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Genetic variability, trait association and yield determinants in kalingada [*Citrullus lanatus* (Thunb.) Matsum & Nakai] : implications for targeted crop improvement

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ABSTRACT

Kalingada is a nutritionally valuable yet underexploited cucurbit crop with substantial potential for genetic improvement. Effective selection requires a comprehensive understanding of the extent of genetic variability and the interrelationships among yield-contributing traits. Twenty-four kalingada genotypes were evaluated for fourteen morphological, yield-related and quality traits to assess genetic variability, trait associations and the contribution of individual traits to fruit yield. Considerable variability was observed among the genotypes, with total number of fruits per plant, total number of pickings, fruit length and fruit yield per plant exhibiting high phenotypic and genotypic coefficients of variation. These traits also recorded high heritability coupled with high genetic advance, indicating the predominance of additive gene effects and the potential effectiveness of selection. Fruit yield per plant exhibited significant positive associations with total number of fruits per plant, total number of pickings, days to last picking and primary branches per vine at both phenotypic and genotypic levels, whereas days to opening of the first female flower, days to first picking and total soluble solids (TSS) showed significant negative associations with yield. Path-coefficient analysis revealed that total number of fruits per plant and average fruit weight exerted the highest positive direct effects on fruit yield, while days to first picking, days to edible maturity, fruit length, total soluble solids (TSS) and days to last picking exhibited negative direct effects; however, fruit diameter and primary branches per vine, despite negligible direct effects, contributed to yield mainly through positive indirect effects via total number of fruits per plant. The results indicated that selection based on fruit number, picking frequency, fruit diameter and primary branches per vine could be effective for enhancing fruit yield in kalingada, whereas fruit weight, despite its high direct effect, showed limited net contribution owing to its non-significant correlation with yield, and the study provides useful information for future genetic improvement programmes

Keywords : Kalingada, genetic variability, heritability, correlation, path analysis

INTRODUCTION

Kalingada [*Citrullus lanatus* (Thunb.) Matsum & Nakai] is a diploid species ($2n = 2X = 22$) belonging to the family Cucurbitaceae and is cultivated in several parts of India, although its commercial potential remains largely underexploited (Levi *et al.*, 2001). It is known by various regional names, including Kalind in Sanskrit, Kalingad in Marathi, Tarbooj in Hindi and Mateera in Marwari. The immature fruits, weighing approximately 100-150 g, are consumed as a vegetable and are valued for their flavour, nutritional properties and tolerance to dry growing conditions. Kalingada possesses considerable nutritional

value, with its fruits and seeds containing carbohydrates, proteins, minerals, fatty acids and several bioactive compounds. The fruits are characterized by the presence of carotenoids, particularly lycopene and β -carotene, as well as phenolic compounds and ascorbic acid, which contribute to their antioxidant potential (Nagal *et al.*, 2012; Zamuz *et al.*, 2021). Kalingada also contains L-citrulline and L-arginine, important amino acids associated with nitric oxide metabolism and vascular health (Tarazona-Diaz *et al.*, 2011; Zamuz *et al.*, 2021). The seeds are nutritionally valuable owing to their appreciable oil and protein contents and their predominance of unsaturated fatty acids, particularly linoleic acid (Mahla *et al.*, 2018). These nutritional and bioactive constituents enhance the dietary and functional

importance of kalingada and provide opportunities for its utilization as a nutrient-rich vegetable and seed crop. Moreover, its adaptation to dry environments and nutritional attributes make kalingada a valuable crop for dietary diversification and sustainable production in water-limited regions (Kumar *et al.*, 2025). Despite these attributes, systematic crop-improvement efforts in kalingada have remained limited.

Any breeding programme requires an understanding of the extent of genetic variability and its heritability, as these determine the effectiveness of selection and the identification of promising genotypes for further advancement. Previous investigations in *Citrullus lanatus* (Thunb.) Matsum & Nakai have revealed substantial genetic variability for yield and its component traits, with high heritability and genetic advance reported for several characters, indicating the potential for effective selection (Mahla and Choudhary, 2013; Mahla *et al.*, 2018). Studies involving Indian *Citrullus* germplasm have also demonstrated considerable variation for phenological, fruit and yield-related traits, along with significant genetic divergence among genotypes, providing valuable opportunities for crop improvement (Singh *et al.*, 2017; Singh *et al.*, 2018). More recently, phenotypic evaluation of seed-purpose *C. lanatus* genotypes under the arid conditions of the Thar region revealed substantial variability for important agronomic traits and identified genotypes with desirable trait combinations, emphasizing the breeding potential of this germplasm (Kumar *et al.*, 2025).

Kalingada exhibits characteristic cucurbit floral morphology, with solitary, axillary, yellow flowers and monoecious sex expression, in which staminate and pistillate flowers are produced separately on the same plant. Flowering and fruit development are influenced by genotype and environmental conditions, and variation in phenological traits such as days to flowering and maturity is of considerable significance for earliness, adaptation and yield improvement (Paris, 2015). Floral biology and pollination behaviour are also important considerations in Kalingada breeding, particularly for the development of controlled crosses and the utilization of diverse germplasm. Correlation and path-coefficient analyses provide additional insight into the relationships among traits by

identifying characters that contribute directly or indirectly to yield. As kalingada has received relatively limited research attention, both in India and elsewhere, the present study was undertaken to assess genetic variability, heritability, genetic advance and inter-trait associations among vegetable-type landraces, to identify promising traits and genotypes for future breeding programmes.

MATERIAL AND METHODS

The study was conducted at the Centre for Crop Improvement (CCI), Sardarkrushinagar Dantiwada Agricultural University (SDAU), Dantiwada, Gujarat during the summer season of 2022. Twenty-four Kalingada genotypes maintained at CCI were evaluated in a Randomized Block Design with three replications, maintaining a spacing of 3.0 × 1.0 m between plants. Standard package of practices was followed throughout the crop period. Observations were recorded on five randomly selected plants from each plot for fourteen traits, *viz.*, days to opening of the first male flower, days to opening of the first female flower, days to first picking, days to edible maturity, average fruit weight (g), fruit length (cm), fruit diameter (cm), total number of fruits per plant, total number of pickings, days to last picking, number of primary branches per vine, length of main vine (m), total soluble solids (°Brix) and fruit yield per plant (g).

Analysis of variance was performed following the procedure of Panse and Sukhatme (1985). Phenotypic and genotypic coefficients of variation, broad-sense heritability and genetic advance as a percentage of the mean were estimated following Burton and Devane (1953), Allard (1960) and Johnson *et al.* (1955), respectively. GCV and PCV were categorized according to Sivasubramanian and Madhavamenon (1973), while heritability and genetic advance as a percentage of the mean were classified as per Johnson *et al.* (1955). The respective criteria presented in Table 1. Genotypic and phenotypic correlation coefficients were estimated following Falconer (1981). Path-coefficient analysis, as proposed by Wright (1921) and adapted for plant breeding by Dewey and Lu (1959), was employed to partition the direct and indirect effects of component traits on fruit yield. The magnitude of direct and indirect effects was interpreted according to the scale suggested by Lenka

Table 1 : Categorization of genetic estimates

Estimates	GCV & PCV (%)	Heritability (h^2b) (%)	GAM (%)
Low	0 to 10	0 to 30	0 to 10
Moderate	10 to 20	30 to 60	10 to 20
High	More than 20	More than 60	More than 20

RESULTS AND DISCUSSION

Analysis of variance among the twenty-four genotypes revealed significant differences for all the traits studied, indicating the presence of substantial variability among the genotypes, which provides considerable scope for effective selection and further genetic improvement of kalingada.

Phenotypic and Genotypic Coefficient of Variation (PCV and GCV)

The highest PCV and GCV were recorded for total number

of fruits per plant, followed by total number of pickings, fruit length and fruit yield per plant (Table 2). Total soluble solids (TSS) and average fruit weight exhibited moderate PCV and GCV, whereas days to opening of the first male flower, days to opening of the first female flower, days to first picking, days to edible maturity, fruit diameter, days to last picking, primary branches per vine and length of main vine recorded comparatively low values for both parameters.

Table 2 : Variability parameters indicating variation among Kalingada genotypes for fourteen traits

Sr. No.	Trait	Mean	Range	σ^2_g	σ^2_p	GCV %	PCV %	$h^2(b)\%$	GA	GAM%
1	MF	35.54	32.67 - 39.33	1.94	3.07	3.92	4.93	63.36	2.29	6.43
2	FF	44.51	41.33 - 47.67	4.14	4.63	4.57	4.83	89.37	3.96	8.90
3	FP	56.97	54.00 - 66.00	9.41	10.74	5.38	5.75	87.59	5.91	10.38
4	DM	6.76	5.00 - 8.33	0.41	0.67	9.48	12.10	61.40	1.04	15.30
5	FW	156.52	129.97 - 190.40	274.47	341.02	10.58	11.80	80.48	30.62	19.56
6	FL	7.97	6.39 - 14.88	2.96	3.19	21.56	22.40	92.60	3.41	42.74
7	FD	6.40	5.82 - 7.00	0.07	0.13	4.17	5.59	55.50	0.41	6.39
8	TF	9.57	5.03 - 13.60	4.67	5.07	22.58	23.63	92.08	4.27	44.64
9	TP	11.51	7.00 - 17.00	6.73	7.64	22.53	24.01	88.08	5.02	43.56
10	DLP	98.47	92.00 - 103.00	8.94	11.88	3.04	3.50	75.31	5.35	5.43
11	PBV	4.08	3.47 - 5.13	0.06	0.37	5.96	14.87	16.05	0.20	4.92
12	LMV	3.26	2.64 - 4.11	0.10	0.29	9.86	16.59	35.32	0.39	12.07
13	TSS	3.81	2.87 - 4.73	0.17	0.21	10.73	12.08	78.93	0.75	19.64
14	FY	1483.1	807.35 - 1948.43	10116.9	11086.6	21.45	22.45	91.25	625.92	42.20

Where, **MF**: Days to opening of first male flower; **FF**: Days to opening of first female flower; **FP**: Days to first picking; **DM**: Days taken for edible maturity; **FW**: Average fruit weight (g); **FL**: Fruit length (cm); **FD**: Fruit diameter (cm); **TF**: Total number of fruits per plant; **TP**: Total number of pickings; **DLP**: Days taken for last picking; **PBV**: Primary branches per vine; **LMV**: Length of main vine (m); **TSS**: Total soluble solids ($^{\circ}$ Brix); **FY**: Fruit yield per plant (g). σ^2_g = Genotypic variance, σ^2_p = Phenotypic variance, **GCV** = Genotypic Coefficient of Variance, **PCV** = Phenotypic Coefficient of Variance, $h^2(b)$ = broad-sense heritability, **GA** = Genetic Advance, **GAM** = Genetic advance expressed as per cent of mean.

The differences between PCV and GCV were relatively narrow for most traits, indicating a comparatively limited environmental influence on their expression. However, comparatively larger differences were observed for primary branches per vine and length of main vine, which were associated with lower heritability estimates, indicating a

greater influence of environmental factors on the expression of these traits. The high PCV and GCV observed for several yield-related traits indicated substantial genetic variability, which could be effectively utilized in selection programmes (Gurve et al., 2021). Similar patterns of variability have been reported in other cucurbit crops, including sponge

gourd (Kumar *et al.*, 2013), cucumber (Kumari *et al.*, 2020) and bottle gourd (Rashid *et al.*, 2020).

Heritability and Genetic Advance (h^2 and GA)

Broad-sense heritability estimates ranged from 16.05 per cent for primary branches per vine to 92.60 per cent for fruit length (Table 2). High heritability was recorded for total number of fruits per plant (92.08%), fruit yield per plant (91.25%), days to opening of the first female flower (89.37%), total number of pickings (88.08%), days to first picking (87.59%), average fruit weight (80.48%), total soluble solids (78.93%), days to last picking (75.31%), days to opening of the first male flower (63.36%) and days to edible maturity (61.40%). Moderate heritability was observed for fruit diameter (55.50%) and length of main vine (35.32%), whereas primary branches per vine exhibited low heritability (16.05%).

Genetic advance as a percentage of the mean (GAM), considered along with heritability, provides an estimate of the expected response to selection. The highest GAM was recorded for total number of fruits per plant (44.64%), followed by total number of pickings (43.56%), fruit length (42.74%) and fruit yield per plant (42.20%). The lowest GAM was observed for primary branches per vine (4.92%), followed by days to last picking (5.43%), fruit diameter (6.39%) and days to opening of the first male flower (6.43%). Moderate GAM was recorded for days to first picking (10.38%), length of main vine (12.07%), days to edible maturity (15.30%), average fruit weight (19.56%) and total soluble solids (19.64%).

The occurrence of high heritability coupled with high genetic advance for several traits suggested a predominant contribution of additive genetic effects, indicating good prospects for improvement through direct selection. In particular, total number of fruits per plant, total number of pickings, fruit length and fruit yield per plant exhibited high heritability and high GAM, indicating substantial scope for genetic improvement of these traits. Similar findings have been earlier reported in other similar cucurbits like bottle gourd (Muralidharan, 2017; Varalakshmi *et al.*, 2018), bitter gourd (Talukder *et al.*, 2018) and sponge gourd (Kumar *et al.*, 2019).

Phenotypic and Genotypic Correlation

Fruit yield and its component traits are generally governed by polygenic inheritance and influenced by environmental variation. Therefore, selection for fruit yield in kalingada may be more effectively guided by the performance of associated component traits. A strong positive association between a component trait and yield may arise due to linkage or pleiotropic effects (Sprague, 1966). In the present study, fruit yield per plant exhibited significant positive correlations at both genotypic and phenotypic levels with fruit diameter, total number of fruits per plant, total number of pickings, days to last picking and primary branches per vine (Table 3). In contrast, days to opening of the first female flower, days to first picking, fruit length and total soluble solids (TSS) showed negative associations with fruit yield.

The present findings were in accordance with earlier reports of positive associations of fruit diameter, number of fruits, number of pickings, days to last picking and number of primary branches with fruit yield in bottle gourd (Deepthi *et al.*, 2016), muskmelon (Reddy *et al.*, 2017), cucumber (Kumar *et al.*, 2018; Rajawat *et al.*, 2018; Karthick *et al.*, 2019) and ridge gourd (Harshita *et al.*, 2019). These results indicated that selection for traits positively associated with fruit yield could contribute to improve fruit yield per plant in Kalingada.

Path Analysis (Direct and Indirect Effects)

Path coefficient analysis (Table 4) was performed to partition the correlations between individual traits and fruit yield into direct and indirect effects. At the genotypic level, total number of fruits per plant (0.999), total number of pickings (0.979) and average fruit weight (0.574) exhibited high positive direct effects, whereas days to opening of the first female flower (0.110) and days to first picking (- 0.122) showed low positive and negative direct effects, respectively. The remaining traits exhibited negligible direct effects according to Lenka and Mishra (1973). Although fruit diameter and primary branches per vine showed significant positive correlations with fruit yield, their positive direct effects were negligible, indicating that their associations with yield were primarily mediated through indirect effects.

Table 3 : Genotypic and phenotypic correlation coefficient among fourteen characters in Kalingada

	FF	FP	DM	FW	FL	FD	TF	TP	DLP	PBV	LMV	TSS	FY
MF	r_g -0.401 -0.294 *	0.019 -0.028 0.586 ** 0.527 **	0.251 0.220 0.116 0.085 0.201 0.163	0.305 0.254 * 0.008 0.010 0.433 * 0.367 **	0.024 0.020 0.505 * 0.462 ** 0.631 ** 0.579 **	-0.310 -0.078 -0.316 -0.199 -0.589 ** -0.399 **	0.183 0.116 -0.855 ** -0.752 ** -0.796 ** -0.728 **	0.192 0.111 -0.873 ** -0.739 ** -0.727 ** -0.648 **	-0.125 -0.107 -0.620 ** -0.489 ** -0.559 ** -0.459 **	0.068 -0.162 -0.801 ** -0.332 ** -0.376 -0.141	-0.057 -0.133 -0.184 -0.094 -0.384 -0.198	-0.295 -0.218 0.764 ** 0.676 ** 0.335 0.298 *	0.351 0.244 * -0.935 ** -0.818 ** -0.706 ** -0.643 **
FF													
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TSS													

*, ** significant at 5% and 1% level of significance, respectively.

MF: Days to opening of first male flower, **FF**: Days to opening of first female flower **FP**: Days to first picking, **DM**: Day taken for edible maturity, **FW**: Average fruit weight (g), **FL**: Fruit length(cm), **FD**: Fruit diameter (cm), **TF**: Total number of fruits per plant, **TP**: Total number of picking, **DLP**: Days taken for last picking, **PBV**: Primary branches per vine, **LMV**: Length of main vine (m), **TSS**: Total Soluble Solids (°Brix), **FY**: Fruit yield per plant(g), r_g : Genotypic correlation coefficient, r_p : Phenotypic correlation coefficient

Table 4 : Direct and indirect effects of yield components on fruit yield in kalingada

Sr. No.	Trait	MF	FF	FP	DM	FW	FL	FD	TF	TP	DLP	PBV	LMV	TSS	Genotypic correlation with FY
1	MF	0.059	-0.044	-0.002	-0.015	0.175	0.000	-0.015	0.183	0.002	0.001	0.002	-0.003	0.010	0.351
2	FF	-0.024	0.110	-0.072	-0.007	0.005	-0.010	-0.016	-0.855	-0.009	0.006	-0.027	-0.011	-0.025	-0.935 **
3	FP	0.001	0.065	-0.122	-0.012	0.249	-0.012	-0.029	-0.795	-0.008	0.005	-0.013	-0.023	-0.011	-0.706 **
4	DM	0.015	0.013	-0.024	-0.061	0.240	-0.010	-0.006	-0.188	-0.002	0.002	-0.005	0.006	-0.005	-0.025
5	FW	0.018	0.001	-0.053	-0.026	0.574	-0.009	-0.003	-0.411	-0.004	0.003	-0.006	-0.031	-0.005	0.048
6	FL	0.001	0.056	-0.077	-0.031	0.258	-0.020	-0.038	-0.580	-0.006	0.004	-0.009	-0.007	-0.014	-0.462 *
7	FD	-0.018	-0.035	0.072	0.007	-0.039	0.015	0.050	0.436	0.004	-0.003	-0.001	0.001	0.004	0.491 *
8	TF	0.011	-0.094	0.097	0.012	-0.236	0.011	0.022	0.999	0.010	-0.007	0.024	0.023	0.023	0.894 **
9	TP	0.011	-0.096	0.089	0.013	-0.210	0.011	0.018	0.979	0.011	-0.007	0.029	0.020	0.024	0.890 **
10	DLP	-0.007	-0.068	0.068	0.015	-0.188	0.008	0.015	0.784	0.008	-0.009	0.019	0.027	0.021	0.692 **
11	PBV	0.004	-0.088	0.046	0.008	-0.095	0.005	-0.002	0.707	0.009	-0.005	0.034	-0.017	0.021	0.626 **
12	LMV	-0.003	-0.020	0.047	-0.007	-0.303	0.002	0.001	0.382	0.004	-0.004	-0.010	0.059	0.008	0.156
13	TSS	-0.017	0.084	-0.041	-0.009	0.093	-0.008	-0.006	-0.677	-0.007	0.006	-0.022	-0.015	-0.033	-0.653 **

*, ** significant at 5% and 1% level of significance, respectively.

MF: Days to opening of first male flower, **FF**: Days to opening of first female flower **FP**: Days to first picking, **DM**: Day taken for edible maturity, **FW**: Average fruit weight (g), **FL**: Fruit length(cm), **FD**: Fruit diameter (cm), **TF**: Total number of fruits per plant, **TP**: Total number of picking, **DLP**: Days taken for last picking, **PBV**: Primary branches per vine, **LMV**: Length of main vine (m), **TSS**: Total Soluble Solids (°Brix), **FY**: Fruit yield per plant(g); (Residual effect = -

CONCLUSION

The present study revealed substantial genetic variability among the kalingada genotypes for yield and associated traits. High heritability coupled with high genetic advance for fruit number, number of pickings, fruit length and fruit yield indicated considerable potential for improvement through direct selection. Correlation and path-coefficient analyses identified fruit number and number of pickings as major direct contributors to fruit yield, while fruit diameter and primary branches per vine, despite their negligible direct effects, showed significant positive associations with yield through positive indirect effects via fruit number, indicating their potential for indirect selection. Although average fruit weight exhibited a high positive direct effect, its association with fruit yield was non-significant owing to a compensatory negative indirect effect through fruit number, suggesting limited utility as a selection criterion. Therefore, simultaneous selection for fruit number, number of pickings, fruit diameter and primary branches per vine may be effective for improving fruit yield in Kalingada. The findings provide useful baseline information for future breeding programmes aimed at developing high-yielding and regionally adapted genotypes.

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