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Genetic analysis of yield and quality traits through variability, heritability and genetic advance in Bitter gourd (*Momordica charantia* L.)

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Abstract
The present investigation was carried out during *z aid* season 2024-25 at the Main Experimental Station, Department of Vegetable Science, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, Uttar Pradesh. Thirty bitter gourd (*Momordica charantia* L.) genotypes were evaluated in a Randomized Complete Block Design (RCBD) with three replications to estimate genetic variability, heritability and genetic advance for eighteen yield and quality traits. Analysis of variance revealed highly significant differences among genotypes for all traits studied, confirming the presence of considerable genetic variability in the experimental material. The phenotypic coefficient of variation (PCV) was consistently higher than the genotypic coefficient of variation (GCV) for all traits, though the narrow difference between them indicated that the variability was predominantly genetic in nature. High GCV and PCV were recorded for vine length, reflecting substantial genetic variability for this trait. Broad-sense heritability ranged from 43.29% (seed flesh ratio) to 98.84% (average fruit weight). High heritability coupled with high genetic advance as per cent of mean was observed for vine length, average fruit weight, fruit yield per plant, dry matter content, fruit diameter and fruit length, indicating the predominance of additive gene action and the effectiveness of direct selection for these traits. Among all genotypes, NDK-9/24 recorded the highest fruit yield per plant (1.38 kg), while NDK-5/24 showed the highest ascorbic acid content (42.70 mg/100g). The findings suggest that direct phenotypic selection for vine length, average fruit weight and fruit yield per plant would be highly effective for developing superior bitter gourd genotypes with improved yield potential and quality.

Keywords: Genetic analysis, *Momordica charantia*, variability, GCV, PCV, heritability, genetic advance, Bitter gourd

Introduction
Bitter gourd (*Momordica charantia* L.), commonly known as karela, is an important cucurbitaceous vegetable crop belonging to family Cucurbitaceae. It is believed to have originated in India, with China as a secondary centre of diversity, and has since spread across Asia, Africa and South America (Jat *et al.*, 2024)[7]. In India, it is cultivated on nearly 101 thousand hectares with an annual production of 1174 million tonnes and an average productivity of 11.90 t/ha (NHB, 2021).

The crop is an annual climbing vine, monoecious in nature with a somatic chromosome number of 2n = 2x = 22, making it a highly cross-pollinated species with broad scope for variability and hybridization (Resmi and Sreelathakumary, 2012). Nutritionally, 100 g of fresh fruit provides protein, carbohydrates, fibre, vitamin C, folate and essential minerals, making it a valuable dietary component especially in micronutrient-deficient regions (Barua *et al.*, 2020) [2]. Medicinally, it contains bioactive compounds such as charantin, momordicin and polypeptide-p, which impart hypoglycaemic, anticancer and anti-inflammatory properties (Patel *et al.*, 2020; Islam *et al.*, 2011) [11, 6].

Despite its immense potential, productivity remains suboptimal due to limited systematic breeding efforts. Yield being a complex polygenic trait, direct selection is less efficient without prior knowledge of genetic variability. Parameters such as genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability and genetic advance help in understanding the nature and magnitude of variability. High heritability coupled with high genetic advance indicates additive gene action, making selection more effective, whereas high heritability with low genetic advance suggests non-additive gene action favouring heterosis breeding (Johnson *et al*., 1955) [8].

Materials and methodes

The present investigation was conducted during the Rabi season 2024-25 at the Main Experimental Station, Department of Vegetable Science, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, Uttar Pradesh. The experimental material comprising bitter gourd genotypes was evaluated in a Randomized Complete Block Design (RCBD) with three replications. Each genotype was planted in a plot measuring 3.0m × 4.5m, maintaining a spacing of 60 cm between rows and 45 cm between plants.

Observations were recorded on fifteen yield and quality traits, namely days to first staminate flower anthesis, days to first pistillate flower anthesis, node number to first staminate flower appearance, node number to first pistillate flower appearance, internodal length (cm), primary branches per plant, vine length (m), fruit length (cm), fruit diameter (cm), days to first fruit harvest, average fruit weight (g), number of fruits per plant, number of seeds per fruit, seed flesh ratio and fruit yield per plant (kg). In addition, biochemical traits including total soluble solids (°Brix), dry matter content (g/100g) and ascorbic acid content (mg/100g) were also recorded. Data for each trait were recorded from five randomly selected plants in each genotype within each replication. The mean value for each trait was calculated by averaging observations from the five sampled plants.

Statistical analysis was performed using analysis of variance (ANOVA) following the procedure described by Panse and Sukhatme (2000) [10] to determine the significance of differences among genotypes. The genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were estimated according to the method of Burton and DeVane (1953) [4]. Broad-sense heritability (h^2bs) was computed following *et al*. (1956) [5], while genetic advance (GA) and genetic advance as per cent of mean were calculated using the methodology proposed by Johnson *et al*. (1955) [8]. These genetic parameters were used to assess the magnitude of variability and the effectiveness of selection for yield and quality traits in bitter gourd.

Result and discussion

The analysis of variance (Table 1) revealed highly significant differences among the genotypes for all eighteen traits studied, indicating the presence of substantial genetic variability in the experimental material. The significant variation observed among the genotypes suggests considerable scope for effective selection and genetic improvement of fruit yield and its associated traits in bitter gourd.

The mean sum of squares due to treatments (Table 2.) was highly significant for all the characters, confirming the existence of considerable variability among the genotypes for the traits under investigation. Days to first male flower anthesis varied from 43.53 days (NDK-18) to 57.30 days (NDK-16), with an overall mean of 50.45 days. Days to first female flower anthesis ranged from 47.40 days (NDK-18) to 60.00 days (NDK-16), with a mean of 54.14 days. Days to first fruit harvest ranged from 63.51 days (IC-44428) to 74.67 days (NDK-14), averaging 69.31 days. Node number to first male flower appearance ranged from 5.16 (NDK-1/24) to 8.87 (NDK-17), with a mean of 6.91. Node number to first female flower appearance varied from 8.66 (NDK-3/24) to 11.85 (NDK-16), with a mean of 9.92. Primary branches per plant ranged from 5.70 (NDK-11) to 8.03 (NDK-9/24), averaging 6.95. Fruit length varied from 4.88 cm (NDK-3/24) to 11.91 cm (NDK-15), with a mean of 9.07 cm. Fruit diameter ranged from 2.74 cm (NDK-17) to 4.89 cm (NDK-19), averaging 3.81 cm. Average fruit weight ranged from 52.44 g (NDK-17) to 81.85 g (NDK-9/24), with a mean of 71.10 g. Internodal length varied from 2.90 cm (NDK-3/24) to 6.57 cm (NDK-19), averaging 4.95 cm. Vine length ranged from 0.94 m (VBT-155) to 2.49 m (NDK-19), with a mean of 1.66 m. Number of fruits per plant ranged from 22.07 (IC-0656) to 27.90 (NDK-17), averaging 24.91. Number of seeds per fruit varied from 10.93 (PB-14) to 17.93 (NDK-19), with a mean of 13.85. Seed flesh ratio ranged from 15.57 (NDK-11/24) to 21.83 (NDK-18), averaging 19.13. Total soluble solids ranged from 4.47 °Brix (NDK-18) to 5.92 °Brix (NDK-9/24), with a mean of 5.13 °Brix. Dry matter content varied from 7.38% (NDK-11) to 12.17% (NDK-1/24), averaging 9.60%. Ascorbic acid content ranged from 30.73 mg/100g (NDK-13) to 42.70 mg/100g (NDK-5/24), with a mean of 38.09 mg/100g. Fruit yield per plant ranged from 0.75 kg (NDK-11) to 1.38 kg (NDK-19), with an overall mean of 1.06 kg.

The estimates of genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) for all eighteen traits are presented in Table 3. In general, PCV values were slightly higher than the corresponding GCV values for all characters, indicating that environmental factors had a relatively small influence on the expression of these traits. High estimates (>20%) of both GCV and PCV were recorded for vine length (GCV: 31.99%, PCV: 32.84%), indicating the existence of substantial genetic variability for this trait. Moderate GCV and PCV values (10-20%) were observed for fruit diameter, fruit length, internodal length, number of seeds per fruit, dry matter content, fruit yield per plant and average fruit weight, suggesting moderate genetic variability and good scope for improvement through selection. The remaining characters, namely days to first male flower anthesis, days to first female flower anthesis, days to first fruit harvest, node number to first male flower appearance, node number to first female flower appearance, primary branches per plant, number of fruits per plant, seed flesh ratio, total soluble solids and ascorbic acid content, exhibited low GCV and PCV estimates (<10%), indicating comparatively narrow genetic variability.

The estimates of broad-sense heritability and genetic advance are also presented in Table 3. Broad-sense heritability ranged from 43.29% for seed flesh ratio to 98.84% for average fruit weight. High heritability (>80%) was recorded for average fruit weight (98.84%), vine length (94.89%), dry matter content (95.36%), ascorbic acid content (92.60%), total soluble solids (86.18%), days to first fruit harvest (83.08%), fruit length (75.90%) and fruit diameter (76.35%), indicating that these traits were predominantly governed by genetic factors with relatively less environmental influence. Moderate heritability (60-

80%) was observed for days to first male flower anthesis (73.92%), days to first female flower anthesis (74.51%), internodal length (73.94%), number of seeds per fruit (74.50%), fruit yield per plant (74.05%) and node number to first male flower appearance (69.75%), whereas comparatively lower heritability estimates were recorded for number of fruits per plant (48.44%), seed flesh ratio (43.29%) and node number to first female flower appearance (63.96%), suggesting greater environmental influence on these characters.

Genetic advance as per cent of mean ranged from 8.24% for number of fruits per plant to 64.20% for vine length. High genetic advance (>20%) was observed for vine length (64.20%), average fruit weight (25.29%), dry matter content (33.06%), ascorbic acid content (16.23%), fruit diameter (26.96%), fruit yield per plant (26.29%), fruit length (23.50%), internodal length (23.17%) and node number to first male flower appearance (23.33%), indicating that substantial improvement in these traits could be achieved through direct selection. Moderate genetic advance (10–20%) was recorded for days to first female flower anthesis, days to first male flower anthesis, number of seeds per fruit, total soluble solids and node number to first female flower appearance, whereas number of fruits per plant and seed flesh ratio exhibited relatively low genetic advance values.

Table 1: Analysis of variance (ANOVA) for growth, flowering, yield, and quality traits in 30 bitter gourd (*Momordica charantia* L.) genotypes.

Source of variation	DF	Days to first male flower anthesis	Days to first female flower anthesis	Days to first fruit harvest	Node number of first male flower appearance	Node number of first female flower appearance	Primary branch per plant	Fruit length (cm)	Fruit diameter (cm)	Average fruit weight (gm)
Replication	2	5.46	5.84	18.42	1.03	0.34	0.03	2.77	1.00	36.50
Genotype	29	36.85**	36.04**	35.37**	3.01**	2.74**	1.61**	4.68**	1.07**	232.17**
Error	58	3.88	3.69	2.25	0.38	0.43	0.35	0.45	0.10	0.90
Total	89	14.66	14.28	13.41	1.25	1.18	0.75	1.88	0.44	77.06
Source of variation	**DF**	**Internodal length (cm)**	**Vine length(m)**	**Number of fruit per plant**	**Number of seed per fruit**	**Seed flesh ratio**	**Total soluble solids (brix)**	**Dry matter (g) %**	**Ascorbic acid content(mg/100g)**	**Fruit yield per plant(kg)**
Replication	2	0.36	0.13	36.68	21.06	3.04	0.082	0.06	9.65	0.003
Genotype	29	1.41**	0.86**	8.32**	9.60**	6.94**	0.668**	7.59**	29.96**	0.082**
Error	58	0.15	0.02	2.18	0.98	2.11	0.034	0.12	0.78	0.009
Total	89	0.56	0.29	4.96	4.24	3.70	0.242	2.55	10.49	0.032

*, ** significant at 5% and 1% level, respectively

Table 2: Mean performance of 30 genotypes for eighteen characters in bitter gourd

SN	Genotypes	DFMFA	DFFFA	DFFH	NNFMFA	NNFFFA	PBP	FL	FD	AFW	IL	VL	NFP	NSP	SFR	TSS	DM	AA	FYP
1	NDK-11	48.50	52.73	67.07	7.11	11.70	5.77	9.25	4.17	53.12	3.59	1.28	22.33	12.41	19.39	4.66	8.53	36.67	0.81
2	NDK-12	50.83	55.00	69.67	5.61	10.50	7.33	10.91	4.77	78.29	4.97	2.31	25.54	13.33	18.06	5.24	7.62	37.63	1.27
3	NDK-13	53.20	57.07	72.13	6.85	10.57	6.17	10.42	4.85	78.97	5.18	2.47	25.81	12.23	18.88	5.65	9.52	30.73	1.30
4	NDK-14	56.22	59.84	74.57	6.38	10.95	6.80	10.08	3.46	59.83	4.84	1.56	24.02	10.93	19.08	5.72	9.40	36.70	0.94
5	NDK-15	47.53	51.18	68.90	8.80	11.08	6.13	11.91	3.44	61.96	5.38	1.12	24.06	12.78	18.47	5.50	11.26	34.67	0.89
6	NDK-16	57.30	60.00	74.60	6.01	11.85	6.93	8.98	3.93	57.84	5.58	1.21	22.93	15.50	18.38	4.67	8.62	33.80	0.75
7	NDK-17	47.67	51.18	69.53	8.87	11.17	5.98	9.56	2.74	52.44	5.55	1.26	25.93	12.93	20.70	5.59	11.99	32.83	0.89
8	NDK-18	43.53	47.40	66.55	6.54	11.02	5.95	8.10	3.05	70.18	5.44	1.26	27.41	14.36	21.83	4.47	7.38	35.63	1.00
9	NDK-19	48.17	51.73	66.59	7.62	9.42	5.70	8.19	4.89	77.91	6.57	2.49	25.04	16.96	15.57	4.63	10.58	36.68	1.21
10	NDK-24-2	51.92	55.73	71.00	6.27	11.00	6.74	9.56	3.01	72.12	5.04	1.20	26.39	13.30	19.74	5.55	9.46	41.73	1.00
11	NDK-1/24	52.83	56.73	72.07	5.16	9.25	7.85	8.95	4.62	73.44	4.81	2.26	26.08	13.69	18.50	5.65	12.17	41.70	1.10
12	NDK-2/24	50.65	53.67	69.33	7.80	11.32	6.90	9.61	4.42	76.45	5.38	2.48	26.10	14.60	20.11	5.58	7.46	41.67	1.07
13	NDK-3/24	45.54	49.07	63.67	6.90	8.75	7.90	8.82	3.31	68.67	2.90	1.48	23.05	11.07	19.43	5.59	11.21	40.47	0.93
14	PB-14	47.66	51.00	64.67	5.74	8.95	7.20	9.10	4.43	79.85	5.27	2.22	22.37	12.12	19.25	4.76	9.21	41.67	1.06
15	PB-15	52.98	56.73	71.00	7.63	9.93	6.32	8.91	3.16	69.23	5.48	1.48	27.90	12.33	17.95	4.58	8.48	40.80	1.00
16	NDK-11/24	46.58	50.17	64.40	6.21	9.23	7.27	9.63	4.47	79.35	5.48	2.30	26.74	13.45	20.47	4.61	7.45	36.36	1.29
17	IC-44428	44.91	48.62	63.51	7.93	9.87	7.05	9.48	4.20	80.27	5.07	2.26	26.05	11.71	17.96	4.64	11.21	37.73	1.38
18	NDK-4/24	53.25	57.10	74.67	6.02	9.30	7.12	10.52	3.66	74.95	5.27	1.41	25.90	12.47	17.38	4.58	11.98	41.03	0.92
19	NDK-5/24	47.53	51.00	66.11	8.24	9.98	7.90	7.81	3.69	75.88	5.19	1.43	26.88	13.53	21.54	4.59	8.57	42.70	0.98
20	NDK-6/24	53.11	56.90	71.42	7.46	9.23	7.87	9.57	4.42	78.13	4.58	2.28	26.72	14.55	19.45	4.72	9.63	40.73	1.36
21	VBT-155	49.66	53.45	68.07	6.48	9.16	7.71	7.24	3.48	54.34	4.05	0.94	24.70	15.10	19.47	4.61	9.38	36.48	0.99
22	Kashi Pratishtha	46.98	50.83	66.56	5.72	9.10	6.96	8.63	3.53	64.80	4.87	1.40	25.06	17.93	17.56	4.61	11.76	40.53	1.08
23	IC-0656	52.96	55.77	63.55	7.04	9.25	7.08	4.88	3.10	66.53	4.63	1.16	22.07	15.19	20.87	5.56	8.60	40.70	0.94
24	VRBTG-169	53.61	57.07	71.96	5.99	8.97	7.16	9.56	3.48	68.00	3.72	1.10	23.38	15.15	19.41	5.35	12.11	36.53	0.90
25	NDK-7/24	51.85	55.77	69.37	8.23	9.98	6.11	7.96	3.63	70.12	4.79	1.16	23.39	12.82	19.81	5.50	7.69	35.59	1.03
26	NDK-8/24	55.23	59.17	74.32	5.93	8.87	5.96	8.24	3.33	72.60	5.03	1.42	25.10	12.84	15.67	5.48	10.52	38.38	1.05
27	NDK-24-3	47.07	51.13	71.07	6.13	8.66	7.06	9.61	4.16	80.64	4.91	2.48	26.39	17.51	18.61	5.42	8.57	40.57	1.37
28	NDK-9/24	54.19	58.07	72.34	8.22	9.98	8.03	8.85	3.74	81.85	4.96	1.12	23.08	14.60	20.63	5.28	7.53	34.60	1.05
29	NDK-10/24	50.57	54.45	69.33	7.34	9.51	7.73	8.57	3.56	80.76	4.87	1.25	23.78	16.25	18.25	5.32	10.99	35.70	1.02
30	Arka harit(c)	51.36	55.56	71.15	7.00	9.05	7.93	9.27	3.46	74.45	5.16	1.98	22.98	13.90	21.47	5.92	9.24	41.62	1.10
	Mean	50.45	54.14	69.31	6.91	9.92	6.95	9.07	3.81	71.10	4.95	1.66	24.91	13.85	19.13	5.13	9.60	38.09	1.06

	Min	43.53	47.40	63.51	5.16	8.66	5.70	4.88	2.74	52.44	2.90	0.94	22.07	10.93	15.57	4.47	7.38	30.73	0.75
	Max	57.30	60.00	74.67	8.87	11.85	8.03	11.91	4.89	81.85	6.57	2.49	27.90	17.93	21.83	5.92	12.17	42.70	1.38
	SE(d)	1.61	1.57	1.22	0.50	0.54	0.48	0.55	0.26	0.78	0.31	0.10	1.21	0.81	1.19	0.15	0.28	0.72	0.08
	C.D.	3.23	3.15	2.46	1.01	1.08	0.97	1.10	0.52	1.56	0.63	0.20	2.42	1.62	2.38	0.30	0.57	1.44	0.15
	C.V.	3.90	3.55	2.16	8.93	6.64	8.49	7.38	8.34	1.34	7.77	7.42	5.93	7.16	7.59	3.59	3.63	2.31	8.78

Table 3: Estimates of range, grand mean, phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), heritability in broad sense, genetic advance (Ga) and Ga in per cent of mean for eighteen characters in bitter gourd germplasm

Genotypes	Mean	Min	Max	Var (g)	Var (p)	Heritability (%)	GA	GA% mean	GCV (%)	PCV (%)	% CONT
Days to first male flower anthesis	50.45	43.53	57.30	10.99	14.87	73.92	5.87	11.64	6.57	7.64	8.45
Days to first female flower anthesis	54.14	47.40	60.00	10.78	14.47	74.51	5.84	10.79	6.07	7.03	7.30
Days to first fruit harvest	69.31	63.51	74.67	11.04	13.29	83.08	6.24	9.00	4.79	5.26	6.32
Node number of first male flower appearance	6.91	5.16	8.87	0.88	1.26	69.75	1.61	23.33	13.56	16.24	7.47
Node number of first female flower appearance	9.92	8.66	11.85	0.77	1.20	63.96	1.45	14.58	8.85	11.06	7.05
Primary branch per plant	6.95	5.70	8.03	0.42	0.77	54.59	0.99	14.17	9.31	12.60	6.14
Fruit length (cm)	9.07	4.88	11.91	1.41	1.86	75.90	2.13	23.50	13.09	15.03	5.58
Fruit diameter (cm)	3.81	2.74	4.89	0.32	0.43	76.35	1.03	26.96	14.98	17.14	3.52
Average fruit weight (gm)	71.10	52.44	81.85	77.09	77.99	98.84	17.98	25.29	12.35	12.42	5.43
Internodal length (cm)	4.95	2.90	6.57	0.42	0.57	73.94	1.15	23.17	13.08	15.21	4.64
Vine length(m)	1.66	0.94	2.49	0.28	0.30	94.89	1.07	64.20	31.99	32.84	3.87
Number of fruits per plant	24.91	22.07	27.90	2.05	4.23	48.44	2.05	8.24	5.75	8.26	7.10
Number of seed per fruit	13.85	10.93	17.93	2.87	3.85	74.50	3.01	21.75	12.23	14.17	3.28
Seed flesh ratio	19.13	15.57	21.83	1.61	3.72	43.29	1.72	8.99	6.63	10.08	4.24
Total soluble solids (brix)	5.13	4.47	5.92	0.21	0.25	86.18	0.88	17.13	8.96	9.65	7.12
Dry matter (g) %	9.60	7.38	12.17	2.49	2.61	95.36	3.17	33.06	16.43	16.83	5.64
Ascorbic acid content(mg/100g)	38.09	30.73	42.70	9.73	10.50	92.60	6.18	16.23	8.19	8.51	2.07
Fruit yield per plant(kg)	1.06	0.75	1.38	0.02	0.03	74.05	0.28	26.29	14.83	17.23	4.78

Conclusion

Among all the traits studied, the phenotypic coefficient of variation (PCV) was consistently higher than the corresponding genotypic coefficient of variation (GCV), indicating the influence of environmental factors on trait expression. However, the relatively narrow differences between PCV and GCV values for most traits suggested that the observed variability was predominantly genetic in nature. High estimates of both PCV and GCV were recorded for vine length, reflecting the presence of substantial genetic variability and a greater scope for improvement through selection. Furthermore, vine length, average fruit weight, fruit yield per plant, dry matter content, fruit diameter and fruit length exhibited high heritability coupled with high genetic advance as per cent of mean. This combination indicates the predominance of additive gene action in the inheritance of these traits and suggests that their expression is largely governed by heritable genetic factors. Therefore, direct phenotypic selection for vine length, average fruit weight and fruit yield per plant would be highly effective for enhancing yield potential and developing superior bitter gourd genotypes.

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