Genetic divergence of parents and F_2 segregation in grain Amaranths

Ram Milan Pandey

Department of Cytogenetics, National Botanical Research Institute, Lucknow-226001, India.

Abstract

R.M. Pandey. 2009. Genetic divergence of parents and F_2 segregation in grain amaranths. Cien. Inv. Agr. 36(1):77-84. Twenty six accessions of grain Amaranths (*Amaranthus hypochondriacus*), including both indigenous and exotic introductions, were evaluated in the rabi season (winter crop, November-March). Based on D^2 analysis, the accessions were grouped into eleven clusters. Clusters I, II, and III had seven, four, and three accessions, respectively; clusters VII, VIII, IX and X had only one accession in each case. The accession in cluster V had the greatest divergence, closely followed by those of clusters IV and I. The maximum and minimum divergences were revealed between clusters VIII and XI and between II and VII, respectively. The pattern of clustering did not show any relationship with geographic origin. In a study of pattern of F_2 segregation in 25 crosses involving 10 parents distributed in six clusters, eight crosses showed high breeding potential. The parents involved in these eight potential crosses showed moderate genetic divergence.

Key words: *Amaranthus hypochondriacus*, D^2 statistics, genetic diversity, grain amaranths.

Introduction

Grain amaranths of the genus *Amaranthus* (Family Amaranthaceae), which are under-utilized crops, are native of South and Central America (Sauer, 1967). The major producing countries are in South and Central America and in some countries of Asia and Africa (e.g., China, India, Ethiopia, Kenya and Nepal). The crops are cultivated in India from Kashmir to Arunachal Pradesh. They are protein-rich pseudocereals that hold cultural significance in remote and tribal areas in many parts of India, particularly the Himalayan tract. Grain amaranths in general are high in nutrients, easily digestible, and have sacred ethnic significance. Commercial amaranth production for human consumption is

found in Mexico and South American countries (Berghofer and Sochoenlechner, 2002).

Amaranth crops show wide adaptability and good performance under normal conditions and under stress. Grain Amaranths have a high yield potential and could become very useful cereal crops given sufficient consumer demand. Genetic divergence analysis using D^2 statistics (Mahalanobis, 1936) can be a powerful tool for quantifying the degree of genetic divergence. Minimal information is available regarding the amount of genetic divergence in amaranth grains. Thus, the present investigation was carried out to measure genetic diversity among grain Amaranth, aiming to identify suitable parents for crop improvement by way of hybridization.

Two field experiments were conducted with the following objectives: (i) Experiment I was conducted to evaluate the performance of the 26 accessions of *Amaranthus hypochondriacus* L. with respect to yield and other related traits, and

to assess genetic divergence among them. (ii) Experiment II aimed to study the pattern of F_2 segregation in 25 crosses involving 10 parents, and to determine the respective relationships with genetic diversity of the parents.

Materials and methods

Experiment I had 26 accessions (Table 1) consisting of indigenous and exotic collections. Experiment II had 25 crosses (F_2 s), involving ten accessions, used along with their parents (Table 2). The experiments were conducted in randomized block designs with three replications during the rabi season (Winter crop, November-March) 2005-2006. In both experiments, each plot consisted of four rows, 3.0 m long, with a spacing of 40 x 15 cm.

Observations in Experiment I were recorded from ten randomly chosen plants in the two middle rows for seven quantitative characteristics (Table 1). Sample means were used for multivariate analysis (Mahalanobis, 1936). Group constellations were made following Tocher's method (Rao, 1952), and canonical analysis was done following Johnson and Wichern (1988).

In Experiment II, ten randomly chosen competitive plants from the middle rows of the parents and 20 plants from crosses were sampled for recording observations on five traits, i.e., plant grain yield, panicles per plant, inflorescence length, test weight of 1000 grains, and branches per plant (Table 3). The variations of individual F_2 s for different characteristics were analyzed in terms of range, variance, and phenotypic and genotypic coefficients of variation. The segregation pattern of the crosses was analyzed in terms of the frequency of positive transgressive segregates (FPTS) and the magnitude of transgression. The average positive transgression of a cross was measured as the difference of the mean of the PTS and the better parent mean. The relationship of the parameters of variation for yield in F_2 with parental diversity was measured by D^2 statistics and examined by computing correlation coefficients among all parameters of variability. Furthermore, the performances of the 10 top yielding F_2 s were examined in relation to parental diversity, classified as high,

medium or low, based on their performance for each of the five traits, including yield.

Results and discussion

The accessions differed significantly with respect to the seven traits (days to flowering, plant height, inflorescence length, panicles and branches per plant, test weight grain, and yield per plant), indicating substantial variation in the material (Table 1). The low level of grain yield per plant ranging from 109.2 to 237.5 g in the AG-23 and AG-67 accessions, respectively, is possibly due to the thermo- and photo-period sensitivities of the genotypes under the short day conditions that characterize the rabi season. Considering grain yield and its components, such as number of panicles per plant, inflorescence length and test weight, five accessions (AG-67, AG-101, AG-114, AG-21 and EC-338810) were found to be superior with respect to yield. Among these, three accessions, AG-21, AG-67 and AG-114, are grown in India, particularly in Uttar Pradesh state, while AG-101 is cultivated in Mexico (Table 1).

On the basis of the general means ($\bar{X}\bar{X}$) and standard errors (SE) of each of the seven characteristics, the genotypes were grouped into three categories: high (H) for values more than ($\bar{X}\bar{X} + SE$), medium (M) for values ($\bar{X}\bar{X} \pm SE$), and low (L) for values less than ($\bar{X}\bar{X} - SE$). This classification also indicated considerable genetic variability. The D^2 values ranged from 0.00 to 876.45 (Table 4). Following Tocher's method, the 26 accessions were grouped into eleven clusters (I – XI), six of which were multi-accession clusters (Table 1). These multi-accession clusters included accessions from different countries and states of India, irrespective of geographical distances. On the other hand, the accessions from the same country and state were included in different clusters. In the present study, the three standard accessions AG-21 (a field selection from Barabanki, U.P.), AG-67 (a selection from the cross AG-24 x AG-21) and AG-114 (a selection from the interspecific cross of *A. hybridus* x *A. hypochondriacus* (AG-20) were included in three different clusters (IV, I and II). Thus, the clustering pattern was not related to geographical origin. Rather, the clustering pattern was re-

Table 1. Characteristic means and clustering pattern of 26 amaranth (*Amaranthus hypochondriacus*) accessions used in Experiment I and their geographical source.

Accessions	Time to flowering day	Per plant						Clusters	Source
		Height m	Inflorescence length m	Panicles no.	Branches no.	Grain yield g	Test weight g		
AG-16	50.0 (H) ¹	0.88 (L) ¹	38.0 (L) ¹	37.68 (L) ¹	8.71 (H) ¹	162.23 (L) ¹	0.65 (L) ¹	I	Calicut (Kerala)
AG-19	42.0 (L)	0.92 (L)	50.80 (M)	43.40 (L)	4.90 (L)	135.06 (L)	0.60 (L)	III	Lucknow (Uttar Pradesh)
AG-19/1	44.0 (L)	1.16 (H)	56.15 (H)	38.99 (L)	6.40 (M)	144.00 (L)	0.64 (L)	III	Lucknow (Uttar Pradesh)
AG-19/2	45.0 (M)	1.09 (H)	60.95 (H)	47.30 (L)	8.70 (H)	147.93 (L)	0.73 (H)	III	NBRI (Uttar Pradesh)
AG-20	48.0 (H)	0.91 (L)	48.10 (M)	63.21 (H)	7.30 (H)	160.20 (L)	0.66 (M)	V	Andhra Pradesh
AG-21	53.0 (H)	1.25 (H)	65.50 (H)	65.38 (H)	8.65 (H)	234.48 (H)	0.68 (M)	IV	Barabanki (Uttar Pradesh)
AG-23	41.0 (L)	0.78 (L)	35.60 (L)	42.80 (L)	8.49 (H)	109.23 (L)	0.60 (L)	VII	China
AG-24	48.0 (H)	0.98 (L)	40.06 (L)	36.62 (L)	5.70 (L)	166.55 (L)	0.79 (H)	II	Garhwal (Uttarakhand)
AG-25	38.0 (L)	0.85 (L)	36.18 (L)	53.41 (H)	4.80 (L)	150.50 (L)	0.72 (H)	VIII	Kew (England)
AG-26	42.0 (L)	0.97 (L)	34.60 (L)	28.92 (L)	5.70 (L)	137.52 (L)	0.70 (H)	IX	Mahabaleshwar (Maharashtra)
AG-29	48.0 (H)	0.81 (L)	32.50 (L)	51.12 (M)	6.45 (M)	159.25 (L)	0.60 (L)	I	Samastipur (Bihar)
AG-30	49.0 (H)	0.79 (L)	30.06 (L)	32.62 (L)	5.92 (L)	165.25 (L)	0.65 (M)	I	Mahabaleshwar (Maharashtra)
AG-34	37.0 (L)	0.97 (L)	31.30 (L)	36.56 (L)	6.76 (M)	170.00 (M)	0.59 (L)	I	Orissa
AG-39	43.0 (L)	1.15 (H)	29.04 (L)	29.56 (L)	4.40 (L)	168.20 (L)	0.68 (M)	II	Madhya Pradesh
AG-45	40.0 (L)	1.05 (M)	35.50 (L)	38.16 (L)	7.60 (H)	145.25 (L)	0.70 (H)	II	Gujarat
AG-50	46.0 (M)	1.25 (H)	37.10 (L)	34.56 (L)	5.50 (L)	160.50 (L)	0.70 (H)	II	Palampur (Himachal Pradesh)
AG-63	42.0 (L)	0.96 (L)	56.50 (H)	40.56 (L)	6.30 (M)	162.25 (L)	0.65 (M)	I	Lowbasti (Arunachal Pradesh)
AG-64	40.0 (L)	0.86 (L)	50.00 (M)	34.50 (L)	7.14 (M)	175.56 (h)	0.66 (M)	I	Kenya (East Africa)
AG-66	48.0 (H)	1.10 (M)	39.70 (L)	30.00 (L)	10.64 (H)	180.25 (H)	0.71 (H)	X	Chem (Arunachal Pradesh)
AG-67	50.0 (H)	1.15 (H)	69.60 (H)	67.58 (H)	5.30 (L)	237.45 (H)	0.73 (H)	IV	Lucknow (Uttar Pradesh)
AG-101	51.0 (H)	1.56 (H)	60.80 (H)	71.91 (H)	6.30 (M)	178.50 (H)	0.70 (H)	VI	Rodale Press (Mexico)
AG-103	49.0 (H)	1.37 (H)	62.20 (H)	63.33 (H)	4.40 (L)	170.25 (M)	0.69 (M)	VI	Rodale Press (Mexico)
AG-114	52.0 (H)	1.25 (H)	65.35 (H)	83.32 (H)	6.08 (M)	225.00 (H)	0.65 (M)	IV	NBRI (Uttar Pradesh)
AG-198	48.0 (H)	0.95 (L)	60.55 (H)	48.45 (M)	7.60 (H)	175.60 (M)	0.70 (H)	V	Lucknow (Uttar Pradesh)
AG-199	46.0 (M)	0.92 (L)	58.20 (H)	42.60 (L)	5.50 (L)	0.71 (H)	170.50(M)	I	Lucknow (Uttar Pradesh)
EC-338810	46.0 (M)	0.98 (L)	46.00 (L)	52.30 (H)	4.90 (L)	0.72 (H)	196.36 (H)	XI	Maryland (America)
Mean	45.61	1.04	47.32	46.72	6.54	0.68	168.76		
SE±	0.84	0.03	2.44	2.74	0.31	0	5.51		
CD, 5%	1.72	0.06	5.02	5.63	0.64	0.004	11.33		
1%	2.33	0.08	6.78	7.61	0.86	0.005	15.31		

¹L = Low, M=Medium, H =High, SE = Standard Error, CD = Critical Difference, and Clusters are those groups from which the genotypes belong: Cluster I (AG-16, AG-29, AG-30, AG-34, AG-63, AG-64, AG-199), Cluster II (AG-24, AG-39, AG-45, AG-50), Cluster III (AG-19, AG-19/1, AG-19/2), Cluster IV (AG-21, AG-67, AG-114), Cluster V (AG-20, AG-198), Cluster VI (AG-101, AG-103), Cluster VII (AG-23), Cluster VIII (AG-25), Cluster IX (AG-26), Cluster X (AG-66), and Cluster XI (EC-338810).

Table 2. Frequency of positive transgressive segregates (PTS) and magnitude of transgression for grain yield (g) in F₂ of 25 crosses and parental divergence in grain amaranths (*Amaranthus hypochondriacus*).

Cross	F ₂ range	Better parent mean	Frequency of PTS, %	Mean of PTS	Mean positive transgressive	Mean top 10% plants	D ² between parents ¹
AG-16XAG-19/2	136.21-170.73	159.37	4	148.25	0.33	162.73	3279
AG-16XAG-21	147.84-249.45	229.92	16	198.5	0.41	240.29	3227
AG-16XAG-30	142.52-172.61	164.74	6	184.6	0.37	168.46	1950
AG-16XAG-45	131.28-169.27	157.59	5	200.46	0.42	162.31	7176
AG-16XAG-64	146.10-181.85	172.63	10	198.16	0.46	176.1	3507
AG-21XAG-24	149.27-243.19	215.24	13	225.35	0.38	223.43	905
AG-21XAG-30	147.71-249.32	219.97	28	220.13	0.88	220.72	8086
AG-21XAG-45	135.25-231.21	201.42	30	217.86	0.79	208.35	6395
AG-21XAG-198	162.74-251.37	231.22	33	246.76	0.47	244.78	12067
AG-24XAG-30	153.49-173.11	165.73	7	158.55	0.31	170.12	918
AG-24XAG-34	150.93-179.82	168.91	7	178.26	0.34	171.24	220
AG-24XAG-50	143.43-169.78	162.28	4	164.56	0.25	166.35	653
AG-24XAG-64	147.41-179.20	172.39	8	181.36	0.39	176.49	3034
AG-24XAG-198	147.93-178.96	172.36	10	192.46	0.41	176.28	2188
AG-24XAG-19/2	133.10-169.71	160.35	7	174.38	0.44	164.73	1506
AG-30XAG-19/2	151.24-177.70	168.74	16	165.86	0.42	172.74	3032
AG-30XAG-45	131.43-168.97	161.44	7	159.56	0.37	165.97	978
AG-30XAG-50	139.88-167.43	160.39	4	175.14	0.39	165.18	1215
AG-30XAG-198	149.43-181.21	172.27	19	200.46	0.5	177.2	12139
AG-50XAG-64	151.32-182.12	172.48	13	182.05	0.97	176.98	4038
AG-64XAG-198	160.91-186.24	175.59	17	205.26	0.54	181.42	25452
AG-45XAG-64	131.42-187.16	179.27	19	185.45	0.59	187.22	3284
AG-34XAG-45	130.32-177.64	168.91	13	166.56	0.42	172.87	1956
AG-19/2XAG198	131.39-180.90	172.18	13	174.46	0.41	176.76	247
AG-198XAG-50	147.41-181.32	174.73	12	177.8	0.47	179.39	936

¹D², Mahalanobis D² Tocher's method (Rao, 1952).

lated to selection pressure, which played a large role in determining the genetic closeness/divergence among the accessions. Similar conclusions were made by Murty *et al.* (1965), Murty and Arunachalm (1966), Bhatt (1970), Gaur *et al.* (1978), Kumar (1977), Narayan and Macfield (1976) and Yadav *et al.* (2007), who suggested that selection may cause greater diversity than geographical distance.

In multivariate analysis following the D² technique, the major factors contributing to genetic

divergence were grain yield per plant (48.0%), followed by panicles per plant (23.08%) and inflorescence length (11.69%). According to canonical analysis in Root 1 (Z₁), the important characteristics responsible for genetic divergence in the major axis of differentiation were grain yield per plant (0.7865) followed by panicles per plant (0.4645); and in Root 2 (Z₂) were panicles per plant (0.6184) followed by inflorescence length (0.3001). These results are in complete agreement with the characteristic contributions assessed by D² analysis.

Table 3. Classification of ten top yielding plants for F_2 populations of amaranths (*Amaranthus hypochondriacus*) and ranking of their parents for five economic traits¹.

Cross	Plant grain yield	Panicles /plant	Inflorescence length	Test weight (1000 grains)	Branches /plant
AG-16 x AG-21	L x H	L x H	L x H	L x M	H x H
AG-21 x AG-24	H x L	H x L	H x L	M x H	H x L
AG-21 x AG-30	H x L	H x L	H x L	M x M	H x L
AG-21 x AG-198	H x M	H x M	H x H	M x H	H x L
AG-21 x AG-45	H x L	H x L	H x L	M x H	H x H
AG-45 x AG-64	L x H	L x L	L x M	H x M	H x H
AG-64 x AG-198	H x M	L x M	M x H	M x H	H x M
AG-198 x AG-50	M x L	M x L	H x L	H x H	M x H
AG-50 x AG-64	L x H	L x L	L x M	H x M	H x L
AG-24 x AG-64	L x H	L x L	L x M	H x M	L x M
Frequency of H x L	7	4	5	0	3
(H x M) + (M x L)	3	3		8	4
(H x H) + (M x M) + (L x L)	0	3	1	2	3

¹H, M, and L indicate high, medium and low levels of performance of the parents in respective traits.

Based on the seven characteristics, canonical analysis confirmed the clustering pattern obtained by D^2 statistics. The compositions of the clusters and their respective dispositions remained almost the same (Figure 1).

Figure 1. Two-dimensional representation of divergence of 26 amaranth (*Amaranthus hypochondriacus*) accessions using the first two canonical (Root 1 and Root 2) as coordinates.

The average inter-cluster values ranged from 6.51 to 29.60, while intra-cluster distances varied from 0.000 to 6.50. The average D^2 values within and between clusters revealed that intra-cluster divergence showed a maximum in cluster V ($D^2 = 42.26$), which included two accessions. The inter-cluster distance had a maximum between clusters IV and VII (876.45, Table 4), indicating a greater genetic divergence between the accessions belonging to these categories. The minimum inter-cluster difference was observed between clusters II and IX (42.40, Table 5), indicating that accessions of these clusters had a maximum number of common gene complexes.

Significant differences among the means and variances for individual crosses (F_2 s) were found with respect to grain yield and four of its components, thus offering ample scope for selection for yield improvement. On the basis of mean, variance, heritability and genetic

Table 4. Average inter-cluster and intra-cluster (diagonal) D^2 values in 26 accessions of amaranth (*Amaranthus hypochondriacus*).

Clusters	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
I	35.06	63.99	71.87	365.56	56.71	216.70	182.92	64.61	79.34	61.81	83.40
II		26.20	92.13	443.53	106.77	198.10	197.07	56.00	42.4	57.33	107.03
III			23.98	477.67	69.09	169.90	93.38	76.76	68.87	143.17	181.12
IV				35.85	248.79	225.30	876.45	459.80	650.15	314.03	151.64
V					42.26	116.40	222.43	78.49	148.56	104.54	66.74
VI						25.06	400.42	199.90	298.42	224.53	153.79
VII							0.00	128.63	87.61	319.88	409.72
VIII								0.00	54.50	137.69	113.19
IX									0.00	121.08	209.66
X										0.00	70.80
XI											0.00

advance for yield, five crosses (AG-16xAG-21, AG-21xAG-24, AG-21xAG-30, AG-21xAG-45 and AG-21xAG-198) showed high breeding potential for advancement through pedigree breeding. Furthermore, analysis of the nature of the magnitude of transgressive segregation and mean performance of the top 10% yielding plants, revealed high breeding potential of some crosses, suggesting that selection for yield in F_2 and later generations would result in substantial improvement (Table 2). Average positive transgressions in these crosses were high, ranging from 0.37 in AG-21xAG-24 to 0.88 in AG-21xAG-30.

Significant positive correlations among all parameters of variability and transgressive segregation were observed, except between the frequency of positive transgressive segregates and the mean of positive transgressive segregates (Table 5). On the other hand, negative correlations of parental diversity were not significant with all parameters, except with the mean of positive transgressive segregates. However, these negative associations with F_2 mean, frequency of positive transgressive segregates and mean of the top 10% plants were of moderate magnitude, suggesting that crosses among parents with wide diversity may not generate potential hybrids. Furthermore, the D^2 values between the parents of the five potential crosses ranged from 905 in AG-21xAG-24 to 12067 in

AG-21xAG-198, and were considered to be moderate. Thus, it can be concluded that a cross has a higher potential when the parents are moderately diverse, rather than less or highly diverse (Chauhan and Singh, 1982, and Arunachalam and Bandyopadhyay, 1984).

The breeding potential of crosses in relation to parental performance was assessed by classifying the 26 accessions in Experiment I into high, medium and low on the basis of performance for yield and four of its components. The crosses were classified as high x high, high x medium, high x low, medium x medium, medium x low and low x low combinations. The performances of the 10 top yielding F_2 s were examined in relation to combination of parental performance for each of the five traits. It was observed that seven out of the 10 top yielding crosses (F_2 s) showed high x low combinations for yield; the remaining crosses were either high x medium or medium x low combinations (Table 4). However, high x high, medium x medium and low x low combinations did not give crosses with high yield potential. When the parental combinations of these crosses were considered for all five traits, it was found that 22 out of 50 crosses were either high x medium or medium x low, 19 high x low, and the remaining nine were of similar parental performance. Thus, the results indicated that high x medium and medium x low crosses are better than high x high, medium x

Table 5. Correlation coefficient among the parameters of variability and transgressive segregation for yield in F_2 and their parental diversity (D^2)¹ in grain amaranths (*Amaranthus hypochondriacus*).

Parameter	D^2	F_2 mean	F_2 variance	Frequency of PTS	Mean of PTS	Mean PT	Mean, top 10% plants
Mean of F_2 cross	-0.44						
Variance of F_2 cross	-0.34	0.72**					
Frequency of positive transgressive segregates, PTS	-0.31	0.66**	0.52*				
Mean of positive transgressive segregates	-0.68**	0.56**	0.56**	-0.25			
Average positive transgression, PT	-0.27	0.42**	0.78**	0.36	0.86**		
Mean, top 10% plants	-0.43	0.88**	0.89**	0.65**	0.57**	0.79**	
Genetic advance	-0.35	0.86**	0.94**	0.59**	0.68**	0.83**	0.88**

¹ D^2 Mahalanobis D^2 Tocher's method (Rao, 1952).*, ** Significant at $p=0.05$ and $p=0.01$, respectively.

medium, low x low and even high x low crosses for yield improvement. This supports the results obtained for parental divergence as measured by D^2 statistics.

From the results of the present study, it may be inferred that accessions with moderate genetic divergence, as measured by D^2 values or by *per se* performance with respect to yield and its components, are likely to produce potential crosses. Thus, while choosing parents in a hybridization program for yield improvement, assessment of

yield performance and important yield components of the accessions may be considered as a simpler and more convenient method than complicated statistical analysis for measuring genetic divergence by D^2 statistics.

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Resumen

R.M. Pandey. 2009. Diversidad genética de padres y segregación F_2 de amaranto para grano. Cien. Inv. Agr. 36(1):77-84. Se evaluaron 26 líneas de amaranto para grano (*Amaranthus hypochondriacus*), incluyendo líneas silvestres y exóticas, durante la estación del rabi (cultivo de invierno en noviembre-marzo). Según los análisis D^2 , las líneas se diferenciaron once grupos. Los Grupos I, II y III tuvieron siete, cuatro y tres líneas, respectivamente; los Grupos VII, VIII, IX y X solo tuvieron una línea cada uno. Las líneas en el Grupo V tuvo la mayor divergencia, seguido muy cerca por aquellas de los Grupos IV y I. La divergencia máxima y mínima se obtuvo entre los Grupos VIII y XI, y entre los Grupos II y VII, respectivamente. El padrón de agrupamiento no se relacionó con el origen geográfico de las líneas. Al estudiar el padrón de segregación F_2 , ocho cruzamientos mostraron un alto potencial de diversidad genética, los que derivaron de 25 cruzamientos que comprometieron 10 padres distribuidos en seis Grupos.

Key words: Amaranto grano, *Amaranthus hypochondriacus*, estadística D^2 , diversidad genética.

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