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GENETIC VARIABILITY, HERITABILITY AND GENETIC ADVANCE IN AMARANTH (*Amaranthus* sp. L.) GENOTYPES FOR GROWTH, YIELD, PHYSIOLOGICAL AND QUALITY TRAITS

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ABSTRACT

Twenty-five diverse amaranth [*Amaranthus* sp. (L.)] genotypes were evaluated in a Randomized Block Design with two replications over two seasons at the Eastern Farm of the Department of Horticulture, PAJANCOA & RI, Karaikal, to estimate the magnitude of genetic variability, heritability and genetic advance for twenty-one growths, yield, physiological and quality traits. Phenotypic coefficient of variation (PCV) exceeded the corresponding genotypic coefficient of variation (GCV) for every character, though the difference was narrow, indicating that observed variation was governed largely by genetic factors with a comparatively minor environmental contribution. High GCV and PCV were recorded for number of nodes plant⁻¹ (71.69% and 76.38%), days to germination (43.65% and 46.52%) and fresh leaf weight plant⁻¹ (35.99% and 36.81%), whereas photosynthetic rate and crude fibre content showed comparatively low estimates. High heritability (>60%) was recorded for all twenty-one traits, ranging from 75.41% (crude fibre content) to 100.00% (oxalate content). High heritability coupled with high genetic advance as per cent of mean was observed for number of nodes plant⁻¹ (138.60%), days to germination (84.38%), fresh leaf weight plant⁻¹ (72.49%), leaf stem ratio (72.16%), leaf area (60.33%) and chlorophyll content (53.91%), indicating predominance of additive gene action and good scope for direct phenotypic selection for these traits. In contrast, plant height, leaf traits and biochemical quality attributes exhibited high heritability but moderate genetic advance, suggesting an appreciable role of non-additive gene effects, for which selection may need to be deferred to later generations or combined with recombination breeding. The results identify number of nodes plant⁻¹, fresh leaf weight plant⁻¹, leaf stem ratio, leaf area and chlorophyll content as reliable selection indices for rapid genetic improvement of foliage yield in amaranth.

Key words: Genotypic coefficient of variation; phenotypic coefficient of variation; heritability; genetic advance; additive gene action

Introduction

Leafy vegetables occupy a pivotal position in human nutrition owing to their short growth duration, low input requirement and dense concentration of vitamins, minerals and antioxidant phytochemicals. Amaranth [*Amaranthus* sp. (L.)], often described as the “poor man’s spinach”

(Negi, 2023), is cultivated widely across India, Africa, South America and South-East Asia both as a leafy

vegetable and as a grain crop. It is valued for its rapid growth, adaptability to diverse agro-climatic niches and rich content of lysine, betalains, flavonoids and polyphenols that impart anti-inflammatory and antioxidant properties (Yadav and Yadav, 2024). India ranks as the world’s second-largest vegetable producer and amaranth contributes substantially to leafy vegetable output in Tamil Nadu, Kerala, Andhra Pradesh, Odisha and West Bengal,

Table 1: Details of twenty-five amaranth genotypes used in the study.

S. No.	Genotypes	Source and location	State
1.	CO2	Tamil Nadu Agricultural University, Coimbatore	Tamil Nadu
2.	CO6	Tamil Nadu Agricultural University, Coimbatore	Tamil Nadu
3.	PLR 1	Vegetable Research Station, Palur	Tamil Nadu
4.	Arka Arunima	Indian Institute of Horticultural Research, Bengaluru	Karnataka
5.	Arka Suguna	Indian Institute of Horticultural Research, Bengaluru	Karnataka
6.	Arka Varna	Indian Institute of Horticultural Research, Bengaluru	Karnataka
7.	Arka Samraksha	Indian Institute of Horticultural Research, Bengaluru	Karnataka
8.	Arun	Kerala Agricultural University, Thrissur	Kerala
9.	Renu Sree	Kerala Agricultural University, Thrissur	Kerala
10.	Vaika	Kerala Agricultural University, Thrissur	Kerala
11.	Pusa Kiran	Indian Agricultural Research Institute, New Delhi	New Delhi
12.	Pusa Lal Chaulai	Indian Agricultural Research Institute, New Delhi	New Delhi
13.	Kashi Suhaavani	Indian Institute of Vegetable Research, Varanasi	Uttar Pradesh
14.	Amaranthus Red	Sarpan Hybrid Seeds Co. Pvt. Ltd.	Karnataka
15.	Indam Lal	Indo American Hybrid Seeds Pvt. Ltd.	Karnataka
16.	Chawli Bhaji	Namdeo Umaji Agritech (India) Pvt. Ltd.	Maharashtra
17.	Red Amaranthus	Namdeo Umaji Agritech (India) Pvt. Ltd.	Maharashtra
18.	Pal Cheera	Yuva Karshaka Agro Farm, Malappuram	Kerala
19.	CO5	Yuva Karshaka Agro Farm, Malappuram	Kerala
20.	Tiruvannamalai Local	Sun Agro Agencies, Tiruvannamalai	Tamil Nadu
21.	Gobichettipalayam Local	Indhu Agro Agencies, Erode	Tamil Nadu
22.	Ananthapuram Local (Green)	Sri Karthika Seeds, Villupuram	Tamil Nadu
23.	Ananthapuram Local (Red)	Sri Karthika Seeds, Villupuram	Tamil Nadu
24.	Kadapa Local (Green)	Pavani Seeds and Pesticides, Kadapa	Andhra Pradesh
25.	Kadapa Local (Red)	Pavani Seeds and Pesticides, Kadapa	Andhra Pradesh

which together account for over 60 per cent of the area under the crop.

The efficiency of any crop improvement programme rests on the extent of exploitable genetic variability present in the base population and the degree to which that variability is transmitted to succeeding generations. Phenotypic expression of a quantitative trait is the resultant of genotypic and environmental influences and simple mean performance alone cannot indicate whether the observed variation is genetically fixable. Partitioning of phenotypic variance into its genotypic and environmental components, expressed as the genotypic and phenotypic coefficients of variation (GCV and PCV), therefore provides breeders with a standardised measure of variability that is independent of the unit of measurement (Burton, 1952).

Heritability in the broad sense estimates the extent to which phenotypic variance is attributable to genotypic causes (Lush, 1940), while genetic advance expresses the expected gain in a trait under a given selection intensity. Heritability estimates in isolation can be misleading, since traits with predominantly non-additive gene action may show high heritability yet low genetic advance; hence, Johnson *et al.*, (1955) recommended that heritability be interpreted jointly with genetic advance to obtain a reliable picture of the type of gene action

governing a trait and to guide the choice of an appropriate breeding methodology.

Materials and Methods

The experiment was laid out in a Randomized Block Design with two replications over two seasons (Rabi and Summer, 2026) at the Eastern Farm of the Department of Horticulture, PAJANCOA & RI, Karaikal, Union Territory of Puducherry (10° 49' –11° 0" N, 79° 52' E). the details of genotypes used in the study are presented in the Table 1 and twenty-one growths, yield, physiological and quality characters were recorded.

Since the error variances of the two seasons were homogeneous by Bartlett's test and the genotype × season interaction was non-significant, pooled analysis of variance was carried out following Sundararaj *et al.*, (1972) and pooled mean values were used for estimating genetic parameters. Genotypic and phenotypic variances were computed following Lush (1940) as $\sigma^2_g = (MS_g - MSe)/r$ and $\sigma^2_{ph} = \sigma^2_g + \sigma^2_e$, where MS_g and MSe are the mean sum of squares for genotypes and error, respectively and r is the number of replications. Genotypic and phenotypic coefficients of variation were calculated as per Burton (1952) and classified as low (<10%), moderate (10–20%) and high (>20%) following Sivasubramanian and Menon (1973). Broad-sense heritability (h^2) was estimated as the ratio of genotypic

Table 2: Pooled analysis of variance (mean sum of squares) for growth, yield, physiological and quality characters of twenty-five amaranth genotypes.

S. No.	Character	Replication mean sum of squares	Treatment mean sum of squares	Error mean sum of squares
1	Days to germination (days)	0.3200	4.3783**	0.2783
2	Plant height (cm)	0.0150	31.7300**	0.7040
3	Leaf length (cm)	0.0808	2.4068**	0.1241
4	Leaf width (cm)	0.0104	1.8003**	0.0468
5	Petiole length (cm)	0.0792	1.3883**	0.0588
6	Stem girth (cm)	0.0020	0.0258**	0.0009
7	Number of leaves plant ⁻¹	0.0381	5.3262**	0.3781
8	Number of nodes plant ⁻¹	0.0000	9.8750**	0.6250
9	Fresh leaf weight plant ⁻¹ (g)	0.0841	7.4116**	0.1667
10	Dry leaf weight plant ⁻¹ (g)	0.1764	0.7064**	0.0949
11	Leaf stem ratio	0.0019	0.2798**	0.0048
12	Total yield plot ⁻¹ (kg)	0.0007	0.6716**	0.0523
13	Estimated yield (t ha ⁻¹)	0.0079	7.4644**	0.5811
14	Harvest index (per cent)	0.0012	0.0063**	0.0006
15	Chlorophyll content (SPAD)	0.0260	179.8650**	1.6940
16	Photosynthetic rate ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$)	8.3968	14.1100**	1.8030
17	Leaf area (cm ²)	0.2610	86.0780**	0.9990
18	Iron content (mg 100g ⁻¹)	6.6250	197.4280**	5.8524
19	Protein content (per cent)	0.0001	0.4649**	0.0253
20	Crude fibre content (per cent)	0.1502	1.3753**	0.1928
21	Oxalate content (per cent)	0.0000	0.0076**	0.0000

**Significant at 1% probability level.

to phenotypic variance (Lush, 1940) and expressed as a percentage and categorised as low (<30%), moderate (30–60%) and high (>60%) following.

Robinson *et al.*, (1949). Genetic advance was calculated as $GA = K \cdot \sigma^2g / \sqrt{\sigma^2ph}$ (Johnson *et al.*, 1955), where K is the selection differential (2.06 at 5% selection intensity) and expressed as a percentage of the general mean; genetic advance as per cent of mean was categorised as low (1–10%), moderate (11–20%) and high ($\geq 21\%$) following Robinson *et al.*, (1949).

Results and Discussion

Pooled analysis of variance revealed highly significant ($P \leq 0.01$) differences among the twenty-five amaranth genotypes for all twenty-one characters (Table 2), confirming adequate genetic variability in the germplasm to permit reliable estimation of variance components, heritability and genetic advance.

Phenotypic and genotypic coefficients of variation

The estimates of variability are presented in Table 3 and depicted graphically in Fig. 1. For every character studied, the phenotypic coefficient of variation was marginally higher than the corresponding genotypic coefficient of variation, indicating that environmental influence on trait expression was comparatively small

and that the observed phenotypic variability was predominantly under genetic control, a pattern consistent with the reports of Venkatesh *et al.*, (2014) and Agadi *et al.*, (2021) in amaranth.

Number of nodes plant⁻¹ recorded the highest PCV (76.38%) and GCV (71.69%) among all traits, followed by days to germination (PCV 46.52%, GCV 43.65%), fresh leaf weight plant⁻¹ (PCV 36.81%, GCV 35.99%) and leaf stem ratio (PCV 36.25%, GCV 35.63%), signifying a broad genetic base for these traits and considerable scope for their improvement through direct selection. Leaf area (PCV 29.98%, GCV 29.63%) and chlorophyll content (PCV 26.67%, GCV 26.42%) also recorded high coefficients of variation. In contrast,

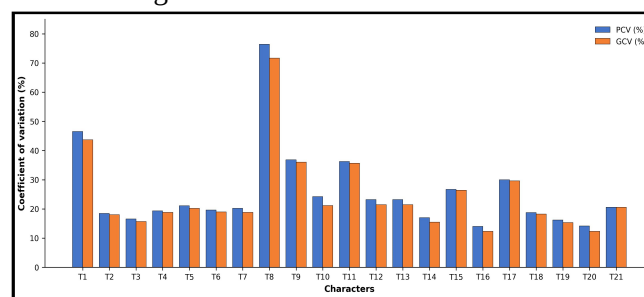


Fig. 1: Phenotypic and genotypic coefficient variation for twenty-one characters in twenty-five amaranth genotypes (trait codes T1–T21 as listed in Table 2).

Table 3: Mean, variability, heritability and genetic advance for twenty-one characters of twenty-five amaranth genotypes.

S. No.	Characters	Mean $\pm$ S. E	Range		PV	GV	PCV (%)	GCV (%)	h ² (%)	GA	GA (%)
			Min.	Max.							
1	Days to germination	3.24 $\pm$ 0.37	2.00	8.00	2.32	2.05	46.52	43.65	88.05	2.77	84.38
2	Plant height (cm)	21.84 $\pm$ 0.59	16.62	32.47	16.21	15.51	18.44	18.03	95.66	7.94	36.34
3	Leaf length (cm)	6.79 $\pm$ 0.24	5.08	9.69	1.26	1.14	16.55	15.71	90.19	2.09	30.74
4	Leaf width (cm)	4.97 $\pm$ 0.15	3.27	7.55	0.92	0.87	19.34	18.85	94.93	1.88	37.83
5	Petiole length (cm)	4.04 $\pm$ 0.17	1.78	5.75	0.72	0.66	21.07	20.20	91.87	1.61	39.88
6	Stem girth (cm)	0.59 $\pm$ 0.02	0.35	0.75	0.01	0.01	19.65	18.98	93.28	0.22	37.75
7	Number of leaves plant ⁻¹	8.36 $\pm$ 0.43	6.03	12.38	2.85	2.47	20.19	18.81	86.74	3.02	36.09
8	Number of nodes plant ⁻¹	3.00 $\pm$ 0.55	1.00	12.00	5.25	4.62	76.38	71.69	88.10	4.16	138.60
9	Fresh leaf weight plant ⁻¹ (g)	5.29 $\pm$ 0.28	2.57	10.34	3.78	3.62	36.81	35.99	95.60	3.83	72.49
10	Dry leaf weight plant ⁻¹ (g)	2.62 $\pm$ 0.21	1.73	4.46	0.40	0.30	24.18	21.12	76.32	0.99	38.02
11	Leaf: stem ratio	1.04 $\pm$ 0.04	0.64	1.80	0.14	0.13	36.25	35.63	96.63	0.75	72.16
12	Total yield plot ⁻¹ (kg)	2.59 $\pm$ 0.16	1.79	4.46	0.36	0.30	23.20	21.46	85.55	1.06	40.89
13	Estimated yield (t ha ⁻¹)	8.64 $\pm$ 0.53	5.98	14.89	4.02	3.44	23.20	21.46	85.56	3.53	40.90
14	Harvest index (per cent)	0.35 $\pm$ 0.01	0.26	0.45	0.01	0.01	16.96	15.44	82.86	0.10	28.96
15	Chlorophyll content (SPAD)	35.73 $\pm$ 0.92	20.91	45.00	90.78	89.08	26.67	26.42	98.13	19.26	53.91
16	Photosynthetic rate (μ mol CO ₂ m ⁻² s ⁻¹)	20.14 $\pm$ 0.95	15.32	26.27	7.95	6.15	14.01	12.32	77.34	4.49	22.32
17	Leaf area (cm ²)	22.01 $\pm$ 0.70	12.28	34.77	43.53	42.53	29.98	29.63	97.70	13.28	60.33
18	Iron content (mg 100g ⁻¹)	53.73 $\pm$ 1.71	36.03	74.36	101.63	95.78	18.76	18.22	94.24	19.57	36.43
19	Protein content (per cent)	3.06 $\pm$ 0.11	2.30	4.27	0.24	0.21	16.19	15.33	89.68	0.91	29.91
20	Crude fibre content (per cent)	6.25 $\pm$ 0.31	4.54	7.67	0.78	0.59	14.16	12.30	75.41	1.38	21.99
21	Oxalate content (per cent)	0.30 $\pm$ 0.01	0.20	0.40	0.00	0.00	20.60	20.60	100.00	0.13	42.45

PV – Phenotypic variance; GV – Genotypic variance; PCV – Phenotypic coefficient of variation; GCV – Genotypic coefficient of variation; h² – Heritability (broad sense); GA – Genetic advance; GA (%)– GA as per cent of mean

photosynthetic rate (PCV 14.01%, GCV 12.32%) and crude fibre content (PCV 14.16%, GCV 12.30%) recorded comparatively low variability, suggesting that these physiological and quality traits are more conserved across the genotypes evaluated. Plant height, leaf length, leaf width, petiole length, stem girth, number of leaves plant⁻¹, dry leaf weight plant⁻¹, total and estimated yield, harvest index, iron content and protein content exhibited moderate-to-high coefficients of variation in the range of 15–30%, in agreement with the variability trends reported by Yogendra *et al.*, (2018) and Panda *et al.*, (2017) for agromorphological and quality traits in vegetable amaranth.

Heritability

Broad-sense heritability was high (>60%) for all twenty-one characters studied, ranging from 75.41% for crude fibre content to 100.00% for oxalate content (Table 3, Fig. 2). Chlorophyll content (98.13%), leaf area (97.70%), leaf stem ratio (96.63%), plant height (95.66%), fresh leaf weight plant⁻¹ (95.60%) and leaf width (94.93%) recorded particularly high heritability estimates, indicating that the observed phenotypic variation for these traits closely mirrors the underlying genotypic variation and is minimally confounded by environmental effects. Uniformly high heritability across nearly all traits reflects

the effectiveness of the pooled analysis in filtering out seasonal environmental variance and is consistent with earlier reports of high heritability for foliage and quality traits in *Amaranthus tricolor* by Ahammed *et al.*, (2012) and Venkatesh *et al.*, (2014).

Genetic advance

Genetic advance as per cent of mean, which reflects the expected genetic gain under selection, varied widely across traits (Table 3, Fig. 2). The highest genetic advance was recorded for number of nodes plant⁻¹ (138.60%), followed by days to germination (84.38%), fresh leaf weight plant⁻¹ (72.49%), leaf stem ratio (72.16%), leaf

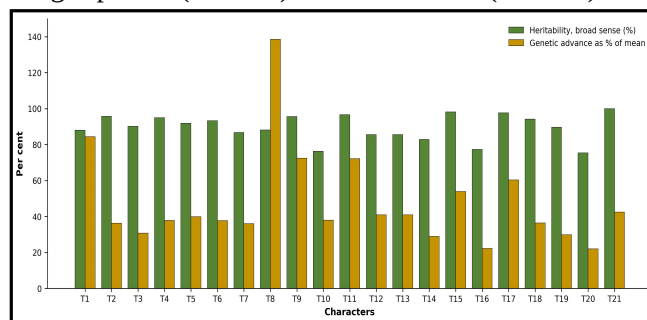


Fig. 2: Heritability (per cent) and genetic advance as per cent of mean for twenty-one characters in twenty-five amaranth genotypes (trait codes T1–T21 as listed in Table 2).

area (60.33%) and chlorophyll content (53.91%), all of which fall well within the high category ($\geq 21\%$). Estimated yield and total yield plot⁻¹ recorded a genetic advance of 40.90% and 40.89% respectively, also indicating substantial genetic gain achievable through selection.

High heritability accompanied by high genetic advance as per cent of mean, observed for number of nodes plant⁻¹, days to germination, fresh leaf weight plant⁻¹, leaf stem ratio, leaf area, chlorophyll content, total and estimated yield, dry leaf weight plant⁻¹ and iron content, indicates that these traits are governed predominantly by additive gene action. Such traits respond reliably to simple phenotypic selection and direct mass selection based on these characters can be expected to yield rapid genetic improvement, corroborating the conclusions of Johnson *et al.*, (1955) that heritability coupled with genetic advance is a more dependable index of selection efficacy than heritability alone.

In contrast, harvest index (h^2 82.86%, GA 28.96%), crude fibre content (h^2 75.41%, GA 21.99%) and photosynthetic rate (h^2 77.34%, GA 22.32%) recorded comparatively lower, though still moderate-to-high, genetic advance relative to their heritability, suggestive of some contribution of non-additive gene effects such as dominance and epistasis in the expression of these traits. Selection for such characters may be more effective if deferred to later segregating generations or combined with biparental mating and recombination breeding to break undesirable linkages, rather than relying solely on simple mass selection.

Overall, the concordance of high GCV, high heritability and high genetic advance for number of nodes plant⁻¹, fresh leaf weight plant⁻¹, leaf stem ratio, leaf area, chlorophyll content and yield attributes strongly support their utility as reliable morphological and physiological indices for early generation phenotypic selection in amaranth improvement programmes targeting foliage yield enhancement under coastal saline conditions.

Conclusion

The present investigation revealed substantial genotypic variability, high heritability and high genetic advance for number of nodes plant⁻¹, days to germination, fresh leaf weight plant⁻¹, leaf stem ratio, leaf area, chlorophyll content and total/estimated yield, indicating that these traits are governed predominantly by additive gene action and are amenable to rapid improvement through direct phenotypic selection. Traits such as harvest index, crude fibre content and photosynthetic rate, which combined high heritability with comparatively moderate genetic advance, may require selection strategies that

account for non-additive gene effects. These findings provide a genetic basis for prioritising selection traits in amaranth breeding programmes aimed at developing high-yielding, nutrient-dense cultivars for coastal saline environments.

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