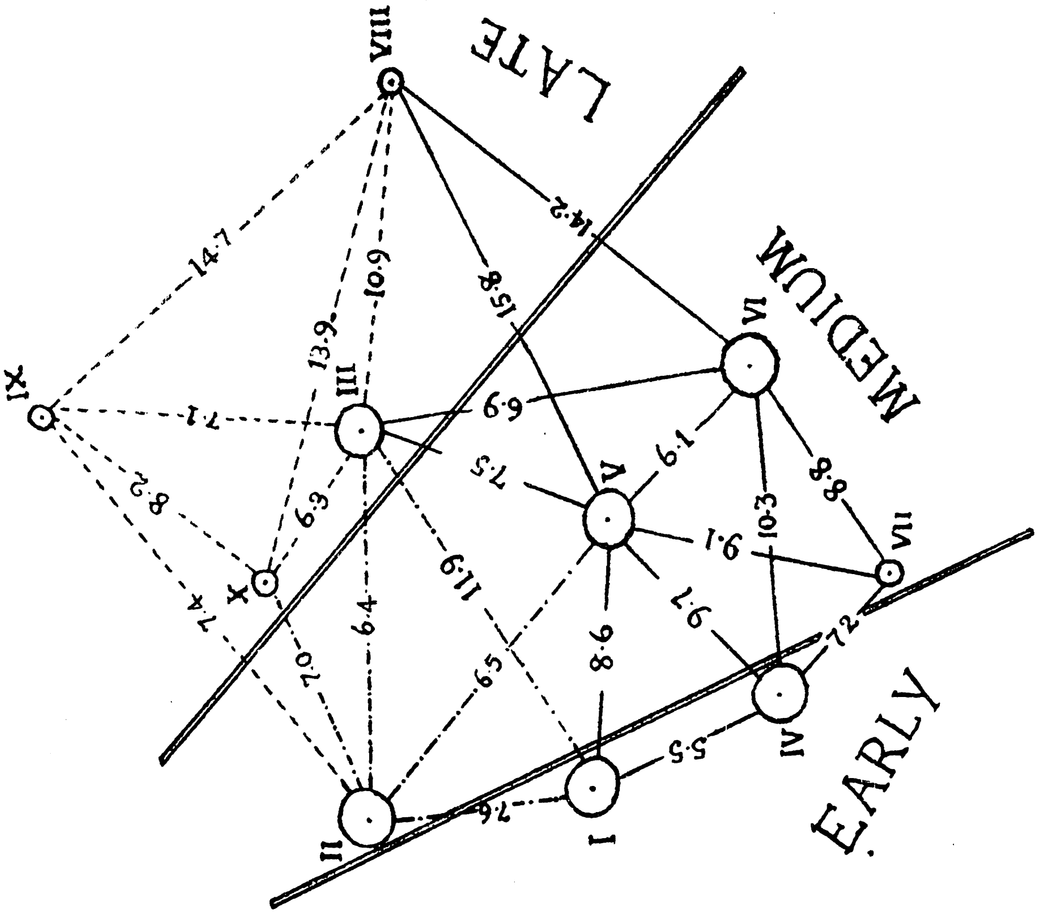

Fig. 1

note that no regular geographic pattern was shown by the clusters. Populations from India and Japan occurred in the same cluster, I. This was also true in the case of early, medium and late populations from these regions. African populations occupied clusters III, IV, V and VI. It was noteworthy that the population from Ethiopia, the centre of origin of *Sorghums*, occupied a separate cluster.

The pattern of the clusters clearly demonstrated that geographic diversity need not be related to genetic diversity. While populations from widely distant geographical regions were found in the same cluster (I, II and III), populations of nearby geographical regions within Africa formed separate clusters (IV, V and VI).

Canonical analysis.—The values of the first two canonical vectors in material A and B are in Table 5. It was observed both in materials A and B, days to 50 per cent. flowering followed by number of leaves per plant and plant height constituted the major axis of differentiation accounting for 63·0 and 54·5 per cent. of total variation respectively, while panicle length, number of leaves per plant, number of whorls on rachis and length of rachis in that order formed the secondary axis of differentiation accounting for 13·1 and 25·7 per cent. of variation respectively. The important contribution of days to 50 per cent. flowering, panicle length, number of leaves per plant and plant height was also clearly brought out in the multivariate analysis of divergence.

Discussion

The material for the study was a stratified sample from the modified nursery consisting of about 950 collections of *Sorghum*, in which material from Africa, Asia, U.S.A. and other countries constituted 25, 40, 25 and 10 per cent. respectively. The present study consisted of a representative sample of 80 populations allocated in the same proportions from the countries included. Hence, it was possible to compare the results for the different geographic regions and physiological groups. The populations included from Ethiopia, Kenya, Mali and other African regions were few in number since the original Modified Nursery itself contained few populations from these regions. Therefore, the conclusions arrived at from the present study are subject to these unavoidable limitations.

This investigation which was mainly undertaken to assess the genetic diversity in three physiological groups and to find out the relationship between geographical and genetic diversity in *Sorghum* brought out some interesting results. Substantial diversity was found among the three physiological groups which permitted a further classification based on genetic divergence. The importance of flowering time as a criterion for physiological grouping was well established by the non-overlapping of the clusters obtained. However, the early, medium and late populations were located in more than one cluster indicating the need for supplementing the physiological grouping by other

TABLE 5

Values of the first two canonical vectors and roots in materials A and B in Sorghum

Material	Vector	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
A	Z_1	−·0411	·8324	·0886	·2758	−·0956	−·0681	·2700	−·0383	·3638	·0277
	Z_2	−·0380	·0607	·2199	−·2308	·1313	·8125	−·2027	·1995	·3458	−·1235
B	Z_1	−·0533	·8553	·1490	·2558	−·0443	·0669	·0447	·0103	·4114	·0077
	Z_2	−·0570	−·1851	·3648	−·2770	·1631	·7510	·0786	·2272	·3006	−·1166

	λ_1	P_1	λ_2	P_2	λ_3	P_3	λ_4	P_4	λ_5–λ_{10}	P_5–P_{10}	Total λ
A	732·1	63·0	152·0	13·1	120·8	10·4	53·9	4·6	101·4	8·9	1160·2
B	220·0	54·5	104·0	25·7	29·2	7·2	20·4	5·0	29·9	7·6	403·5

λ_i—Value of $_i$th canonical root; P_i—Percentage contribution of $_i$th canonical root to total variation.

criteria. On the other hand, assessment of divergence by D^2-statistic was powerful enough to bring out this intra-group divergence in the early, medium and late types.

The flowering pattern of the physiological groups was clearly delineated irrespective of the geographical regions to which they belonged (Table 6). Moreover, a study of the inter-group diversity found in the early, medium and late populations demonstrated that flowering time was adequate as a criterion of physiological grouping as compared to other characters such as height, leaf number etc. (Table 6). The early group (clusters I and IV) was situated in a lower plane and the late group (clusters III, VIII, IX and X) in an upper plane with the medium group occupying an intermediate position (Fig. 1).

Such a regular pattern was absent in the case of populations belonging to different geographical regions (Fig. 2). A study of the clustering pattern in materials A and B clearly indicated that geographic diversity was not related to genetic diversity. While populations from India and Japan which were geographically far apart got grouped together in both A and B, those from Ethiopia and Kenya, which are much nearer, formed separate clusters. Murty, Mathur and Arunachalam (1965) and Murty and Arunachalam (1966) also did not find any relationship between geographic and genetic diversity in *Brassica* and linseed. Dobzhansky (1963) discussed the different mechanisms generating genetic diversity. Timothy (1963) in examining about 12,000 genetic stocks of maize from different geographical regions could not relate the range of variation for different characters in populations from different geographical regions which were not necessarily associated with genetic diversity. Sokal and Thomas (1965) while analysing the geographic variation of the aphid, *Pemphigus populitransversus* in Eastern North America observed that the differences found for a set of characters in populations of different geographic regions were likely to be due to climatic factors, adaptation to which occurred independently in different morphotypes of those populations. Further, they could not separate genetic from environmental covariation at the interlocality level since the organisms would be ecotypically different responding to a complex interaction of genetic and environmental differences. The present study also revealed that factors other than geographic variation could be responsible for the spectrum of diversity found in the genus *Sorghum*. This was confirmed in an investigation by factor analysis (Murty and Arunachalam, 1967) in which it was shown that three factors termed as growth, reproductive and panicle shape factors were mainly responsible for the diversity found in this genus.

An examination of the characters chosen revealed the important contribution of flowering time, number of leaves per plant, height, number of whorls in the rachis and length of the rachis to divergence. The role of flowering time in such studies was established in cross-pollinated crops like *Brassica* and self-pollinated ones like linseed and wheat (Murty *et al.*, 1965; Murty and Arunachalam, 1966). The choice of characters for studies of this type was quite important which was supported by the observations of Sokal (1961) that

TABLE 6

Cluster means for 10 characters

Cluster	Rate of 50% seedling emergence	Days to 50% flowering	Number of whorls on rachis	Height (cm.)	Number of tillers	Panicle length (cm.)	Panicle breadth (cm.)	Length of rachis (cm.)	Number of leaves per plant	Stem diameter(cm.)
				Material A						
I	5·4	70·8	9·1	139·6	1·3	19·2	5·7	15·8	9·9	1·2
II	4·0	90·9	9·2	215·2	1·3	18·4	8·2	15·4	13·3	1·5
III	5·1	108·4	9·5	222·3	1·0	22·1	8·0	18·4	16·0	1·6
IV	5·3	64·0	7·6	149·3	1·6	15·3	9·7	20·3	9·0	1·1
V	4·7	91·0	10·6	147·0	1·7	26·6	8·0	21·9	14·6	1·4
VI	4·3	92·3	11·3	230·1	1·0	31·4	10·3	25·8	13·8	1·3
VII	5·0	76·0	6·9	224·2	1·2	15·8	9·8	11·9	12·9	1·4
VIII	4·3	123·3	12·3	267·5	1·0	17·7	20·4	16·3	16·3	2·0
IX	4·0	105·0	8·5	270·2	2·1	31·4	7·6	25·8	14·1	1·4
X	5·0	112·6	6·2	239·5	1·0	14·6	5·0	12·5	12·2	1·6
				Material B						
I	5·0	91·0	9·0	203·0	1·2	20·0	7·7	16·8	13·1	1·4
II	5·0	81·0	8·5	192·6	1·2	19·9	9·7	15·8	12·3	1·4
III	5·2	70·8	8·5	141·6	1·4	20·5	7·1	16·4	9·7	1·2
IV	4·4	99·1	11·2	197·0	1·4	28·3	8·3	24·1	15·0	1·4
V	4·6	92·3	10·3	242·0	1·5	12·8	7·9	11·4	14·2	1·7
VI	5·0	112·6	6·2	239·5	1·0	14·6	5·0	12·5	12·2	1·6

application of factor analysis to insect behaviour could not achieve the original aim of the investigation since " the choice of experimental variables had been unfortunate ". The contribution of rate of seedling emergence and stem diameter to divergence was negligible which was also confirmed by the size of the coefficients in the first two canonical vectors (Tables 5 and 6).

The diversity in the African material was quite substantial which was expected since Africa is the centre of origin of this genus. The diversity was more in the late than in the early or the medium populations of Africa. Considerable diversity was also found in the Mexican material (obtained from U.S.A.) which could be due to the fact that most of the Mexican collections were introductions from Africa.

In view of the enormous diversity in the African material it is imperative for the breeder to utilize this diversity for the maximum exploitation of hybrid vigour in this crop. The diversity within each maturity group permits a wide range of recombinations for other desirable attributes including yield and quality.

Summary

The diversity in a population consisting of 80 genetic stocks of *Sorghum* from 16 countries was studied utilizing ten characters by multivariate analysis using D^2-statistic. The population was divided into three physiological groups on the basis of days to 50 per cent. flowering, namely, early (up to 75 days), medium (76–99 days) and late (more than 100 days). The study revealed substantial intra- and inter-group diversity. An analysis of geographical and genetic diversity demonstrated that geographic diversity need not be related to genetic diversity. It was found that the amount of diversity in populations from Africa was quite high compared to those from India and Japan which are geographically far distant from each other.

Days to 50 per cent. flowering, number of leaves per plant, height, number of whorls in rachis and length of rachis were found to be important for divergence; this was supported by canonical analysis also.

The inter-group diversity in the early, medium and late populations indicated the adequacy of flowering time as a criterion for physiological grouping.

The African populations were found to possess a wealth of diversity which can be profitably utilized for further breeding work in this crop.

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