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Estimation of Genetic Parameters, Inter-Relationships and Genetic Divergence of Vegetable Amaranths

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ABSTRACT

In the present study, 11 genotypes of vegetable amaranths collected from different places in the country were evaluated for different horticultural traits for genetic variation, character association, cause-effect analysis and genetic diversity. All nine characters under study differed significantly among the genotypes. High to moderate GCV and PCV values were found for shoot weight per plant, green yield per plant, shoot-leaf ratio, leaf weight, numbers of leaf per plant and plant height. Higher estimates of broad sense heritability coupled with higher genetic advance were observed for green yield per plant, shoot weight per plant, leaf weight per plant, shoot-leaf ratio, numbers of leaf per plant and plant height. Association studies revealed that genotypic correlation coefficients were higher than their phenotypic correlation coefficients in most cases. From the correlation and path analysis, it can be concluded that emphasis should be given to shoot weight per plant, stem diameter and leaf-shoot ratio for selecting high yielding genotypes. Based on the degree of divergence the genotypes were grouped into two clusters. The top two characters which contributed most towards genetic divergence were shoot weight per plant and leaf weight per plant. Genotypes belonging to Cluster I could be regarded as useful sources of gene for improving green yield of vegetable amaranths.

Keywords: vegetable amaranths, genetic variability, correlation, path analysis, genetic divergence

INTRODUCTION

Among leafy vegetables, amaranths (*Amaranthus* sp.) is an annual C_4 plant that grows best at warm temperature and high light intensities (El-Sharkawy *et al*. 1968) and is regarded as the most common crop grown in the Indo-Gangetic plains of eastern India. The cultivated amaranths are utilized as food grains, leafy vegetables, and forage crops in diverse geographic areas, such as America, China, Greece, Italy, Russia, Nepal, and India (Stallknecht and Schulz-Schaeffer 1993). Among the vegetable types, *Amaranthus tricolor* L. occupies a predominant position in India and other prominent cultivated species are *A. blitum* and *A. tristis* (Hazra *et al*. 2011). The superior nutrition (Becker *et al*. 1981; Bressani *et al.* 1987; Prakash and Pal 1991; Bejosano and Corke 1998; Shukla *et al*. 2006), biotic and abiotic stress tolerance, wider adaptability (Lee *et al.* 2008) and increasing rate of consumption have made this Native American crop more attractive for cultivation in developing countries such as India (Ray and Roy 2009). Cultivars vary considerably in plant height, colour of leaf and stem, branching habit, flowering time and response to cutting (Wu *et al.* 2000; Varalakshmi 2004). Despite being monoecious (Mosyakin and Robertson 2003) and self-pollinated (Murray 1940) in nature, varying amounts of out-crossing (Agong and Ayiecho 1991) and interspecific and intervarietal hybridization (Murray 1940; Grant 1959; Rubaihayo 1994) have caused such wide variation in amaranths genotypes. In India, there are many local cultivars of vegetable amaranths belonging to different species grown by the farmers under different vernacular names. The preference of either leaf/or stem type vegetable amaranths by the consumer is different in agro-climatic zones of eastern India. Proper identification of genotype belonging to different species is essential for germplasm conservation. However, exact identification in this crop has been a long-term challenge (Wax 1995).

Yield of a crop is a complex quantitative trait, considerably affected by environment; therefore, selection of genotypes based on yield is not effective. Higher yield can be achieved by improving its component traits. Limited information on interrelationship among traits is available in vegetable type amaranths (Rubaihayo 1994; Shukla and Singh 2000; Shukla *et al.* 2010). However, the studies on genetic variability and heritability and choice of parents for hybridization through D^2 statistics are scanty in the Gangetic alluvium which is the most productive zone of vegetables in eastern India. Green yield can possibly be improved through the knowledge of interrelationship among various agronomic characters along with direct and indirect influence of component characters on yield. This helps in the prediction of correlated response to differential selection and identification of traits that serve as useful indicators of the more important ones under consideration (Johnson *et al*. 1955). Keeping in view the immense importance of the crop, an attempt has been made to determine the extent of genetic variability parameters for important growth characters influencing green yield, their interrelationship and their direct and indirect effect on yield and to analyze the genetic divergence of collected materials based on some important quantitative traits.

MATERIALS AND METHODS

The present investigation was conducted from July to September 2012, at the experimental plot of "C" Block Farm, Bidhan Chandra Krishi Viswavidyalaya, Kalyani, West Bengal, India which is located at 22° 56′ N latitude and 88° 32′ E longitude, with an altitude of 9.75 m above mean sea level. Soil type at the experimental site was sandy loam in texture having pH 6.5. The experimental material consisted of 11 distinct genotypes of vegetable amaranths comprising both leaf and stem types, which are

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Table 1 Genetic variability parameters in different characters of amaranths genotypes.

Characters	Mean	Range	CV (%)	GCV (%)	PCV (%)	GCV: PCV	Heritability (%) in b.s.	GA as % of mean
Plant height (cm)	63.06	36.30 to 97.60	7.96	29.34	29.92	98.0	96.17	59.28
No. of leaves per plant	26.72	15.40 to 45.44	7.65	33.12	34.57	95.0	91.83	65.39
Leaf length (cm)	13.71	11.85 to 14.55	4.21	7.35	12.48	58.0	34.74	8.93
Leaf breadth (cm)	8.94	7.73 to 10.18	3.20	6.15	14.65	41.0	17.62	5.32
Stem diameter (cm)	1.66	1.19 to 2.17	3.05	18.01	19.10	94.0	88.90	34.98
Leaf weight (g) per plant	34.43	12.20 to 55.40	6.62	39.86	40.41	98.0	97.28	80.99
Shoot weight (g) per plant	52.03	13.60 to 104.10	9.80	60.38	60.77	99.0	98.72	123.60
Shoot-leaf ratio	1.46	0.63 to 2.27	4.10	40.10	41.38	96.0	93.89	80.05
Green yield per plant (kg)	9.45	2.88 to 19.58	5.25	58.80	59.92	98.0	96.29	118.86

maintained at All India Coordinated Research Project on Vegetable Crops, BCKV, India.

Field growing and experimental design

Seeds of genotype, after treatment with Thiram (3 g/kg of seed), were sown during the 1st week of July, 2012 and at 1.0 cm deep furrows with 30 cm spacing between rows and 10 cm between plants in plots that were 3.0 × 3.0 m in well prepared land in a randomized block design (RBD) with three replicates. Fertilizer at the rate of 80 kg N, 50 kg P_2O_5 and 50 kg K_2O per hectare was applied pre-plant to the soil. Nitrogen was from urea, P was from single-super phosphate and K was from muriate of potash. Additional nitrogen at 20 kg per ha was applied after 1st cutting at 30 days after sowing (DAS). Management practices for raising good crops were followed as per Chattopadhyay *et al*. (2007). Observation on plant height (cm), numbers of leaf per plant, leaf length (cm), leaf breadth (cm), stem diameter (cm), leaf weight (g) per plant, shoot weight (g) per plant, shoot-leaf ratio, and green yield (kg) per plant were recorded from fifteen randomly selected plants from each genotype. During the crop season two cuttings from 10 cm of the base of the plant were done at 30 DAS and 55 DAS, which commenced from the 1st week of August, 2012. The data on total green yield per plot (kg) was taken comprising the entire cuttings.

Statistical analyses

Data were subjected to analysis of variance (Panse and Sukhatme 1984). The genotypic co-efficient of variation (GCV) and phenotypic co-efficient of variation (PCV) were calculated by the formula given by Burton (1952). For the estimates of heritability (broad sense) and genetic advance as percentage of mean, the method of Hanson *et al*. (1956) was followed. Later correlation coefficients at genotypic and phenotypic levels were calculated (Johnson *et al*. 1955). Path coefficient was done as per Dewey and Lu (1959). D^2 statistic was used for assessing the genetic divergence between populations (Mahalanobis 1936). The grouping of the populations was done by using Tocher's method as described by Rao (1952).

RESULTS AND DISCUSSION

Genetic variability and heritability analysis

The variance analysis showed that genotypes differ significantly among themselves for all the characters under study. The co-efficient of variation (CV) were below 10% for all the characters studied confirming the reliability of the experiment and also suggesting less G × E interactions (**Table 1**). Genetic variability in the base population plays a very important role in any crop improvement programme. The extent of diversity in the germplasm determines the limit of selection for improvement. The characters of economic importance are generally quantitative in nature and exhibit considerable degree of interaction with the environment. Thus, it becomes imperative to compute variability present in the breeding material and its partitioning into genotypic, phenotypic and environmental ones. The relative contribution of genetic variation is best expressed as GCV since this variable takes into account the mean value as well as the unit of measurement into consideration. In the present study, GCV agreed closely with PCV for all the traits except leaf length and leaf breadth but the magnitude of PCV was higher than GCV for all cases (**Table 1**). The small difference between PCV and GCV for almost all the traits indicated that the variability was primarily due to genotypic differences. Similar results have also been reported by previous workers (Shukla *et al*. 2006). The GCV ranged from 6.15% to 60.38%, while PCV ranged from 12.48% to 60.77%. High to moderate GCV and PCV values were found for shoot weight per plant, green yield per plant, shoot-leaf ratio, leaf weight, numbers of leaf per plant and plant height indicating the potential of simple selection for the improvement of these characters. High values of coefficient of variation for foliage yield per plant (Shukla *et al*. 2006) and leaf weight and numbers of leaf per plant (Anuja 2012a) have been observed. On the contrary to the present findings, Shukla *et al*. (2006) also observed low values of coefficient of variation for numbers of leaf per plant and plant height. However, they agreed well with the present findings of low values of coefficient of variation for stem diameter. High proportion of GCV to PCV is desirable in selection process because it depicts that the traits are much under the genetic control rather than the environment (Kaushik *et al*. 2007). The proportion of GCV in PCV observed in this study ranged from 41.0% in leaf breadth to 99.0% in shoot weight per plant. The traits with high proportion of GCV in PCV are reliable for selection in genetic improvement of the amaranths genotypes. Traits (leaf breadth and leaf length) whose expressions were environmentally dependent may not be reliable descriptors for morphological characterization (Samaee *et al*. 2003; Pandey *et al*. 2008).

Traits with high broad sense heritability estimates suggest that they have high genetic potential; the effect of the environment in determining them is low. The values of heritability estimates were high for all the characters except leaf length and breadth and ranged from 17.62% for leaf breadth to 98.72% for shoot weight per plant. High heritability values in vegetable amaranths have also been reported (Revanappa and Madalageri 1998; Shukla *et al*. 2006; Anuja 2012a). These broad sense heritability values were likely to be over estimated as in this calculation it was not possible to exclude variation due to different genetic components and their interactions. The heritability estimates were, therefore, to be considered with these limitations in view.

High heritability alone is not enough to make sufficient improvement through selection generally in advance generations unless accompanied by substantial amount of genetic advance (Bhargava *et al*. 2003). High estimates of broad sense heritability (more than 90%) coupled with high genetic advance (more than 59%) for green yield per plant, shoot weight per plant, leaf weight per plant, shoot-leaf ratio, numbers of leaf per plant and plant height are indicative of additive gene action (Panse 1957) and selection based on these parameters would be more reliable. Previous workers (Shukla *et al*. 2006; Anuja 2012a) also supported our findings for plant height, numbers of leaf per plant and green yield per plant. However, high heritability accompanied (more than 88%) with low genetic advance (less

Table 2 Phenotypic and genotypic correlation coefficients of eight characters of vegetable amaranths.

Characters	No. of leaves per plant	Leaf length	Leaf breadth	Stem diameter	Leaf weight per plant	Shoot weight per plant	Shoot-leaf ratio	Green yield per plant
Plant height	P 0.592	0.459	-0.255	0.784**	0.592	0.931**	0.822**	0.939**
	G 0.621	0.792	-0.616	0.868	0.613	0.955	0.862	0.971
No. of leaves per plant		P 0.183	0.115	0.785**	0.798**	0.693*	0.250	0.626*
		G 0.387	0.200	0.837	0.851	0.723	0.258	0.665
Leaf length			P 0.477	0.407	0.392	0.519	0.331	0.509
			G -0.622	0.721	0.722	0.880	0.505	0.862
Leaf breadth				P -0.076	0.158	-0.105	-0.335	-0.178
				G -0.301	0.483	-0.305	-1.013	-0.515
Stem diameter					P 0.740**	0.824**	0.425	0.808**
					G 0.805	0.881	0.472	0.857
Leaf weight per plant						P 0.794**	0.226	0.721*
						G 0.811	0.262	0.750
Shoot weight per plant							P 0.746**	0.972**
							G 0.753	0.985
Shoot: leaf ratio								P 0.783**
								G 0.796

P = phenotypic correlation coefficients; G = genotypic correlation coefficients; * Significant at 5% level; ** Significant at 1% level.

Table 3 Path-coefficient analysis of the components of green yield per plant at phenotypic level.

Characters	Plant height	No. of leaves per plant	Leaf length	Leaf breadth	Stem diameter	Leaf weight per plant	Shoot weight per plant	Shoot-leaf ratio	Phenotypic correlation with green yield per plant
Plant height	**-0.95409**	-0.05517	0.03646	0.06236	0.50263	0.06664	0.82905	0.48307	0.939**
No. of leaves per plant	-0.59249	**-0.08884**	0.01782	-0.02029	0.48472	0.09248	0.62757	0.14438	0.626*
Leaf length	-0.75565	-0.03440	**0.04603**	0.06295	0.41731	0.07856	0.76383	0.28305	0.509
Leaf breadth	0.58762	-0.01780	-0.02862	**-0.10125**	-0.17449	0.05256	-0.26492	-0.56783	-0.178
Stem diameter	-0.82812	-0.07437	0.03317	0.03051	**0.57909**	0.08751	0.76540	0.26426	0.808**
Leaf weight per plant	-0.58469	-0.07556	0.03325	-0.04895	0.46607	**0.10873**	0.70430	0.14706	0.721*
Shoot weight per plant	-0.91078	-0.06420	0.04048	0.03089	0.51036	0.08818	**0.86847**	0.42197	0.972**
Shoot-leaf ratio	-0.82258	-0.02289	0.02325	0.10262	0.27312	0.02854	0.65406	**0.56030**	0.783**

Residual effect = 0.11; Direct effects = bold diagonal; * Significant at 5% level; ** Significant at 1% level.

than 35%) for stem diameter indicated advancement of non-additive gene action and the high heritability is being exhibited due to favourable influence of the environment rather than genotypes. This result corroborates earlier observations of Shukla *et al*. (2006). Low heritability (less than 40%) and low genetic advance (less than 10%) for leaf length and leaf breadth indicated that selection based on these characters will be less effective. Johnson *et al.* (1955) suggested that high GCV along with high heritability and genetic advance gave better picture for the selection of the genotypes than heritability values alone. Such association was found in traits like shoot weight per plant, green yield per plant and shoot-leaf ratio. The disparities of some results might due to use of genotypes belonging to different genotypes of amaranths tested under different environmental conditions by previous workers.

Character association and cause of association

Mutual association of traits is often expressed by phenotypic, genotypic and environmental correlations (Akinyele and Osekita 2006). Phenotypic correlation is directly proportional to genotypic and environmental correlations. On the other hand, a positive genetic correlation between two desirable traits makes selection easy for improving both traits simultaneously while the reverse is the case for negative correlation. In the present study, genotypic correlation coefficients were higher than corresponding phenotypic correlation coefficients, indicating greater contribution of genotypic factor in the growth and development of these traits association (**Table 2**). Positive and significant ($P \leq 0.05$) phenotypic correlations were observed for plant height (r = 0.939), numbers of leaf per plant (r = 0.626), stem diameter (r = 0.808), leaf weight per plant (r = 0.721), shoot weight per plant (r = 0.972) and shoot-leaf ratio (r = 0.783) with green yield per plant. Significantly positive phenotypic correlations between plant height and foliage yield (Shukla *et al*. 2010; Anuja 2012b) and between leaf weight and stem weight with foliage yield (Anuja 2012b) have been reported. Green yield per plant also exerted positive but insignificant phenotypic correlations with leaf length. On the other hand, negative correlations were exhibited for leaf breadth (r = -0.178) with green yield per plant. It could be implied that amaranths genotypes having narrow leaves would produce more green yield. Anuja (2012b) also observed negative phenotypic correlation between leaf size and foliage yield per plant. Moreover, 10 significantly positive interrelationships were found among the characters studied.

In the present study, the phenotypic correlations were partitioned into direct and indirect effects to identify relative importance of yield component towards green yield of vegetable amaranths. Hence, the direct effect and positive association with green yield per plant was considered essential. Among the eight yield component traits, shoot weight per plant followed by stem diameter and leaf-shoot ratio showed substantial positive direct effects on green yield per plant (**Table 3**) which corroborate the findings of Anuja (2012b) for stem weight and Shukla *et al*. (2010) for stem diameter. The direct selection for these three characters could be beneficial for green yield improvement of vegetable amaranths since these characters also showed significantly positive correlation with green yield per plant. Though leaf weight per plant, plant height and numbers of leaf per plant had significant positive correlation with green yield per plant but their direct effects were negligible/or negative. In such case, direct selection based on these characters will not be very effective. Residual effect was very low (0.11) suggesting inclusion of maximum green yield influencing characters of vegetable amaranths in the present analysis.

Genetic diversity through multivariate analysis

Based on the determination of divergence, all the eleven genotypes could meaningfully be grouped into two clusters (**Table 4**). Cluster I had the maximum of 6 genotypes and Cluster II comprised of 5 genotypes. In general, the pattern

Table 4 Cluster classification and source of collection of eleven genotypes of amaranths.

Cluster number	Name of the genotype
I	AM-1, AM-2, AM-3, AM-4, AM-5, AM-6
II	AM-7, Arun, Arka Shaguna, Jabakusum, Katoa Green

Table 5 Inter- and intra-cluster distances of eleven genotypes of amaranths.

Cluster number	I	II
I	13.201	27.152
II	-	10.712

Table 6 Contribution of different characters (%) towards divergence.

Characters	Number of first rank	(%) contribution
Plant height	1	1.818
No. of leaves per plant	2	3.634
Leaf length	0	0.000
Leaf breadth	1	1.818
Stem diameter	0	0.000
Leaf weight per plant	12	21.818
Shoot weight per plant	31	56.363
Leaf-shoot ratio	3	5.454
Green yield per plant	5	9.090

Table 7 Cluster means of nine characters of amaranths genotypes.

Cluster/ Characters	Plant height	No. of leaves per plant	Leaf length	Leaf breadth	Stem diameter	Leaf weight per plant	Shoot weight per plant	Shoot-leaf ratio	Green yield per plant
I	77.348	32.274	14.289	8.758	1.892	44.069	77.914	1.818	13.938
II	45.930	20.062	13.026	9.158	1.397	22.873	20.973	1.033	4.074

of distribution of genotypes from diverse geographical region into different clusters was random. It might be due to free and frequent exchange of genetic materials among the farmers and breeders of different regions. Differential selection pressure according to regional preference also produced greater uniformity in the germplasm. The absence of relationship between genetic diversity and geographical distance indicates that forces other than geographical origin such as exchange of genetic stock, genetic drift, spontaneous mutation, natural and artificial selection are responsible for genetic diversity. Therefore, the selection of genotypes for hybridization should be based on genetic divergence rather than geographic diversity. Environmental influence on the composition of cluster was also recorded earlier in different self-pollinated crops like tomato (Peter and Rai 1976), pea (Kalloo *et al*. 1980) and cowpea (Hazra *et al.* 1992).

The intra-and inter-cluster distance among 17 genotypes revealed that Cluster I showed the maximum intra-cluster value (13.201) indicating that genotypes belonging in this cluster are diverse (**Table 5**). On the other hand, Cluster II had the minimum intra-cluster value (10.712). At inter-cluster level, the maximum inter-cluster value was observed between cluster I and II (27.152) which indicated that the genotypes included in these clusters had the maximum divergence. Hence, inter-mating between the genotypes included in these clusters was expected to give transgressive segregates in the advanced generation. Kalloo *et al*. (1980) suggested that the crosses between selected varieties from widely separated clusters were most likely to give desirable recombinants.

The top two characters which contributed most towards the genetic divergence (**Table 6**) were shoot weight per plant (56.363%) followed by leaf weight per plant (21.818%). These characters may be used in selecting genetically diverse parents for hybridization programme to exploit either maximum heterosis or to execute efficient selection in the segregating generation.

The cluster means of 11 genotypes (**Table 7**) showed that the mean values of the clusters varied in magnitude for all the eight traits. Considerable distances in cluster mean were observed for the characters like plant height, numbers of leaf per plant, leaf weight per plant, shoot weight per plant and green yield per plant. The maximum cluster mean was observed in Cluster I for all the characters studied except leaf breadth. Therefore, genotypes belonging to this cluster could be used as donor parent for improving green yield of vegetable amaranths.

CONCLUSIONS

From the study, it can be concluded that attention should be paid on selection based on shoot weight per plant, stem diameter and leaf-shoot ratio for green yield improvement of vegetable amaranths. Genotypes belonging to Cluster I could be utilized in breeding programme for improving green yield of vegetable amaranths.

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REFERENCES

Agong SG, Ayiecho PO (1991) The rate of out-crossing in grain amaranths. *Plant Breeding* **107 (2)**, 156-160

Akinyele BO, Osekita OS (2006) Correlation and path coefficient analyses of seed yield attributes in okra (*Abelmoschus esculentus* (L.) Monech). *African Journal of Biotechnology* **5**, 1330-1336

Anuja S (2012a) Genetic variability studies in vegetable amaranthus. *Crop Research* **43 (1, 2 & 3)**, 102-105

Anuja S (2012b) Correlation and path analysis in amaranthus. *Crop Research* **43 (1, 2 & 3)**, 106-111

Becker R, Wheeler EL, Lorenz K, Stafford AE, Grosjean OK, Betschart AA, Saunders RM (1981) A compositional study of amaranth grain. *Journal of Food Science* **46**, 1175-1180

Bejosano FP, Corke H (1998) Protein quality evaluation of *Amaranthus* wholemeal flours and protein concentrates. *Journal of the Science of Food and Agriculture* **76**, 100-106

Bhargava AS, Shukla RS, Katiyar, Ohri D (2003) Selection parameters for genetic improvement in *Chenopodium* grain on sodic soil. *Journal of Applied Horticulture* **5 (1)**, 45-48

Bressani R (1990) Grain amaranth: Its chemical composition and nutritive value. In: *Proceedings of the 4th Amaranth Symposium*, Minnesota, Minnestota Agricultural University, Minnestosa, Saint Paul

Bressani R, Gonzales JM, Zuniga J, Brauner M, Elias LG (1987) Yield, selected chemical composition and nutritive value of 14 selections of amaranth grain representing four species. *Journal of the Science of Food and*

Agriculture **38**, 347-356

Burton GW (1952) *Quantitative Inheritance in Grasses*, National Publishing Co., Washington D.C., New York.

Chattopadhyay A, Dutta S, Bhattacharya I, Karmakar K, Hazra P (2007) Leaf amaranth. In: *Technology for Vegetable Crop Production*, All India Coordinated Research Project on Vegetable Crops, Nadia, West Bengal, India, pp 218-222

Dewey DR, Lu HK (1959) A correlation and path-coefficient analysis of components of crested wheat grass production. *Agronomy Journal* **51**, 515-518

El-Sharkawy MA, Loomis RS, Williams WA (1968) Photosynthetic and respiratory exchanges of carbon dioxide by leaves of the grain amaranth. *Journal of Applied Ecology* **15**, 243-251

Grant WF (1959) Cytogenetic studies in *Amaranthus* III. Chromosome numbers and phylogenetic aspects. *Canadian Journal of Genetics and Cytology* **1**, 313-328

Hanson CH, Robinson HF, Comstock RE (1956) Biometrical studies of yield in segregating population of Korean lespedza. *Agronomy Journal* **48**, 268-272

Hazra P, Chattopadhyay A, Karmakar K, Dutta S (Eds) (2011) *Modern Technology in Vegetable Production*, New India Publishing Agency, New Delhi, India, 480 pp

Hazra P, Som MG, Das PK (1992) Selection of parents for vegetable cowpea breeding by multivariate analysis. *Vegetable Science* **19**, 166-173

Johnson HW, Robinson RW, Comstock RE (1955) Estimate of genetic and environmental variability in soybean. *Agronmy Journal* **47**, 314-318

Kalloo G, Singh VP, Dudi BS, Pratap PS (1980) Analysis of variation and genetic diversity in garden pea (*Pisum sativum* L.). *Haryana Agricultural University Journal of Research* **10**, 540-546

Kaushik N, Kumar K, Kumar S, Kaushik N, Roy S (2007) Genetic variability and divergence studies in seed traits and oil content of jatropha (*Jatropha curcas* L.) accessions. *Biomass and Bioenergy* **31**, 497-502

Lee JR, Hong GY, Dixit A, Chung JW, Ma KH, Lee JH, Kang HK, Cho YH, Gwag JG, Park YJ (2008) Characterization of microsatellite loci developed for *Amaranthus hypochondriacus* and their cross-amplifications in wild species. *Conservation Genetics* **9**, 243-246

Mahalanobis P (1936) On the generalized distance in statistics. *Proc National Institute of Science* (India) **12**, 49-55

Mosyakin SL, Robertson KR (2003) Amaranthus. In: *Flora of North America. North of Mexico*, Oxford University Press, New York, USA, pp 11-21

Murray MJ (1940) The genetics of sex determination in the family *Amaranthaceae*. *Genetics* **25**, 409-431

Pandey S, Kumar S, Rai M, Mishra U, Singh M (2008) Assessment of genetic diversity in Indian ash gourd (*Benincasa hispida*) accessions using RAPD markers.1. Cucurbitaceae 2008 (genetics and breeding of Cucurbitaceae). In *Proceedings of the IXth EUCARPIA*, May 21-24th, 2008, INRA, Avignon, France, pp 59-66

Panse VG (1957) Genetics of quantitative characters in relation to plant breeding. *Indian Journal of Genetics and Plant Breeding* **17**, 318-328

Panse VG, Sukhatme PV (1984) *Statistical Methods for Agriculture Workers*, Indian Council of Agricultural Research, New Delhi, India

Peter KN, Rai B (1976) Genetic divergence in tomato. *Indian Journal of Genetics* **36**, 379-383

Prakash D, Pal M (1991) Nutritional and anti-nutritional composition of vegetable and grain amaranth leaves. *Journal of the Science of Food and Agriculture* **57**, 573-583

Rao CR (1952) *Advanced Statistical Methods in Biometrics*, John Willey and Sons Inc., New York

Ray T, Chandra RS (2009) Genetic diversity of *Amaranthus* species from the Indo-Gangetic plains revealed by RAPD analysis leading to the development of ecotype-specific SCAR marker. *Journal of Heredity* **100**, 338-347

Revanappa, Madalageri BB (1998) Genetic variability studies regarding quantitative traits in amaranthus. *Karnataka Journal of Agricultural Science* **11**, 139-142

Rubaihayo E (1994) Indigenous vegetables (local) in Uganda. In: *Proceedings of the African Crop Science Conference* **1**, 120-124

Samaee SM, Shobbar ZS, Ashrafi H, Hosseini-Mazinani M (2003) Molecular characterization of olive germplasm in iran by use of random amplified polymorphic DNA (RAPD): Correlation with phenotypic studies. *Acta Horticulturae* **623**, 169-175

Shukla S, Singh SP (2000) Studies on genetic parameters in vegetable amaranth. *Indian Journal of Genetics and Plant Breeding* **54**, 133-135

Shukla S, Singh SP (2002) Varietal performance and foliage yield in vegetable amaranth. *South Indian Horticulture* **50**, 241-244

Shukla S, Bhargava A, Chatterjee A, Singh SP (2004) Estimates of genetic parameters to determine variability for foliage yield and its different quantitative and qualitative traits in vegetable amaranth (*A. tricolor*). *Journal of Genetics and Breeding* **58**, 169-176

Shukla S, Bhargava A, Chatterjee A, Srivastava A, Singh SP (2006) Genotypic variability in vegetable amaranth (*A. tricolor*) for foliage yield and its contributing traits over successive cuttings and years. *Euphytica* **151**, 103-110

Shukla S, Bhargava A, Chatterjee A, Srivastava J, Singh N, Singh SP (2006) Mineral profile and variability in vegetable amaranths (*Amaranthus tricolor*). *Plant Foods for Human Nutrition* **61**, 23-28

Shukla S, Bhargava A, Chatterjee A, Pandey AC, Kumar A (2010) Genetic interrelationship among nutritional and quantitative traits in the vegetable amaranth (*Amaranthus tricolor* L.). *Crop Breeding and Applied Biotechnology* **9**, 16-22

Stallknecht GF, Schulz-Schaeffer JR (1993) Amaranth rediscovered. In: Janick J, Simon JE (Eds) *New Crops*, Wiley, New York, pp 211-218

Varalakshmi B (2004) Characterisation and preliminary evaluation of an vegetable amaranth (*Amaranthus* sp.) germplasm. *Plant Genetic Resources Newsletter* **137**, 55-57

Wax LM (1995) Pigweeds of the Midwest - distribution, importance, and management. *Proceedings of the Iowa Integrated Crop Management Conference* 7, 239-242

Wu H, Sun M, Yue S, Sun H, Cai Y, Huang R, Brenner D, Corke H (2000) Field evaluation of an *Amaranthus* genetic resource collection in China. *Genetic Resources and Crop Evolution* **47**, 43-53