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RESEARCH ARTICLE

Assessment of genetic variability among vegetable amaranth (*Amaranthus tricolor* L.) genotypes in Indo-Gangetic plains

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Abstract

Amaranth is an annual or short-perennial, dicotyledonous plant, globally cultivated for its grains and leaves. The plant is recognized as one of the earliest domesticated vegetables with exceptional nutraceutical and therapeutic properties. The present investigation aims to evaluate the genetic diversity and breeding potential of 22 vegetable amaranthus genotypes. The experiment was conducted in randomized block design with three replications during summer 2023, with observations recorded on 14 agro-morphological traits. The analysis of variance revealed significant differences for all the traits, depicting a wide range of variation for these traits. Further, the genotype VRAM-45 was found most promising for leaf yield, while VRAM-44 excelled for seed yield. A significant and positive correlation exists between leaf yield/plant, leaf length and leaf width, implying a potential link between leaf area and the efficiency of photosynthesis. Principal component analysis highlighted the significance of the first two components, explaining a substantial 53.71% of the total variation. Traits such as plant height at the vegetative stage, leaf length, and days to 50% flowering emerged as significant contributors to the variance. Clustering analysis categorized the 22 genotypes into four clusters. Cluster IV, though was found monogenotypic, but found superior for most of the economic traits, followed by cluster III. Thus, focusing on these clusters in breeding or selection programs could lead to more favorable outcomes in terms of economic productivity and other desirable characteristics.

Keywords: Amaranth, Genetic variability, Divergence, Quality, Leafy vegetable

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Introduction

Amaranth (*Amaranthus* spp.), a member of the Amaranthaceae family, is a lesser-known annual or short-cycle perennial (Petruzzello et al., 2016) plant cultivated worldwide for both grain and leaves. The crop has gained recognition as a third-millennium crop plant (Rastogi & Shukla, 2013). The genus *Amaranthus* comprises over 70 species (Thapa et al., 2018) and three subgenera (Schmid et al., 2017). About 17 of these species are specifically cultivated for their tender edible leaves, with the most predominant leafy species being *Amaranthus tricolor*, commonly known as vegetable amaranth in India. This type of amaranth is believed to have originated in South or Southeast Asia, with India being one of its possible origins (Rai and Yadav, 2005). The crop is extensively cultivated across India primarily as a vegetable, renowned for its rapid growth and short growth cycle. The diversity exhibited by vegetable amaranth in terms of leaf characteristics, such as color and flavor and its culinary similarity to cereals distinguishes it as a pseudo-cereal (Sagar et al., 2021a, 2021b). Furthermore, the NAD-ME type of C4 metabolism (Wolosik et al., 2019) significantly enhances its water-use efficiency and photosynthesis (Milakar et al., 2009), leading to higher yield potential per unit area. In developing nations where the availability of protein-rich foods is restricted, vegetable amaranth provides an important alternative source of food for vegetarian communities (Malaghan et al., 2018). The plant offers significant nutritional and medicinal benefits, surpassing lettuce in terms of vitamin A, vitamin C, calcium, and iron content (Shukla et al., 2006; Guillet, 2004). The leaves contain lysine and sulfur-containing amino acids, nutrients often absent in many vegetables and cereal grains (Panda et al., 2017). Besides its nutritional potential, vegetable amaranth is resistant to diseases and tolerant of extreme heat and drought (Rastogi and Shukla, 2013; Barrio and Anon, 2010). Unlike many other green vegetables, it thrives without the need for cold or specific climates, making it cultivable during the summer when other green leafy vegetables are scarce in the market (Rastogi and Shukla, 2013). As an underutilized and genetically promising orphan crop, limited attention has been dedicated to the genetic improvement of this plant. Further, to develop high-yielding varieties, crop improvement initiatives require genetic heterogeneity and variability studies within the existing germplasm. Moreover, the relation of characters with yield, the extent of environmental influences on these traits and the heritability of the characters are essential (Devi et al., 2015). Principal component and cluster analysis is another multivariate technique that helps the breeders to determine the genetic diversity and relationship between traits to explain the variation between genotypes. With this background, the current investigation was designed to assess the genetic variability in 22 vegetable amaranth (*A. tricolor* L.) genotypes for different growth and yield-contributing traits.

Materials and Methods

Experimental Site, Materials and Design

The present experiment was conducted at ICAR-Indian Institute of Vegetable Research, Varanasi, located at 82.52°E longitude and 25.10°N latitude, with a mean elevation of 228.62 meters above MSL. The site receives an annual rainfall of approximately 1000 mm, spread over a period of more than 100 days, with the peak period occurring between July and August. The study was conducted on 22 genotypes of vegetable Amaranth, primarily collected through exploration from different parts of the country and maintained at the ICAR-Indian Institute of Vegetable Research, Varanasi. These 22 genotypes also included the released cultivars *viz.,* Pusa Kirti and Pusa Lal Chaulai from the Indian Agricultural Research Institute, New Delhi and Kashi Suhavani from ICAR-IIVR, Varanasi. The experiment was laid out in Randomized Block Design (RBD) with three replications. After initial plowing by a tractor, the field was pulverized to create homogeneous blocks. The genotypes were sown in three replications, three blocks, and twenty-two plots per block. Each unit plot measured 3m in length, and 1.50 m in breadth, covering an area of 4.5 m^2. Within each replication, each genotype was grown in five rows, spaced 30 cm apart, with a plant-to-plant distance of 5 cm.

Data Collection

The observations were recorded for fourteen quantitative traits *viz*., days to germination (DTG; No), plant height at vegetative and flowering stages (PHVS, PHRS; cm), stem base diameter (SBD; cm), leaf length (LL; cm), leaf width (LW; cm), number of leaves/plant (NL/P; No), number of branches/plant (NB/P; No), days to 50% flowering (DTF; No), average leaf yield/plot (LY/P; kg), gross yield/plot (GLY/P; kg), leaf yield/hectare (LY/H; quintals), seed yield/plant (SY/P; g), and 1000-seed weight (1000-SW; g).

Statistical Analysis

Analysis of variance was estimated by the procedure of Panse and Sukhatme (1954). Genotypic and phenotypic variance, broad-sense heritability (h^2b) and genetic advance, as per Searle (1961) were calculated. The computation of the correlation coefficient between two variables was conducted following the methodology proposed by Al-Jibouri et al. (1958). Principal Component Analysis (PCA), along with eigenvalues, eigenvectors, biplot visualization, and cluster analysis, was conducted as suggested by Kaiser (1960). Additionally, R version 4.3.2 was used to analyze hierarchical clustering using the Ward D^2 method with Euclidean distance to understand the patterns of similarity and dissimilarity among the 22 genotypes tested for 14 agro-morphological traits.

Result and Discussion

Analysis of Variation and Mean Performance

Significant variations were observed across all measured traits, as presented in Table 1, depicting the highest genetic variation for the traits, *viz.,* number of leaves/plant (5.37), followed by number of branches/plant (2.94) and seed yield/plant (2.77) under investigation. Days to germination varied notably among genotypes, with VRAM-41 demonstrating the quickest germination in 4 days, while VRAM-301 and Pusa Lal Chaulai exhibited the longest duration of 7 days. In terms of vegetative stage attributes, VRAM-145 displayed the maximum plant height at the vegetative state (24.95 cm) compared to the grand mean of 21.85 cm, while seven other genotypes were also at par with this genotype. Stem base diameter ranged from 1.02 cm (VRAM-35) to 1.58 cm (VRAM-21). The genotypes VRAM-145 and Pusa Lal Chaulai exhibit the maximum leaf length (11.23 cm and 10.71 cm, respectively), while it was observed minimum in VRAM-304 (5.56 cm). The genotype, Pusa Kirti produced wider leaves of 7.82 cm. Many other researchers (Nandi et al., 2017; Yadav et al., 2022; and Kumar et al., 2017) noticed a considerable variance in leaf length and leaf width in various amaranth genotypes from India. Further, VRAM-44

Table 1: Mean performance of 22 vegetable Amaranthus (*A. tricolor*) genotypes for 14 quantitative traits

S. No.	*Genotypes*	*DTG (no.)*	*PHVS (cm)*	*SBD (cm)*	*LL (cm)*	*LW (cm)*	*NL/P (no.)*	*NB/P (no.)*	*PHFS (cm)*	*DTF (%)*	*LY/P(kg)*	*GY/P (kg)*	*LY/H (q)*	*SY/P (g)*	*TSW (g)*
1	VRAM-2	4.67	22.05	1.30	9.80	5.57	15.73	10.54	136.46	55.00	2.65	13.52	156.05	8.60	0.82
2	VRAM-7	5.00	21.87	1.34	9.09	5.60	12.53	10.93	133.21	58.00	1.79	7.70	94.71	7.72	0.75
3	VRAM-9	5.67	23.83	1.28	8.32	5.95	12.81	12.40	147.68	61.67	2.09	10.12	115.35	9.09	0.93
4	VRAM-17	6.00	19.12	1.33	9.05	5.77	16.05	17.98	179.89	52.00	4.55	20.37	243.00	6.94	0.76
5	VRAM-19	4.33	24.35	1.46	8.29	5.59	15.31	10.85	98.00	67.00	3.44	17.08	195.40	7.05	0.72
6	VRAM-21	5.33	23.98	1.58	8.84	5.71	13.34	14.47	120.55	63.67	3.83	18.49	213.79	6.98	0.91
7	VRAM-23	5.67	24.54	1.31	9.02	6.66	14.19	24.41	139.97	59.33	1.28	5.10	59.14	6.89	0.80
8	VRAM-35	6.33	20.71	1.02	6.26	4.14	9.39	9.88	73.92	59.33	1.32	5.32	60.71	8.18	0.68
9	VRAM-41	4.00	21.86	1.17	6.74	5.71	14.82	12.08	137.91	57.33	1.95	9.43	106.46	8.17	0.76
10	VRAM-41-A	6.33	23.11	1.36	8.81	5.45	14.73	9.66	113.31	65.33	1.81	8.43	95.96	9.18	0.87
11	VRAM-44	5.33	17.73	1.24	9.04	5.58	22.08	10.18	142.24	66.00	5.03	20.95	229.89	13.30	0.97
12	VRAM-45	6.00	15.95	1.37	8.97	6.20	21.93	21.81	134.80	64.33	5.46	25.53	294.83	12.73	0.83
13	VRAM-59	4.67	21.38	1.42	8.21	6.40	13.51	10.85	128.13	62.33	1.34	6.04	64.20	7.68	0.74
14	VRAM-145	6.67	24.95	1.40	11.23	7.39	16.97	17.53	176.85	55.67	2.93	15.15	174.43	6. 65	0.79
15	VRAM-150	6.00	23.81	1.25	8.17	6.76	11.54	20.43	140.44	58.67	2.63	11.69	128.99	6.96	0.70
16	VRAM-203	6.33	21.23	1.35	7.86	6.11	11.75	12.62	88.41	53.00	1.23	4.86	54.65	6.02	0.71
17	VRAM-301	7.00	22.33	1.45	8.94	5.74	15.83	11.40	146.36	57.33	1.28	5.68	65.81	8.22	0.87
18	VRAM-303	5.33	24.10	1.30	7.15	5.04	17.83	17.61	140.50	60.67	1.20	4.25	48.71	6.97	0.75
19	VRAM-304	6.33	18.76	1.23	5.56	4.25	15.95	13.12	90.12	56.00	1.13	4.45	50.42	6.37	0.89
20	Pusa Lal Chaulai	7.00	22.41	1.39	10.28	6.64	12.27	13.61	138.55	50.67	1.96	8.66	98.74	7.40	1.38
21	Kashi Suhavani	6.00	19.64	1.41	9.12	6.28	11.22	13.69	171.65	58.00	3.49	19.87	230.61	6.76	0.93
22	Pusa Kirti	5.33	22.78	1.33	10.71	7.82	13.34	31.87	129.76	61.67	5.08	21.20	244.19	7.20	1.39
Mean		5.70	21.85	1.33	8.61	5.93	14.69	14.91	132.22	58.86	2.61	12.00	137.55	7.96	0.86
CD @ 5%		1.91	2.04	0.15	0.61	0.50	0.54	0.40	7.52	3.92	0.39	0.93	4.74	0.87	0.02
CV%		2.69	2.60	1.68	1.47	1.94	5.37	2.94	2.04	2.64	2.76	1.90	2.10	2.77	1.73

Table 2: Assessment of genetic variability, heritability, and genetic advance among 22 genotypes of vegetable Amaranthus

S. No.	*Genotypes*	*Genetic Variance*	*Phenotypic Variance*	*PCV%*	*GCV %*	*Heritability*	*GA%*
1	DTG (no.)	0.21	0.30	21.98	8.42	69.95	6.65
2	PHVS (cm)	5.17	6.70	11.85	10.41	77.16	18.84
3	SBD (cm)	0.01	0.02	9.21	6.06	50.00	8.22
4	LL (cm)	1.79	1.92	16.11	15.52	93.23	30.79
5	LW (cm)	0.71	0.80	15.12	14.22	88.75	27.54
6	NL/P (no.)	9.79	9.90	21.43	21.31	98.89	43.65
7	NBP (no.)	31.45	31.51	37.66	37.62	99.81	77.43
8	PHFS (cm)	727.88	748.73	20.70	20.41	97.22	41.45
9	DTF (%)	16.00	21.67	7.91	6.80	73.83	12.03
10	LY/P (kg))	1.99	2.05	54.81	54.05	97.07	109.82
11	GY/P (kg)	45.09	45.41	56.15	55.95	99.30	114.86
12	LY/H (q)	6036.07	6044.33	56.52	56.48	99.86	116.28
13	SY/P (g)	3.29	3.57	23.73	22.79	92.16	45.08
14	TSW (g)	0.07	0.09	21.97	21.90	87.00	44.99

Whereas; DTG: days taken to germination; PHVS & PHRS: plant height at vegetative and flowering stages; SBD: stem base diameter; LL: leaf length; LW: leaf width; NL/P: number of leaves/plant; NB/P: number of branches/plant; DTF: days to 50% flowering; LY/P: average leaf yield/plot; GLY/P: gross yield/plot; LY/H: leaf yield/hectare; seed yield/plant (SY/P);1000-SW:1000-seed weight; PCV%: Phenotypic Coefficient of Variability; GCV%: Genotypic Coefficient of Variability.GA%:Genetic advance as % of mean.

exhibited the highest number of leaves/plant (22.08), while Pusa Kirti displayed the maximum number of branches/plant (31.87). These results highlight substantial diversity in the vegetative characteristics of the studied genotypes, with certain genotypes exhibiting notably higher leaf or branch abundance compared to others. Delayed bolting is a desirable character in leafy Amaranthus as leaves are available for longer period of time, the genotypes VRAM-19 took a maximum number of days for flowering compared to the most popular cultivars Pusa Lal Chaulai that flowered quite early (50.67 days). Further, VRAM-45 was found promising for leaf (294.83 q/ha) as well seeds yield (12.73 g/plant) and thereby showing its potential for dual-purpose cultivars.

Genetic Variability, Heritability and Genetic Advance

The genotypic variance (Vg), phenotypic variance (Vp), genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), broad-sense heritability (h^2b), and genetic advance in percent of the mean (GAPM) for the 14 traits under study is presented in Table 2. The highest PCV and GCV (≥20) was observed for the trait *viz.,* leaf yield (56.52 and 56.48%) followed by gross yield/plot, leaf yield/plot, number of branches/plant, seed yield/plant, 1000-seed weight, and number of leaves/plant. Traits displaying higher PCV and GCV values indicate that these traits are primarily governed by genetic factors, enabling streamlined and targeted selection strategies for continual improvement (Rana et al., 2005). Larger differences between PCV and GCV suggest a greater impact of environmental factors governing these traits. In our study, the close proximity of phenotypic and genotypic variance suggests less environmental influence, indicating genetic control dominated the traits through genotypic variance. According to the heritability categorizations by Robinson et al. (1949), delineating low (5–10%), moderate (10–30%), and high (30% and above) levels, our findings exhibited high heritability across all traits. This suggests a predominant influence of genetic factors, indicating limited impact from environmental factors on these traits (Sarkar et al., 2014). Johannsen (1909) stressed that for estimating the actual effects of selection, heritability alone could not be the sole guideline for improvement since high heritability does not mean high expected genetic advance. Generally, when a trait is governed by non-additive gene action, it may exhibit high heritability but limited genetic advance. Conversely, traits influenced by additive gene action tend to display high values for both heritability and genetic advance (Johnson, 1955). Hence, prediction on the basis of both estimates could be more useful. In this context, high heritability coupled with high genetic advance (more than 50) were noticed for a number of branches/plant, leaf yield/plot, gross yield/plot and leaf yield/hectare, which indicated the role of additive gene action for the inheritance of these traits and are likely to respond better to selection. These findings coincide with the results made by Venkatesh et al. (2014) for high heritability for traits, *viz.*, stem girth and seed yield/plant in *Amaranthus spp.*

Table 3: The correlations coefficient for 14 quantitative traits of 22 vegetable amaranth (*A. tricolor*) genotypes

Traits	*DTG (no.)*	*PHVS (cm)*	*SBD (cm)*	*LL (cm)*	*LW (cm)*	*NL/P (no.)*	*NB/P (no.)*	*PHFS (cm)*	*DTF (%)*	*LY/P (kg)*	*GY/P (kg)*	*LY/H (q)*	*SY/P (g)*
PHVS (cm)	-0.105												
SBD (cm)	0.089	0.228											
LL (cm)	0.156	0.211	0.556**										
LW (cm)	0.059	0.293	0.423*	0.777**									
NL/P (no.)	-0.101	-0.414	0.087	0.135	-0.042								
NB/P(no.)	0.080	0.100	0.042	0.361	0.636**	0.093							
PHFS (cm)	0.065	0.038	0.273	0.592**	0.524*	0.269	0.275						
DTF (%)	-0.402	0.023	0.123	-0.078	-0.083	0.327	-0.003	-0.227					
LY/P (kg)	-0.144	-0.400	0.197	0.481*	0.364	0.469*	0.413	0.354	0.325				
GY/P (kg)	-0.150	-0.367	0.270	0.501*	0.369	0.421	0.347	0.403	0.306	0.981**			
LY/H (q)	-0.143	-0.364	0.280	0.507*	0.366	0.408	0.355	0.413	0.284	0.977**	0.999**		
SY/P (g)	-0.092	-0.576**	-0.182	0.042	-0.136	0.622**	-0.156	-0.012	0.495*	0.432*	0.377	0.354	
TSW (g)	0.234	-0.016	0.179	0.495*	0.433*	-0.020	0.366	0.148	-0.082	0.324	0.276	0.272	0.071

Whereas,*Significant at 5%, **Significant at 1%, DTG: days taken to germination; PHVS & PHRS: plant height at vegetative and flowering stages; SBD: stem base diameter; LL: leaf length; LW: leaf width; NL/P: number of leaves/plant; NB/P: number of branches/plant; DTF: days to 50% flowering; LY/P: average leaf yield/plot; GLY/P: gross yield/plot; LY/H: leaf yield/hectare; seed yield/plant (SY/P);1000-SW:1000-seed weight

Correlations Studies

The correlation between quantitative traits of vegetable amaranth is shown in Table 3. Leaf length demonstrated highly significant and positive associations with leaf width (r = 0.777) and plant height at the flowering stage (r = 0.592). This indicates that longer leaves tend to be wider and are associated with taller plants during the flowering stage, potentially reflecting increased biomass accumulation or favorable growing conditions. A highly significant and positive correlation exists between gross yield per plant and leaf yield per plant (r = 0.981). Similarly, highly significant and positive correlations were found between leaf yield/hectare and gross yield/plant (0.999) and leaf yield/plant (r = 0.977). Similarly, positive and significant relationships were found between gross yield/plant and leaf length (r = 0.501) and leaf yield/plant, implying a potential link between leaf length and the efficiency of photosynthesis. Seed yield per plant showed a significant negative correlation with plant height at the vegetative stage (r = -0.576), suggesting a potential trade-off between vegetative growth and seed production. Taller plants during the vegetative stage may allocate more resources towards structural growth rather than reproductive development, resulting in reduced seed yield. Conversely, there was a highly significant and positive association between seed yield/plant and number of leaves/plant (r = 0.622), indicating that a greater leaf count/plant is linked to higher seed yield. The correlation result of this study is corroborated by the results of Yadav et al. (2022), Sood et al. (2018), and Patial et al. (2014).

Principle Component and Cluster Analysis

Based on 14 agro-morphological traits, the PCA analysis of traits resulted in 10 components with five principal components PC1, PC2, PC3, PC4, and PC5, having eigenvalue 4.79, 2.74, 1.21, 1.07 and 1.06, respectively, explaining of the 77.62% of total variation (Table 4). The remaining components, i.e., PC6 to PC10 yielded progressively smaller eigenvalues (≤1). The PC1 and PC2, representing 35.5 and 20.5% of the variance, respectively, are visualized in Fig.1. The first primary principal component (PC1), accounting for 34.17% of the total variance, displayed the highest values in traits associated with yield, notably leaf yield/plot (0.43) and gross yield/plot (0.43). These traits exhibited significant positive correlations with PC1, indicating their collective impact on this component. The PC2, contributing 19.54% to the total variance, the highest positive value (0.440) in seed yield, suggesting a strong association with this principal component. The PCA reveals the significance of primary contributors to the total variance at each differentiation axis (Menzir, 2012). Traits exhibiting minimal impact, indicated by values close to zero, suggest their lesser role in defining the variance captured by this principal component. Similarly, the traits *viz.*, days to germination and 1000-seed weight showed maximum positive loading in PC3; number of

Table 4: Eigenvalues variance, cumulative variance, and principal component scores (Eigenvectors) of the first five components of genetic divergence in a panel of 22 Amaranthus genotypes.

Trait with primary principal component					
	PC1	*PC2*	*PC3*	*PC4*	*PC5*
Eigenvalue variance	4.79	2.74	1.21	1.07	1.06
Variance. percent	34.18	19.55	8.64	7.67	7.59
Cumulative. Variance. percent	34.18	53.73	62.37	70.03	77.62
Eigenvectors					
DTG (no.)	0.01	-0.11	0.43	-0.55	0.61
PHVS (cm)	0.10	-0.42	-0.47	0.01	0.02
SBD (cm)	-0.16	-0.25	-0.21	-0.50	-0.31
LL (cm)	-0.32	-0.03	-0.03	-0.22	-0.05
LW (cm)	-0.26	-0.40	-0.11	0.06	0.17
NL/P (no.)	-0.24	0.29	-0.07	-0.03	-0.01
NB/P (no.)	-0.23	-0.23	0.02	0.42	0.52
PHFS (cm)	-0.27	-0.22	0.17	-0.12	-0.25
DTF (%)	-0.12	0.23	-0.67	-0.67	-0.08
LY/P (kg)	0.43	0.11	0.05	0.13	0.01
GY/P (kg)	0.43	0.10	0.08	0.13	-0.09
LY/H (q.)	-0.43	0.10	0.11	0.16	-0.12
SY/P (g)	-0.18	0.44	-0.14	-0.22	0.13
TSW (g)	0.21	-0.19	0.23	0.45	-0.19

Whereas; DTG: days taken to germination; PHVS & PHRS: plant height at vegetative and flowering stages; SBD: stem base diameter; LL: leaf length; LW: leaf width; NL/P: number of leaves/plant; NB/P: number of branches/plant; DTF: days to 50% flowering; LY/P: average leaf yield/plot; GLY/P: gross yield/plot; LY/H: leaf yield/hectare; seed yield/plant (SY/P);1000-SW:1000-seed weight.

Table 5: Grouping 22 VA (*A. tricolor*) genotypes into 5 clusters based on the mean values of 14 quantitative traits.

Cluster	*Number of genotypes*	*Name of comprised genotypes*
I	03	VRAM-304, VRAM-203 and VRAM-35
II	10	VRAM-41-A, VRAM-150, VRAM-9, VRAM-41, Pusa Lal Chaulai, VRAM-7, VRAM-59, VRAM-301, VRAM-303 and VRAM-23
III	08	VRAM-21, VRAM-19, Pusa Kirti, VRAM-44, Kashi Suhavani, VRAM-17, VRAM-2, and VRAM-145
IV	01	VRAM-45

branches /plant and 1000-seed weight in PC-4, and days to germination and number of branches/plant in PC-5. The study's findings highlighted the pivotal role of PC1 and PC2 as primary contributors to traits associated with growth and yield, as vividly illustrated in Fig 1. These principal components emerged as significant indicators, aligning closely with and supported by the results of Dinssa et al. (2018), Yeshitila et al. (2023), and Showemimo et al. (2021). The consistency across these independent studies further strengthens the understanding that PC1 and PC2 play fundamental roles in capturing and characterizing the diverse spectrum of growth and yield-related traits in Amaranthus.

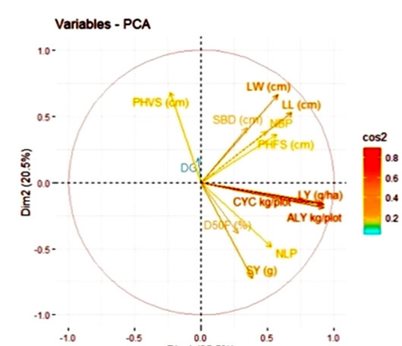

Fig. 1: A variable correlation plot illustrates the relationships among 14 quantitative traits within the 22 vegetable amaranth genotypes. The abbreviated names (codes) of the respective traits are shown in Table 1

Table 6: Cluster wise mean performance for 14 different quantitative traits

Traits	*Cluster*				*Grand mean*
	I	*II*	*III*	*IV*	
DTG (no.)	6.33	5.67	5.46	6.00	5.9
PHVS (cm)	20.23	22.92	21.82	15.95	20.2
SBD (cm)	1.22	1.33	1.37	1.37	1.3
LL (cm)	6.56	8.47	9.51	8.97	8.4
LW (cm)	4.84	6.00	6.21	6.20	5.8
NL/P (no.)	12.36	14.01	15.50	21.93	16.0
NB/P (no.)	11.87	14.34	15.89	21.81	16.0
PHFS (cm)	84.15	136.61	144.43	134.80	125.0
DTF (%)	56.11	59.13	59.88	64.33	59.9
LY/P(kg)	1.23	1.73	3.88	5.46	3.1
GY/P (kg)	4.88	7.71	18.33	25.53	14.1
LY/H(q)	55.26	87.81	210.92	294.83	162.2
SY/P	7.16	7.83	7.82	12.73	8.9
TSW (g.)	0.76	0.86	0.91	0.83	0.8

Whereas; DTG: days taken to germination; PHVS & PHRS: plant height at vegetative and flowering stages; SBD: stem base diameter; LL: leaf length; LW: leaf width; NL/P: number of leaves/plant; NB/P: number of branches/plant; DTF: days to 50% flowering; LY/P: average leaf yield/plot; GLY/P: gross yield/plot; LY/H: leaf yield/hectare; seed yield/plant (SY/P);1000-SW:1000-seed weight.

Cluster Analysis

The 22 vegetable amaranth genotypes were grouped into four groups based on quantitative traits using the Euclidean distance clustering approach's hierarchical agglomerative ward D^2 dendrogram. Table 5 enlists the number and names of genotypes detected in each cluster. Cluster II contained ten genotypes (45.45%) followed by cluster III and I, which had 08 (36.36%) and 03 (13.63%), whereas cluster I was found to be monogenotypic. Genotypes within the same cluster represent high homogeneity or have the fewest genetic variations within these genotypes, and the likelihood of developing good segregants through hybridization among parents within the cluster would be low. Therefore, crosses should be attempted between the genotypes falling in the diverse clusters in order to get superior recombinants. Further, cluster means showed that Cluster IV (VRAM-45) was found more superior for most of the economic traits *viz.*, stem base diameter, number of leaves/plant, number of branches/ plant, days to 50% flowering, average leaf yield/ plot, gross yield/plot, leaf yield/hectare and seed yield/ plant. Similarly, cluster II is also found to be better for the traits days taken to germination, stem base diameter, leaf length, leaf width, plant height, leaf yield per hectare, and 1000-seed weight (Table 6). Thus, focusing on these clusters in breeding or selection programs could lead to more favorable outcomes in terms of economic productivity and other desirable characteristics.

Conclusion

The investigation involving 22 vegetable amaranth genotypes unveiled significant traits based on mean performance, correlation studies, PCA, and genotype clustering. Analysis of variance revealed significant differences across all fourteen characters among 22 vegetable amaranth genotypes. The highest PCV and GCV were observed for the trait *viz.,* leaf yield followed by gross yield/plot, leaf yield/plot, number of branches/ plant, seed yield/plant, 1000-seed weight, and number of leaves/plant. Leaf yield displayed highly significant positive correlations with leaf length, while seed yield per hectare showed significant and positive correlations with days to 50% flowering, number of leaves/plant, and leaf yield/plot, signifying their role in enhancing yield. PCA analysis showed that the first two principal components made substantial contributions to the overall variation within amaranth genotypes. Clustering analysis categorized genotypes into four clusters based on performance, highlighting the maximum leaf-yielding genotypes in the fourth cluster and high grain-yielding genotypes in cluster III. Notably, VRAM-45, VRAM-44, Pusa Kirti, and Kashi Suhavani exhibited promising results in terms of yield attributes, suggesting their potential utilization in future breeding and improvement programs for vegetable amaranth.

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सारांश

चौलाई एक वार्षिक या लघु-बारहमासी द्विबीजपत्री पौधा है जिसकी विश्व स्तर पर अनाज और पत्तियों के लिए खेती की जाती है। इस पौधे को असाधारण न्यूट्रास्युटिकल और चिकित्सीय गुणों के साथ, घरेलू सब्जियों में से एक माना जाता है। वर्तमान जांच का उद्देश्य 22 वनस्पति ऐमारैंथस जीनोटाइप की आनुवंशिक विविधता और प्रजनन क्षमता का मूल्यांकन करना है। यह प्रयोग 2023 की गर्मियों के दौरान तीन प्रतिकृतियों के साथ यादृच्छिक ब्लॉक डिजाइन में आयोजित किया गया था जिसमें 14 कृषि-रूपात्मक लक्षणों पर अवलोकन दर्ज किए गए थे। विचरण के विश्लेषण से सभी लक्षणों के लिए महत्वपूर्ण अंतर का पता चला जो इन लक्षणों के लिए भिन्नता की विस्तृत श्रृंखला को दर्शाता है। इसके अलावा जीनोटाइप वीआरएएम-45 को पत्ती की उपज के लिए सबसे आशाजनक पाया गया, जबकि वीआरएएम 44 को बीज की उपज के लिए उत्कृष्ट पाया गया। पत्ती की उपज/पौधा, पत्ती की लंबाई और पत्ती की चौड़ाई के बीच महत्वपूर्ण और सकारात्मक सहसंबंध मौजूद है, जो पत्ती क्षेत्र और प्रकाश संश्लेषण की दक्षता के बीच एक संभावित संबंध दर्शाता है। प्रमुख घटक विश्लेषण ने पहले दो घटकों के महत्व पर प्रकाश डाला, जिसमें कुल भिन्नता का 53.71 प्रतिशत बताया गया। वानस्पतिक अवस्था में पौधे की ऊंचाई, पत्ती की लंबाई और 50 प्रतिशत फूल आने के दिन जैसे लक्षण भिन्नता में महत्वपूर्ण योगदानकर्ता के रूप में उभरे। क्लस्टरिंग विश्लेषण ने 22 जीनोटाइप को चार समूहों में वर्गीकृत किया। हालांकि क्लस्टर IV को मोनोजेनोटाइपिक पाया गया, लेकिन अधिकांश आर्थिक लक्षणों के लिए बेहतर पाया, इसके बाद क्लस्टर III को पाया गया। इस प्रकार, प्रजनन या चयन कार्यक्रमों में इन समूहों पर ध्यान केंद्रित करने से आर्थिक उत्पादकता और अन्य वांछनीय विशेषताओं के संदर्भ में अधिक अनुकूल परिणाम मिल सकते हैं।