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Genetic interrelationship among nutritional and quantitative traits in the vegetable amaranth

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ABSTRACT - *The present investigation was conducted to elucidate the interrelationship among various agronomic and quality traits and their direct and indirect effect on foliage yield in 39 distinct cultivars of vegetable amaranth (A. tricolor). Among the agronomic traits, plant height and number of inflorescence exhibited significant positive association with foliage yield, while chlorophyll a, chlorophyll b, carotenoid, fiber and ascorbic acid were positively correlated with foliage yield. Chlorophyll a and chlorophyll b exhibited significant positive association with carotenoid, fiber and ascorbic acid. Ascorbic acid was positively correlated with fiber and carotenoid. Protein was associated with plant height, branches per plant and 500 seed weight. Chlorophyll a, carotenoid and inflorescence length revealed high positive direct effect on foliage yield, while branches plant^{-1}, leaf size, seed yield, chlorophyll b, moisture content and ascorbic acid showed negative path coefficient with foliage yield. Suitable traits have been marked out to enhance foliage yield in vegetable amaranth.*

Key words: *A. tricolor*, genetic association, carotenoid, protein, ascorbic acid.

INTRODUCTION

The family Amaranthaceae consists of hardy, weedy, herbaceous, fast growing cereal like plants (Opute 1979). Amaranth (also known as pigweed) is an important member of this family whose grain and leaves are utilized as food by humans as well as animals (Saunders and Becker 1984, Tucker 1986). The nutritional composition of both grain and vegetable amaranth has been previously studied (Teutonico and Knorr 1985, Bressani 1990, Shukla et al. 2006a). Vegetable amaranth (*A. tricolor*) has been rated equal or superior in taste to spinach and is considerably higher in carotenoids (90-200 mg kg^{-1}), protein (14-30% on dry weight basis) and ascorbic acid (about 28 mg 100g^{-1}) (Wu-Leung et al. 1968, Makus 1990, Prakash and Pal 1991, Shukla et al. 2006b). It is an under exploited plant with promising economic value, which has been recognized by the USA National Academy of Sciences (1984). The main vegetable type (*A. tricolor*) seems to have originated in south Asia (Grubber and Van Stolen 1981) and then spread throughout the tropics and temperate areas (Martin and Telek 1979). *A. tricolor* has been extensively cultivated, primarily in southern china (Martin and Ruberte 1979). Vegetable amaranths are predominately self pollinated due to the presence of a number of male flowers per glomerule, terminal inflorescence and development of axillary glomerules (Rajan and Markose 2007).

In spite of the fact that vegetable amaranth is used as a cheap source of protein and staple food crop in many parts of the world, negligible efforts have been made for its genetic improvement (Shukla and Singh

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2000 and 2002, Shukla et al. 2004). Although genetic variability and interrelationship studies among traits are available in other crops (Sukhchain et al. 1997, Lopez et al. 1998, Finne et al. 2000), such reports on vegetable amaranth are rare. Foliage yield can possibly be improved through the knowledge of interrelationship among various agronomic and quality characters along with direct and indirect influence of component characters on yield. This helps in the prediction of correlated response to differential selection and detection 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 for the first time to work out the interrelationships among different agronomic and quality traits in vegetable amaranth. The direct and indirect effects of different agronomic and quality traits on foliage yield were also studied which may help in determining the component traits affecting yield potential. Based on this information an effective selection program can be proposed for the genetic improvement of the crop.

MATERIAL AND METHODS

The present investigation was conducted from March to August 2003, at the experimental plot of National Botanical Research Institute, Lucknow (NBRI), India. The experimental material consisted of 39 distinct cultivars of vegetable amaranth (*A. tricolor*), which are maintained at N.B.R.I., Lucknow, India.

Experimental design

The crop was sown in a randomized block design (RBD) with three replicates. The plot size for each cultivar was 1 m^2, with a row-to-row and plant-to-plant distance of 25 cm and 10 cm, respectively. During crop season, normal cultural practices were followed. Five plants were randomly selected from each replicate and were tagged before obtaining agronomical data. Data was recorded from these plants in each replicate for seven quality characters viz. protein content (100 mg g^{-1}), ascorbic acid content (100 mg g^{-1}), chlorophyll a (mg g^{-1}), chlorophyll b (mg g^{-1}), carotenoids (mg g^{-1}), fiber content (%), and moisture content (%). Data was also recorded for seed yield (g $plant^{-1}$) and its seven other contributing agronomic traits viz. leaf area (cm^2), branches $plant^{-1}$, leaves $plant^{-1}$, stem diameter (cm), plant height (cm), inflorescence length (cm) and 500 seed weight (g). All the data was taken separately for each strain. Simultaneously, another experiment was conducted comprising the 39 cultivars in a randomized block design with three replicates to record the total foliage yield of each strain. The plot size was 2 m^2 for each strain, with row-to-row distance 25 cm and plant-to-plant 15 cm. During the crop season four foliage cuttings were done at the interval of 15 days, which commenced from the 3rd week of sowing. The data on total foliage yield $plot^{-1}$ (kg) was taken comprising the entire cuttings. Moisture content was estimated on the ratio of fresh leaves wt. and 100 ^{0}C dry wt. The extraction and estimation of chlorophyll a, chlorophyll b and carotenoid was done according to Jensen (1978). Protein content in green leaves was estimated for each cutting following Peterson (1977). Ascorbic acid content was estimated as per the method suggested by Glick (1954), while fiber content was estimated according to Watson (1994).

Statistical analysis

The experimental data was compiled by taking the mean of each strain for all the three replicates and were subjected to further statistical and biometrical analysis. Genotypic and phenotypic correlation estimates were worked out following the formula proposed by Robinson et al. (1951). Path coefficient was carried out following Dewey and Lu (1959), where foliage yield was assumed to be dependent variable (effect) that is influenced by the independent variables (causes) directly, as well as indirectly through other characters. The estimates of genotypic and phenotypic correlation were calculated by the following formulas:

$$r(x,y) = Cov(x,y)/\sqrt{\sigma x^2\ \sigma y^2}$$

where

$r(x,y)$ is genotypic correlation between variables x and y

$Cov(x,y)$ is the genotypic covariance between the two variables

σx^2 is the genotypic variance of the variable x; and

σy^2 is the genotypic variance of the variable y

Phenotypic variance ($\sigma^2 p$) = genotypic variance + error variance

RESULTS AND DISCUSSION

The analysis of variance for nine quantitative and seven quality traits are presented in Table 1. The Anova for the 39 cultivars was significant for all the characters at 1% level of significance while no significant differences were observed within replication which suggested that the cultivars have enough variability for all the traits to carry out further genotypic studies.

The genotypic correlation coefficient between different characters pair was similar in sign and nature to the corresponding phenotypic correlation coefficient (Table 2). However, genotypic correlations were generally higher in magnitude than the corresponding phenotypic correlation. The higher magnitude of genotypic correlation than respective phenotypic correlations between various characters in amaranth have also been reported earlier (Shukla and Singh 2002). In the present study, foliage yield showed significant positive (genotypic and phenotypic) association with plant height (0.41, 0.33), chlorophyll a (0.61, 0.53), chlorophyll b (0.66, 0.56), carotenoid (0.61, 0.47), fiber content (0.76, 0.49) and ascorbic acid content (0.47, 0.39) which indicated that selection based on these parameters would considerably enhance foliage yield. Plant height had significant positive association with stem diameter (0.27), leaves plant^{-1} (0.25), leaf size (0.53), 500 seed weight (0.35), seed yield (0.28), ascorbic acid (0.25) and protein content (0.28) suggesting that these traits may contribute substantially to increase plant height. Stem diameter affects the primary branches and seed yield, as the association of this was positive and significant with these traits at both genotypic and phenotypic levels. It is interesting to note that stem diameter exhibited significantly negative correlation with all the qualitative characters except moisture and protein content. Similarly branches plant^{-1} had negative correlation with all the qualitative characters except moisture and protein content. However branches plant^{-1} was positively correlated with leaves per plant (0.51), seed yield (0.24), 500 seed weight (0.28), moisture (0.52) and protein content (0.30). Leaves plant^{-1} showed significant negative correlation with fiber content (-0.43) but positive significant correlation with any of the traits was not noticed.

Inflorescence length and leaf size were positively correlated with 500 seed weight and seed yield, while inflorescence length had positive correlation with leaf size (0.24). Leaf size revealed negative correlation with chlorophyll b (-0.30), carotenoid (-0.28) and fiber content (-0.34).

500 seed weight showed significant positive correlation with seed yield (0.281), ascorbic acid (0.24) and protein content (0.37). However, seed yield was negatively correlated with chlorophyll b (-0.31), fiber (-0.46) and ascorbic acid content (-0.25). Chlorophyll a and chlorophyll b exhibited significant positive association with carotenoid (0.92, 0.90), fiber (0.64, 0.79)

Table 1. Analysis for variance for nine agronomic and seven quality characters in vegetable Amaranth

Sl. No.	Characters	Mean Squares		
		Replications (df 2)	Genotypes (df 38)	Error (df 76)
1	Plant height (cm)	8.988	622.035**	94.729
2	Stem diameter (cm)	0.024	0.396**	0.075
3	Branches plant^{-1}	6.396	76.767**	22.694
4	Leaves plant^{-1}	9.874	132.439**	26.850
5	Inflorescence length (cm)	26.973	200.498**	22.670
6	Leaf size (cm^2)	291.779	468.101**	68.063
7	500 seed weight (g)	0.001	0.007**	0.001
8	Seed yield (g)	0.364	1.411**	0.190
9	Chlorophyll a (mg g^{-1})	0.036	0.821**	0.036
10	Chlorophyll b (mg g^{-1})	0.002	0.110**	0.005
11	Carotenoid (mg g^{-1})	0.396	0.491**	0.449
12	Fiber (%)	0.614	1.709**	0.165
13	Moisture (%)	74.790	8.734**	5.744
14	Ascorbic acid (mg 100g^{-1})	1142.988	3937.756**	583.924
15	Protein (mg 100g^{-1})	0.027	0.017**	0.004
16	Foliage yield (kg)	1.739	2.276**	0.514

** Significance at 1%

Table 2. Genotypic and phenotypic (in brackets) correlation among various nutritional and agronomic traits in vegetable Amaranth

Characters	Plant height	Stem diameter	Branches plant^{-1}	Leaves plant^{-1}	Inflore-scence length	Leaf size	500 Seed weight	Seed Yield	Chloro-phyll a	Chloro-phyll b	Carotenoid	Fibre	Moisture	Ascorbic acid	Protein
Foliage yield (kg plot^{-1})	0.414**	-0.214*	-0.378**	-0.209	0.274*	-0.064	0.216	-0.013	0.611**	0.658**	0.614**	0.755**	-0.397**	0.472**	0.175
	(0.331**)	(-0.209)	(-0.282*)	(-0.144)	(0.189)	(-0.074)	(0.172)	(-0.018)	(0.529**)	(0.563**)	(0.471**)	(0.486**)	(-0.286**)	(0.392**)	(0.139)
Plant height (cm)		0.270*	0.159	0.252*	0.131	0.532**	0.353**	0.280*	0.101	-0.025	-0.014	0.018	-0.507**	0.245*	0.276*
		(0.279*)	(0.204)	(0.245*)	(0.111)	(0.489**)	(0.305**)	(0.278*)	(0.097)	(-0.020)	(-0.022)	(-0.010)	(-0.262*)	(0.220*)	(0.223*)
Stem diameter (cm)			0.572**	-0.045	0.195	0.005	0.161	0.497**	0.617**	0.660**	0.532**	0.466**	0.729**	-0.561**	0.123
			(0.492**)	(0.027)	(0.223*)	(0.073)	(0.142)	(0.475**)	(-0.542**)	(-0.564**)	(-0.448**)	(-0.336**)	(0.391**)	(0.474**)	(0.084)
Branches plant^{-1}				0.505**	0.159	0.004	0.278*	0.238*	-0.481**	-0.587**	-0.633**	-0.800**	0.518**	-0.492**	0.295*
				(0.511**)	(0.143)	(0.044)	(0.254*)	(0.264*)	(-0.407**)	(-0.453**)	(-0.507**)	(-0.460)	(0.251*)	(-0.369**)	(0.183)
Leaves plant^{-1}					0.168	0.155	0.093	0.106	0.001	-0.130	-0.168	-0.430**	-0.031	0.172	0.178
					(0.157)	(0.149)	(0.081)	(0.142)	(-0.020)	(-0.108)	(-0.158)	(-0.267*)	(-0.060)	(0.161)	(0.115)
Inflorescence length (cm)						0.239*	0.291	0.328**	0.029	-0.131	-0.242*	-0.154	0.170	0.138	0.187
						(0.226*)	(0.273*)	(0.313**)	(-0.024)	(-0.105)	(-0.225*)	(-0.111)	(0.112)	(0.111)	(0.139)
Leaf size (cm^2)							0.275*	0.272*	-0.111	-0.302**	-0.279*	-0.343**	0.183	0.110	0.059
							(0.240*)	(0.266*)	(-0.103)	(-0.266*)	(-0.235*)	(-0.214)	(0.084)	(0.105)	(0.040)
500 seed wt. (g)								0.281*	0.204	0.133	0.130	0.161	-0.269*	0.241*	0.374**
								(0.290**)	(0.193)	(0.136)	(0.115)	(0.112)	(-0.170)	(0.231*)	(0.310**)
Seed yield (gm)									-0.199	-0.314**	-0.087	-0.459**	0.385**	-0.250*	0.167
									(-0.178)	(-0.283**)	(-0.095)	(-0.295**)	(0.208)	(-0.198)	(0.121)
Chlorophyll a (mg g)$^{-1}$										0.969**	0.924**	0.637**	-1.050	0.779**	-0.116
										(0.945**)	(0.845**)	(0.466**)	(-0.654**)	(0.732**)	(-0.084)
Chlorophyll b (mg g)$^{-1}$											0.903**	0.790**	-0.975**	0.685**	-0.116
											(0.831**)	(0.573**)	(-0.636**)	(0.647**)	(-0.112)
Carotenoid (mg g)$^{-1}$												0.664**	-0.756**	0.706**	0.017
												(0.464**)	(-0.489**)	(0.639**)	(-0.018)
Fiber (%)													-0.574**	0.387**	-0.150
													(-0.251*)	(0.284**)	(-0.123)
Moisture (%)														-0.938**	-0.056
														(-0.631**)	(-0.094)
Ascorbic acid (mg 100g)$^{-1}$															0.150
															(0.094)
Protein (mg 100g)$^{-1}$															

* and **, Significance at 5 and 1% respectively

and ascorbic acid content (0.78, 0.69), while both of the chlorophylls revealed negative correlation with moisture content. However chlorophylls a and b were positively correlated with each other. Carotenoid and fiber content showed negative correlation with moisture content, but had positive correlation with ascorbic acid both at genotypic and phenotypic levels. Ascorbic acid was positively correlated with fiber (0.39) and carotenoid content (0.71). Protein content was associated with plant height (0.28), branches per plant (0.30) and 500 seed weight (0.37). From the correlation study, it is evident that there is no way in which foliage yield can be changed without changing one or more of the characters. Moreover all changes in the components would not be expressed in changes in yield (as components may tend to counter balance each other), but all changes in foliage yield would be accompanied by changes in one or more of the characters. Path coefficient analysis is used to divide the observed correlation coefficient into direct and indirect effects of yield component that provide a more obvious picture of the character association for formulating efficient selection strategy. Path analysis differs from simple correlation in that as it points out the causes and their relative importance where as, the latter measures simply the mutual association ignoring the causation (Jaiswal and Gupta 1967).

Path coefficient analysis was carried out using genotypic correlation coefficient among various characters to estimate the direct and indirect effect of 15 characters of manifestation on foliage yield (Table 3 and Figure 1). The chlorophyll a (3.87), carotenoid (1.23) and inflorescence length (0.82) exerted very high positive direct effect on foliage yield. The protein (0.61), plant height (0.12), stem diameter (0.21), leaves per plant (0.45), 500 seed weight (0.47)and fiber content (0.51) also had substantial positive direct effects on foliage yield. The characters branches per plant (-1.22), leaf size (-0.27), seed yield (-0.82), chlorophyll b (-4.54), moisture content (-0.81) and ascorbic acid (-2.26) showed negative direct effect on foliage yield. However, except for chlorophyll b and ascorbic acid all of these characters also exhibited negative genotypic correlation, which indicated that these characters were inversely correlated. It is surprising that all the qualitative components except moisture content showed a positive genotypic correlation with foliage yield and was indirectly affected via other components. The ascorbic

Table 3. Direct (diagonal) and indirect effects of different agronomic and quality characters on foliage yield at genotypic levels in different cuttings of vegetable amaranth

Characters	Plant height	Stem diameter	Branches plant^{-1}	Leaves plant^{-1}	Inflore-scence length	Leaf size	500 Seed weight	Seed Yield	Chloro-phyll a	Chloro-phyll b	Carotenoid	Fibre	Moisture	Ascorbic acid	Protein	Genotypic correlation foliage yield
Plant height (cm)	**0.115**	0.031	0.018	0.029	0.015	0.060	0.041	0.032	0.011	-0.022	0.011	0.012	0.058	0.028	0.031	0.414**
Stem diameter (cm)	0.057	**0.212**	0.121	-0.010	1.041	0.001	0.034	0.105	-0.131	-0.140	0.112	-0.099	0.154	-0.119	0.026	-0.220*
Branches plant^{-1}	-0.194	-0.695	**-1.215**	-0.614	0.193	-0.005	-0.338	-0.289	0.585	-0.713	0.770	0.973	-0.633	0.598	-0.358	-0.379**
Leaves plant^{-1}	0.112	0.020	0.225	**0.446**	0.075	0.069	0.042	0.047	0.010	-0.058	0.075	-0.191	-0.014	0.076	0.079	-0.209
Inflorescence length (cm)	0.108	0.161	0.130	0.138	**0.821**	0.960	0.239	0.269	-0.023	-0.087	0.199	-0.127	0.014	0.113	0.159	0.274*
Leaf size (cm^2)	-0.143	-0.001	-0.001	-0.041	-0.064	**-0.269**	-0.074	-0.073	0.030	0.101	0.075	0.092	-0.052	-0.029	-0.016	-0.064
500 seed wt. (g)	0.059	0.027	0.046	0.015	0.049	0.046	**0.169**	0.047	0.034	0.022	0.022	0.027	-0.045	0.040	0.063	0.216
Seed yield (gm)	-0.229	-0.406	-0.194	-0.086	-0.268	-0.233	0.230	**-0.817**	0.142	0.256	0.071	0.374	-0.314	0.204	-0.132	-0.013
Chlorophyll a (mg g)$^{-1}$	0.393	-2.366	-1.859	0.004	-0.112	-0.431	0.788	-0770	**3.865**	3.748	3.573	2.463	-4.059	3.014	-0.448	0.611**
Chlorophyll b (mg g)$^{-1}$	0.166	2.997	2.664	0.590	0.595	1.374	-0.602	1.425	4.403	**-4.539**	4.097	-3.567	4.426	-3.111	0.526	0.658**
Carotenoid (mg\g)$^{-1}$	0.017	-0.652	-0.776	-0.206	-0.297	-0.342	0.160	-0.016	1.133	1.106	**1.225**	0.813	-0.926	0.865	0.008	0.614**
Fiber (%)	0.009	-0.239	-0.411	-0.220	-0.070	-0.176	0.083	-0.235	0.327	0.405	0.340	**0.513**	-0.294	0.198	-0.072	0.755**
Moisture (%)	0.413	-0.594	-0.422	0.025	-0.138	-0.153	0.220	0.313	0.855	0.794	0.615	0.467	**-0.814**	0.764	0.046	-0.396**
Ascorbic acid (mg 100g)$^{-1}$	0.556	1.277	1.114	-0.389	-0.312	-0.249	-0.545	0.566	-1.765	-1.551	1.548	-0.875	1.124	**-2.263**	-0.340	0.473**
Protein (mg 100g^{-1})	0.169	0.076	0.181	0.109	0.114	0.036	0.230	0.099	-0.710	-0.071	0.014	-0.092	-0.034	0.092	**0.613**	0.176

* and **, Significance at 5 and 1% respectively

acid had a high direct negative path on foliage yield (-2.26) but indirectly affected via stem diameter, branches per plant, seed yield, carotenoid, moisture and protein content. It also had a significant positive genotypic correlation with foliage yield (0.47) which suggested that indirect traits had much influence on ascorbic acid leading to an enhancement in foliage yield though ascorbic acid had a negative direct path with foliage yield. Similarly chlorophyll b, which showed a high negative direct path (-4.54) but indirectly affected via plant height, stem diameter, branches per plant, inflorescence length, leaf size, seed yield, chlorophyll a, carotenoid, moisture and protein content. It also had significant positive correlation with foliage yield (0.66). However, it is interesting to note that only plant height showed direct path on foliage yield (0.16) and also indirectly affected via all traits except chlorophyll b, it also had significant genotypic correlation with foliage yield (0.41). The only agronomic characters stem diameter, leaves per plant, inflorescence length and 500 seed weight had a positive direct path on foliage yield. However, from these, only inflorescence length and 500 seed weight exhibited positive correlation with foliage yield.

It was concluded from the present study that the foliage yield can be enhanced following the selection based on plant height, inflorescence length, 500 seed weight, stem diameter and considering all the quality characters except moisture content. The quality characters also may be a great impetus towards an increase of foliage yield along with enhancement in them also.

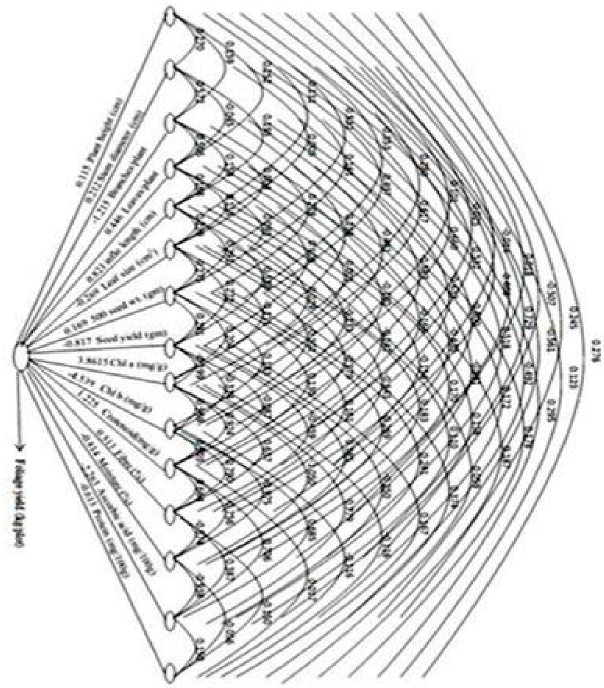

Figure 1. Path diagram showing foliage yield (dependent variable) and other traits (independent variables) in vegetable amaranth

Interrelacionamento genético entre caracteres nutricionais e quantitativos em amarantus (*Amaranthus tricolor* L.)

RESUMO - *O presente trabalho investigou a interrelação entre caracteres agronômicos e de qualidade e seu efeito direto e indireto na produção de folhagem em 39 cultivares de amarantus. Entre os agronômicos, altura de planta e número de inflorescência apresentaram associação positiva e significativa com produção. A mesma associação com produção foi verificada para Clorofilas a, b, carotenóide, fibra e ácido ascórbico. Clorofilas a e b foram associadas positiva e significativamente com carotenóide, fibra e ácido ascórbico. Este último foi correlacionado positivamente com fibra e carotenóide. Proteína foi associada com altura de planta, ramos por planta e peso de 500 sementes. Clorofila a, carotenóide e comprimento de inflorescência revelaram efeito direto positivo com produção, enquanto ramos por planta, tamanho de folha, produção de sementes, clorofila b, teor de umidade e ácido ascórbico mostraram coeficiente de trilha negativo com ela. Caracteres favoráveis foram focados para incremento da produção.*

Palavras-chave: *A. tricolor*, associação genética, carotenóide, proteína, ácido ascórbico.

REFERENCES

Bressani R (1990) Grain amaranth: it's chemical composition and nutritive value. In: **Proceeding of fourth Amaranth symposium Minnesota**, Minnesota Agricultural University, Saint Paul, 22p.

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

Finne MA, Rognli OA and Schjelderup I (2000) Genetic variation in a Norwegian germplasm collection of white clover (*Trifolium repens* L.). **Euphytica 112**: 57-68.

Glick D (1954) **Methods of biochemical analysis**. Interscience Publishers, New York, pp. 127-132.

Grubben GJH and Van Stolen DH (1981) Genetic resources and Amaranths, Intl. **Board for Plant Genetic Resources**, Food and Agriculture Organization, Rome, 45p.

Jaiswal SV and Gupta VP (1967) Selection criteria in improving erect type of groundnut. **Journal of Research Punjab Agriculture University 4**: 188-191.

Jensen A (1978) Chlorophylls and carotenoids. In: Hellebust JA and Craigie JS (Eds.) **Handbook of physiological methods**: physiological and biochemical methods. Cambridge University Press, Cambridge, pp. 5-70.

Johnson HW, Robinson HF and Comstock RE (1955) Genotypic and phenotypic correlation in soybean and their implication in selection. **Agronomy Journal 47**: 477-485.

Lopez AFS, Firpo IT, Garcia SM and Cointry EL (1998) Estimation of genetic parameters for yield traits in globe artichoke (*Cynara scolymus* L.). **Euphytica 103**: 61-66.

Makus DJ (1990) Composition and nutritive value of vegetable amaranth as affected by stage of growth, environment and method of preparation. In: **Proceeding of fourth Amaranth symposium Minnesota**, Minnesota Agricultural University, Saint Paul, pp. 35-46.

Martin FW and Ruberte RM (1979) **Edible leaves of the tropics**. US Department of Agriculture, Mayaguez Institute of Tropical Agriculture, Mayaguez, 235p.

Martin FW and Telek L (1979) **Vegetables of hot humid tropics**. Part 6: Amaranth and Celosia. US Department of Agriculture, New Orleans, pp. 1-21.

National Academy of Sciences (NAS) (1984) Amaranth: modern prospects for an ancient. **Crop. National Academy of Science**, USA, pp. 33-55.

Opute FI (1979) Seed lipids of the grain *Amaranthus*. **Journal of Experimental Botany 30**: 601.

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

Peterson GL (1977) A Simplification of the protein assay method of Lowry *et al.*, which is more generally applicable. **Analytical Biochemistry 83**: 346-56.

Rajan S and Markose BL (2007) **Propagation of horticultural crops**. In: Peter KV (Ed.) New India Publishing Agency, New Delhi, India, pp.110-113.

Robinson HF, Comstock RE and Harvey PH (1951) Phenotypic and genotypic correlation in corn and their importance in selection**. Agronomy Journal 43**: 282-287.

Saunders RM and Becker R (1984) *Amaranthus*: A potential food and feed resources. In: Pomeranz Y (Ed.) **Advances in cereal science technology**. American Association of Cereal Chemistry, Minnesota, pp. 357.

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

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

Shukla S, Bhargava A, Chatterjee A and 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 and Singh SP (2006a) 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 and Singh SP (2006b) Mineral profile and variability in vegetable amaranth (*Amaranthus tricolor*). **Plant Foods for Human Nutrition 61**: 23-28.

Sukhchain, Sandhu D and Saini GS (1997) Inter-relationships among cane yield and commercial cane sugar and their component traits in autumn plant crop of sugarcane. **Euphytica 95**: 109-113.

Teutonico RA and Knorr D (1985) Nondestructive method for oxalate determination of cultured *A. tricolor* cells. **Journal of Agriculture and Food Chemistry 33**: 60.

Tucker JB (1986) Amaranth: the once and future crop. **Biological Science 36**: 9-13.

Watson CA (1994) **Official and standardized methods of analysis**. 3rd ed., The Royal Society of Chemistry, Cambridge, p.6.

Wu-Leung, Busson F and Jardin C (1968) **Food composition table for use in Africa**. Food and Agriculture Organization, Italy, 306p.