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Vridulashree V
Department of Seed Science and
Technology, College of Agriculture,
Dharwad, University of
Agricultural Sciences, Dharwad,
Karnataka, India

Mangi VL
Department of Horticulture,
Agricultural Research Station,
Kallolli, University of Agricultural
Sciences, Dharwad, Karnataka,
India

Badiger BA
Department of Seed Science and
Technology, College of Agriculture,
Dharwad, University of
Agricultural Sciences, Dharwad,
Karnataka, India

Harsha B
Department of Horticulture,
College of Agriculture, Dharwad,
University of Agricultural Sciences,
Dharwad, Karnataka, India

Manu B
ICAR-Indian Institute of Pulses
Research, Regional Research
Station, Dharwad, University of
Agricultural Sciences, Dharwad,
Karnataka, India

Hosamani J
Department of Seed Science and
Technology, College of Agriculture,
Dharwad, University of
Agricultural Sciences, Dharwad,
Karnataka, India

Corresponding Author:
Vridulashree V
Department of Seed Science and
Technology, College of Agriculture,
Dharwad, University of
Agricultural Sciences, Dharwad,
Karnataka, India

Genetic variability, trait association and divergence analysis of ridge gourd [*Luffa acutangula* (L.) Roxb.] genotypes for growth, flowering and yield related traits

Vridulashree V, Mangi VL, Badiger BA, Harsha B, Manu B and Hosamani J

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Abstract

During the *kharif* season of 2025, eight ridge gourd genotypes were evaluated at the Agricultural Research Station, Kallolli, employing a randomized complete block design with three replications for 15 growth, flowering and yield related traits. Analysis of variance revealed significant genotypic variation for all the traits studied. Gujanatti Local recorded the highest fruit yield (26.26 tonnes per hectare) and seed yield (1.85 tonnes per hectare), whereas Kashi Khushi despite flowering earlier recorded the lowest fruit yield (1.71 tonnes per hectare) due to its limited vegetative growth. Arka Prasanna was the better performing released variety (17.10 tonnes per hectare). Fruit and seed yield traits showed high genotypic and phenotypic coefficients of variation (54.12 to 61.29 per cent and 55.98 to 62.11 per cent, respectively), high heritability (above 90 per cent) and high genetic advance expressed as percentage of mean (107.8 to 124.6 per cent), indicating good scope for improvement through direct selection. Fruit yield per vine was significantly and positively correlated with fruit weight ($r = 0.96$), seed yield ($r = 0.94$) and vine length @ 45 DAS ($r = 0.92$). Path coefficient analysis, carried out after screening for multicollinearity, showed that sex ratio, number of fruits per vine and seed yield exerted the greatest direct effect on fruit yield. Principal component analysis accounted for 90.38 per cent of the total variability in the first two components and clearly separated the higher yielding genotypes, Gujanatti Local and Mallapur Local, from the poor performing genotype Kashi Khushi. Genetic divergence, assessed through standardized squared Euclidean distance and Tocher's clustering method, grouped the eight genotypes into four clusters, with Kashi Khushi and Arka Sumeet each forming distinct single genotype clusters. The maximum inter-cluster distance separated Kashi Khushi from the high yielding cluster comprising Gujanatti Local and Mallapur Local. On the basis of yield performance, genetic divergence and multivariate analysis, Gujanatti Local, Mallapur Local and Arka Prasanna were identified as the most promising genotypes for further evaluation and utilization in breeding programmes in the Northern transition zone of Karnataka.

Keywords: Genetic advance, genetic divergence, genetic variability, heritability, path analysis, principal component analysis

Introduction

Ridge gourd [*Luffa acutangula* (L.) Roxb.], a warm season diploid ($2n = 2x = 26$) native to the Indian subcontinent, is cultivated for its immature fruit as well as for its high nutritional and therapeutic properties (Shendge and Belemkar, 2018) ^[1]. At the national level, the crop area is approximately 24,800 hectares with an annual production of 3,16,925 metric tonnes (MT). However, the 3,210 hectares of crop land in Karnataka only produced 8.94 MT/ha (Directorate of Horticulture, 2023) ^[2], which is significantly lower than yield potential for the crop. India's rich cucurbit genetic diversity (Bose and Som, 1986) ^[3] offers the potential to close this gap, but fruit yield in ridge gourd is governed by numerous interrelated component traits comprising vegetative growth, reproductive behaviour, fruit and seed development, accordingly germplasm must be screened across a broad trait complex rather than for just yield.

Partitioning phenotypic variability into its genotypic and environmental components through genotypic and phenotypic coefficients of variation, heritability and genetic advance helps identify traits amenable to direct selection (Burton, 1952; Johnson *et al.*, 1955) ^[4,5] and correlation studies

reveal patterns of trait association and path coefficient analysis partitions these correlations into direct and indirect effects, permitting more reliable indirect selection (Dewey and Lu, 1959)^[6]. Principal component analysis summarizes multi-trait variability along a few orthogonal axes and thereby facilitates identification of divergent, complementary genotypes (Iezzoni and Pritts, 1991^[7]; Mohammadi and Prasanna, 2003^[8]), while standardized squared Euclidean distance together with Tocher's clustering provides a complementary, quantitative basis for grouping genotypes according to overall genetic distance and for identifying divergent parental combinations for hybridization (Singh and Chaudhary, 1985)^[9]. Combined evaluations of this kind have been reported in ridge gourd by Shah and Kale (2002)^[10], Hanumegowda (2011)^[11], Bhargava *et al.* (2017)^[12], Shodhan Jain *et al.* (2023)^[13] and Amulya *et al.* (2025)^[14] and in other cucurbits. However, studies comparing released varieties alongside local landraces within a single evaluation panel remain scarce for this crop. Most earlier studies have evaluated either released varieties or local collections but not both together, which limits the scope for identifying complementary parental combinations for breeding programmes. The present study therefore evaluated eight ridge gourd genotypes for growth, flowering and yield related traits, together with their genetic variability, trait association and multivariate diversity, with the objective of identifying superior genotypes and reliable selection criteria for cultivation and breeding.

Material and Methods

Field evaluation was conducted in *kharif* 2025 at the Agricultural Research Station, Kallolli, University of Agricultural Sciences, Dharwad, Karnataka (16°08'N latitude, 74°49'E longitude, 534 m above sea level). The soil at the experimental site was sandy to medium black, with a pH of 7.5 to 8.0. The climate was semi-arid, with an average annual rainfall of around 600 mm. During the crop season (August–November 2025), the mean maximum and minimum temperatures ranged between 28–30°C and 16–21°C, respectively. Eight genotypes (Arka Sumeet, Arka Prasanna, Pusa Nasdar, Kashi Shivani, Kashi Nanda, Kashi Khushi, Mallapur Local and Gujanatti Local) were evaluated in a randomized complete block design with three replications, at a spacing of 120 cm × 90 cm and plot size of 10.8 m². Vine length and number of primary branches (at 45 and 90 days after sowing), days to first male and female flower, days to 50% flowering, sex ratio (male to female flower ratio), number of fruits per vine, fruit weight, fruit yield (kg per vine and t/ha), number of seeds per fruit, seed yield and test weight (100-seed weight) were recorded on five randomly tagged plants per replication. Seed of the released cultivars was obtained from ICAR-Indian Institute of Horticultural Research, Bengaluru; ICAR-Indian Agricultural Research Institute, New Delhi; and ICAR-Indian Institute of Vegetable Research, Varanasi, while local landraces were collected from farmers in the Northern transition zone of Karnataka. Crop management followed the recommended package of practices for ridge gourd in the region, including basal application of farmyard manure at 20 t/ha and fertilizer at 100:50:50 kg NPK per hectare, with 50% of the nitrogen and the full dose of phosphorus and potassium applied basally and the remaining nitrogen applied in two split doses at 30 and 60 days after sowing. Irrigation was provided as required to maintain adequate soil moisture.

Statistical analysis

Analysis of variance was carried out following Panse and Sukhatme (1985)^[15]. Genotypic and phenotypic coefficients of

variation were calculated following Burton (1952)^[4] as:

$$PCV(\%) = \frac{\sqrt{\text{Phenotypic variance}}}{\text{Mean}} \times 100$$

$$GCV(\%) = \frac{\sqrt{\text{Genotypic variance}}}{\text{Mean}} \times 100$$

Broad-sense heritability was calculated following Lush (1940)^[16] as:

$$h^2(bs) = \frac{\text{Genotypic variance}}{\text{Phenotypic variance}}$$

Genetic advance was calculated following Johnson *et al.* (1955)^[5] as:

$$GA = k \times h^2 \times \sqrt{\text{Phenotypic variance}}$$

wherein *k* is the standardized selection differential (*k* = 2.06 at 5% selection intensity).

Genetic advance expressed as percentage of mean was calculated as:

$$GAM = \frac{GA}{\text{Mean}} \times 100$$

Genotype mean values were used to calculate Pearson's correlation coefficient, applied both to examine trait associations and as the basis for principal component analysis as:

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \times \sum(y_i - \bar{y})^2}}$$

Before path coefficient analysis, the predictor traits were screened for multicollinearity using the variance inflation factor:

$$VIF = \frac{1}{(1 - R_i^2)}$$

wherein *R*_i² is the coefficient of determination obtained by regressing each predictor trait on the remaining predictor traits and a subset of five traits with variance inflation factor below 10 was retained for path analysis. Path coefficient analysis was carried out following Dewey and Lu (1959)^[6], partitioning the correlation of each trait with fruit yield per vine as:

$$r_{ij} = p_{ij} + \sum_k (r_{ik} \times p_{kj})$$

wherein *p*_{ij} is the direct effect of trait *i* on fruit yield per vine and the summation term gives the indirect effects operating through all other traits *k*, with the residual effect calculated as

$$R_{eff} = \sqrt{1 - R_j^2}$$

Genetic divergence among the genotypes was assessed using the standardized squared Euclidean distance:

$$D^2 = \sum_k (Z_{ik} - Z_{jk})^2$$

for each pair of genotypes i and j , wherein Z_{ik} is the standardized value of trait k in genotype i , computed across all 15 traits. This approach removes scale differences among traits while preserving their relative contribution to overall divergence, thereby providing a robust basis for genotype clustering. Genotypes were grouped into clusters following Tocher's method (Rao, 1952; Singh and Chaudhary, 1985) [17, 9], with the cluster-formation threshold defined as the mean of each genotype's minimum squared distance to its nearest neighbour; genotypes were added sequentially to a cluster only while their average distance to the existing cluster members remained below this threshold. All analyses were performed using R software (R Core Team, 2024) [18].

A composite rank-sum multi-trait selection index was additionally computed as:

$$RSI_i = \sum_{t=1}^m Rank(T_{it})$$

summed across traits t , by ranking all eight genotypes from 1 (best) to 8 (poorest) for seven yield-determinant traits, namely fruit yield per vine, fruit yield per hectare, seed yield, fruits per vine, fruit weight, test weight and vine length at 45 DAS and summing the ranks across traits for each genotype. A lower rank-

sum indicates superior overall performance across this set of traits.

Results and Discussion
Plant growth, flowering and yield performance

Analysis of variance revealed significant genotypic differences for all 15 quantitative traits studied (Table 1). Vine length at 90 days after sowing ranged from 2.03 m in Kashi Khushi to 4.24 m in Mallapur Local, with Gujanatti Local (4.05 m) and Arka Prasanna (3.92 m) statistically on par with the highest value. The number of primary branches showed a broadly similar genotype-wise pattern. Genotypic variation in vine length and branching in ridge gourd has similarly been reported by Koppad *et al.* (2015) [19], Rathore *et al.* (2017) [20] and Sushmitha *et al.* (2019) [21]. Days to first male flower, first female flower and 50% flowering ranged from 35.83 to 42.00, 41.00 to 51.50 and 43.33 to 52.00 days, respectively, while sex ratio ranged from 20.84 in Kashi Khushi to 24.48 in Arka Sumeet. Kashi Khushi with combined earliest flowering and the lowest sex ratio with the lowest fruit yield, indicating that a favourable sex ratio alone cannot compensate for limited vegetative growth, a pattern consistent with the findings of Shah and Kale (2002) [10] and Karuppaiah *et al.* (2005) [22].

Table 1: Per se performance of eight ridge gourd genotypes for growth, flowering and yield attributing traits

Trait	Pusa Nasdar	Arka Sumeet	Arka Prasanna	Kashi Shivani	Kashi Nanda	Kashi Khushi	Gujanatti Local	Mallapur Local
Vine length – 45 DAS (m)	2.20	2.05	2.28	1.95	2.02	1.52	2.58	2.62
Vine length – 90 DAS (m)	3.07	2.37	3.92	3.56	3.43	2.03	4.05	4.24
Primary branches – 45 DAS	2.51	2.06	2.62	2.48	2.54	1.17	3.02	2.95
Primary branches – 90 DAS	4.06	3.13	4.15	3.88	4.08	2.19	4.52	4.42
Days to first male flower	37.50	42.00	39.83	38.77	38.40	35.83	39.50	40.90
Days to first female flower	41.00	51.50	45.00	45.50	46.77	41.50	42.73	47.00
Days to 50% flowering	44.67	52.00	48.00	47.00	47.67	43.33	46.67	49.67
Sex ratio (M:F)	22.14	24.48	23.12	21.04	22.46	20.84	23.64	22.92
Fruits per vine	11.90	9.90	13.00	14.00	12.00	8.90	15.00	16.00
Fruit weight (g)	117.97	165.60	185.00	120.60	152.96	38.60	252.17	206.26
Fruit yield per vine (kg)	1.75	1.89	3.42	1.65	2.46	0.40	5.23	4.11
Fruit yield (t/ha)	8.20	9.14	17.10	7.98	11.96	1.71	26.26	20.18
Seeds per fruit	138.60	126.67	150.00	139.60	147.60	90.60	168.60	156.60
Seed yield (t/ha)	0.48	0.75	1.42	0.65	1.26	0.27	1.85	1.64
Test weight (g)	11.47	10.87	12.27	12.07	11.67	9.27	13.07	12.67

DAS-Days after sowing; M:F-Male:female flowers. Mean, S.Em±, CD (5%) and CV for each trait are given in Table 2. Seed coat colour was uniform (RHS Black 202A) across all genotypes.

Fruit yield varied from 1.71 t/ha in Kashi Khushi to 26.26 t/ha in Gujanatti Local, followed by Mallapur Local (20.18 t/ha) and Arka Prasanna (17.10 t/ha). The superior genotypes generally combined a higher number of fruits per vine with greater fruit weight, more seeds per fruit and higher seed yield, results are in agreement with Harika *et al.* (2012) [23], Varalakshmi *et al.* (2015) [24] and Sushmitha *et al.* (2019) [21]. Considerable variation in fruit number, fruit weight, fruit yield and seed-related traits has likewise been reported in ridge gourd by Ananthan and Krishnamoorthy (2017) [25], Bhargava *et al.* (2017) [12] and Shodhan Jain *et al.* (2023) [13], supporting the usefulness of these traits for genotype discrimination and selection. Similarly wide variability for yield and yield-attributing traits, together with good prospects for genotype selection, has recently been reported for ridge gourd germplasm accessions by Jha *et al.* (2025) [26] and for other cucurbits such as snap melon by Kumar *et al.* (2026) [27].

Genetic variability parameters

For every trait studied, the phenotypic coefficient of variation exceeded the genotypic coefficient of variation (Table 2), indicating some environmental contribution to phenotypic expression, although the difference between the two was

relatively small for several yield traits. The narrow gap between genotypic and phenotypic coefficients of variation for fruit yield per hectare (61.29 and 62.11%, respectively) and for seed yield (54.12 and 55.98%, respectively) suggested minimal environmental influence on these traits, reinforcing their reliability for direct selection. In contrast, the wider gap observed for sex ratio (genotypic coefficient of variation 4.45% against phenotypic coefficient of variation 7.13%) indicated substantial environmental modulation, consistent with the known sensitivity of sex expression to environmental factors in cucurbits. Fruit weight, fruit yield per vine, fruit yield per hectare and seed yield showed high heritability (above 85%) together with high genetic advance expressed as percentage of mean (84.1 to 124.58%), indicating substantial genetic variation and favourable prospects for selection. Following the classification of Johnson *et al.* (1955) [5], these traits fell into the category of high heritability combined with high genetic advance, suggesting a good response to selection. Similar combinations of high genotypic and phenotypic coefficients of variation, heritability and genetic advance have been reported in ridge gourd by Koppad *et al.* (2015) [19], Ananthan and Krishnamoorthy (2017) [25], Narasannavar *et al.* (2017) [28], Shodhan Jain *et al.* (2023) [13], Subhash *et al.* (2024)

[29] and Rai *et al.* (2025) [30]. In contrast, sex ratio combined relatively low heritability (38.92%) with low genetic advance (1.29%), suggesting greater environmental influence and a less predictable response to direct selection. Variation in heritability

and genetic advance among flowering and sex expression traits has also been reported previously by Varalakshmi *et al.* (2015) [24] and Deokar *et al.* (2024) [31].

Table 2: Descriptive statistics and genetic parameters for growth, flowering and yield attributing traits in ridge gourd genotypes

Trait	Mean	Range	S.Em±	CD (5%)	CV (%)	GCV (%)	PCV (%)	h ² (bs) (%)	GA	GA (% mean)
Vine length - 45 DAS (m)	2.15	1.52-2.62	0.15	0.44	11.67	15.12	19.10	62.68	0.53	24.66
Vine length - 90 DAS (m)	3.33	2.03-4.24	0.17	0.50	8.62	23.27	25.06	86.19	1.48	44.49
Primary branches - 45 DAS	2.42	1.17-3.02	0.15	0.45	10.60	23.38	25.77	82.27	1.06	43.68
Primary branches - 90 DAS	3.76	2.19-4.52	0.15	0.45	6.82	19.85	21.12	88.28	1.44	38.41
Days to first male flower	39.09	35.83-42.00	0.45	1.35	1.98	4.80	5.23	84.33	3.55	9.08
Days to first female flower	45.12	41.00-51.50	0.73	2.20	2.79	7.45	7.97	87.31	6.47	14.34
Days to 50% flowering	47.38	43.33-52.00	0.96	2.91	3.51	5.34	6.42	69.11	4.33	9.14
Sex ratio (M:F)	22.58	20.84-24.48	0.72	2.17	5.49	4.45	7.13	38.92	1.29	5.71
Fruits per vine	12.59	8.90-16.00	0.53	1.61	7.31	18.79	20.25	86.15	4.52	35.93
Fruit weight (g)	154.90	38.60-252.17	6.55	19.84	7.32	41.47	42.12	96.91	130.27	84.10
Fruit yield per vine (kg)	2.61	0.40-5.23	0.16	0.48	10.55	59.04	60.03	96.72	3.13	119.60
Fruit yield (t/ha)	12.82	1.71-26.26	0.74	2.25	10.02	61.29	62.11	97.37	15.97	124.58
Seeds per fruit	140.23	90.60-168.60	5.79	17.53	7.14	16.45	17.46	88.70	44.75	31.91
Seed yield (t/ha)	1.05	0.31-1.85	0.05	0.14	7.65	54.12	55.98	93.46	1.13	107.78
Test weight (g)	11.67	9.27-13.07	0.38	1.16	5.68	9.64	11.24	73.56	1.99	17.03

GCV-Genotypic coefficient of variation; PCV-Phenotypic coefficient of variation; h² (bs)-Heritability in broad sense (single environment); GA-Genetic advance; DAS-Days after sowing; S.Em±-Standard error of mean; CD-Critical difference; CV-Coefficient of variation (experimental). Error degrees of freedom = 14 (RCBD, r = 3, t = 8).

Correlation and path analysis

Phenotypic correlation among the traits studied (Table 3 and Fig. 1) showed that fruit yield per vine was most strongly associated with fruit weight ($r = 0.96$), seed yield ($r = 0.94$) and vine length at 45 days after sowing ($r = 0.92$). Positive associations of fruit yield with fruit weight, fruits per vine, vine length and branching have been reported previously by Varalakshmi *et al.* (2015) [24], Ananthan and Krishnamoorthy (2017) [25], Narasannavar *et al.* (2017) [28] and Deokar *et al.* (2024) [31]. Days to flowering traits formed a comparatively distinct group, consistent with earlier reports of weaker or negative associations between earliness traits and yield by Karuppaiah *et al.* (2005) [22].

Path coefficient analysis using the five-trait subset (Table 4) revealed that sex ratio (0.506), fruits per vine (0.496) and seed yield (0.485) exerted the greatest direct effects on fruit yield per vine. Notably, Varalakshmi *et al.* (2015) [24], evaluating ten ridge gourd genotypes, reported fruit weight as the trait with the highest direct effect (0.847) on fruit yield per hectare, whereas in the present study fruit weight was not retained in the final path model owing to screening for multicollinearity and sex ratio, fruits per

vine and seed yield emerged instead as the principal direct contributors. This difference may be attributed to the different genotype panels used, the inclusion of local landraces alongside released varieties in the present study and the multicollinearity screening applied, which removed redundant predictor traits. Ananthan and Krishnamoorthy (2017) [25] and Manikandan *et al.* (2017) [32] reported similar positive direct contributions of fruits per vine and fruit weight, though the extent and relative significance of the direct effects differed among studies. In a larger, companion evaluation of 27 ridge gourd genotypes by Harsha *et al.* (2026) [33] likewise identified average fruit weight and number of fruits per vine as the traits with the highest direct effects on yield, lending independent support to the central role of these two traits, even though their relative ranking against sex ratio and seed yield differed from that observed in the present panel. Primary branches at 90 days after sowing and days to first female flower acted mainly through indirect pathways. The path model accounted for 99.6% of the variation in fruit yield per vine (residual effect - 0.065).

Table 3: Pearson phenotypic correlation coefficients among 15 growth, flowering, fruit and seed-yield traits in ridge gourd genotypes (genotype mean values, n = 8)

Trait	VL45	VL90	B45	B90	MF	FF	D50F	SR	F/V	FW	FY/V	FY/ha	S/F	SY	TW
VL45	1.00														
VL90	0.83**	1.00													
B45	0.91**	0.92**	1.00												
B90	0.88**	0.90**	0.98**	1.00											
MF	0.61	0.38	0.52	0.40	1.00										
FF	0.11	-0.01	0.11	0.00	0.82*	1.00									
D50F	0.42	0.23	0.37	0.25	0.96**	0.94**	1.00								
SR	0.61	0.23	0.45	0.41	0.83*	0.59	0.76*	1.00							
F/V	0.83*	0.95**	0.89**	0.83*	0.39	-0.01	0.22	0.16	1.00						
FW	0.91**	0.77*	0.86**	0.81*	0.73*	0.31	0.57	0.77*	0.73*	1.00					
FY/V	0.92**	0.84**	0.85**	0.82*	0.54	0.07	0.35	0.60	0.80*	0.96**	1.00				
FY/ha	0.92**	0.84**	0.84**	0.82*	0.53	0.07	0.35	0.60	0.80*	0.96**	1.00**	1.00			
S/F	0.89**	0.92**	0.99**	0.96**	0.53	0.12	0.37	0.45	0.89**	0.88**	0.87**	0.86**	1.00		
SY	0.80*	0.81*	0.78*	0.77*	0.50	0.20	0.40	0.54	0.74*	0.89**	0.94**	0.94**	0.79*	1.00	
TW	0.89**	0.95**	0.98**	0.94**	0.53	0.11	0.36	0.41	0.93**	0.87**	0.88**	0.87**	0.99**	0.80*	1.00

VL45/VL90-Vine length 45/90 DAS; B45/B90-Primary branches 45/90 DAS; MF/FF-Male/female flowers; D50F-Days to 50% flowering; SR-Sex ratio; F/V-Fruits per vine; FW-Fruit weight; FY/V-Fruit yield per vine; FY/ha-Fruit yield per hectare; S/F-Seeds per fruit; SY-Seed yield; TW-Test weight. Tabulated values correspond to the heat map shown in Fig. 1. *, ** Significant at 5% and 1% probability levels, respectively (critical r at n=8, df=6; $r_{0.05}=0.707$, $r_{0.01}=0.834$).

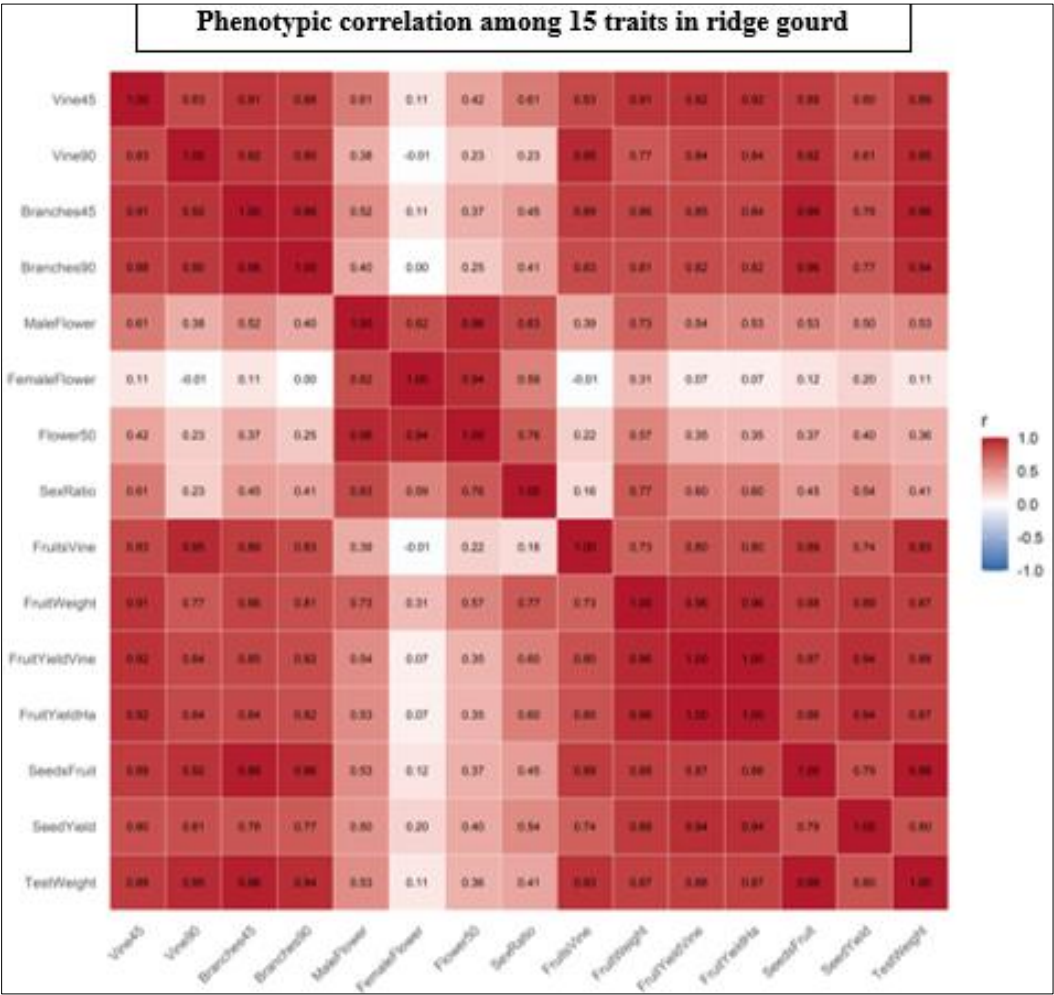


Fig 1: Heat map of phenotypic correlation coefficients among 15 growth, flowering, fruit and seed-yield traits in ridge gourd (genotype mean values, n = 8).

Table 4: Path coefficient analysis showing direct (diagonal, bold) and indirect effects of five traits on fruit yield per vine in ridge gourd genotypes

Trait	B90	FF	SR	FV	SY	r with FYV
B90	-0.168	-0.000	0.209	0.410	0.372	0.823**
FF	-0.000	-0.311	0.297	-0.007	0.097	0.075
SR	-0.069	-0.182	0.506	0.081	0.264	0.600
FV	-0.138	0.004	0.083	0.496	0.358	0.803*
SY	-0.128	-0.062	0.276	0.366	0.485	0.937**

B90-Primary branches @ 90 DAS; FF-Days to first female flower; SR-Sex ratio; FV-Fruits per vine; SY-Seed yield; FYV-Fruit yield per vine. Residual effect = 0.065; R² = 0.996. Values in the r with FYV column followed by one or two asterisks are significant at 5% and 1%, respectively.

Principal component analysis

Principal component analysis of all 15 quantitative traits (Table 5 and Fig. 2) accounted for 90.38% of the total variation through the first two components, with the first component (71.22%) representing an overall vigour and yield axis. Gujanatti Local and Mallapur Local were positioned towards the negative side of this axis, associated with higher fruit yield, fruits per vine, fruit weight and seed yield, whereas Kashi Khushi occupied the contrasting region, reflecting its lower yield and vegetative growth. The second component (19.16%) mainly differentiated flowering behaviour, with Arka Sumeet associated with late flowering and a higher sex ratio. Similar multivariate discrimination of ridge gourd genotypes on the basis of vegetative, flowering and yield traits has been reported by Yadav *et al.* (2017)^[34] and Sushmitha

et al. (2019)^[21] and more recently in the wider *Luffa* genus by Zeng *et al.* (2026)^[35] and in sponge gourd by Prabakaran *et al.* (2025)^[36].

Table 5: Principal component analysis of growth, flowering and yield related traits in ridge gourd genotypes

Component / Trait	PC1	PC2
Eigenvalue	10.68	2.87
Variance (%)	71.22	19.16
Cumulative variance (%)	71.22	90.38
Vine length - 45 DAS	-0.291	0.037
Vine length - 90 DAS	-0.274	0.202
Primary branches - 45 DAS	-0.291	0.104
Primary branches - 90 DAS	-0.277	0.158
Days to first male flower	-0.206	-0.420
Days to first female flower	-0.077	-0.534
Days to 50% flowering	-0.158	-0.492
Sex ratio	-0.190	-0.375
Fruits/vine	-0.263	0.203
Fruit weight	-0.296	-0.081
Fruit yield/vine	-0.290	0.064
Fruit yield/ha	-0.289	0.064
Seeds/fruit	-0.292	0.100
Seed yield	-0.273	0.025
Test weight	-0.293	0.115

PC1, PC2, First and second principal components; DAS, Days after sowing. Values in the trait rows are loadings (eigenvector coefficients) of each trait on the respective component; loadings correspond to the biplot shown in Figure 2.

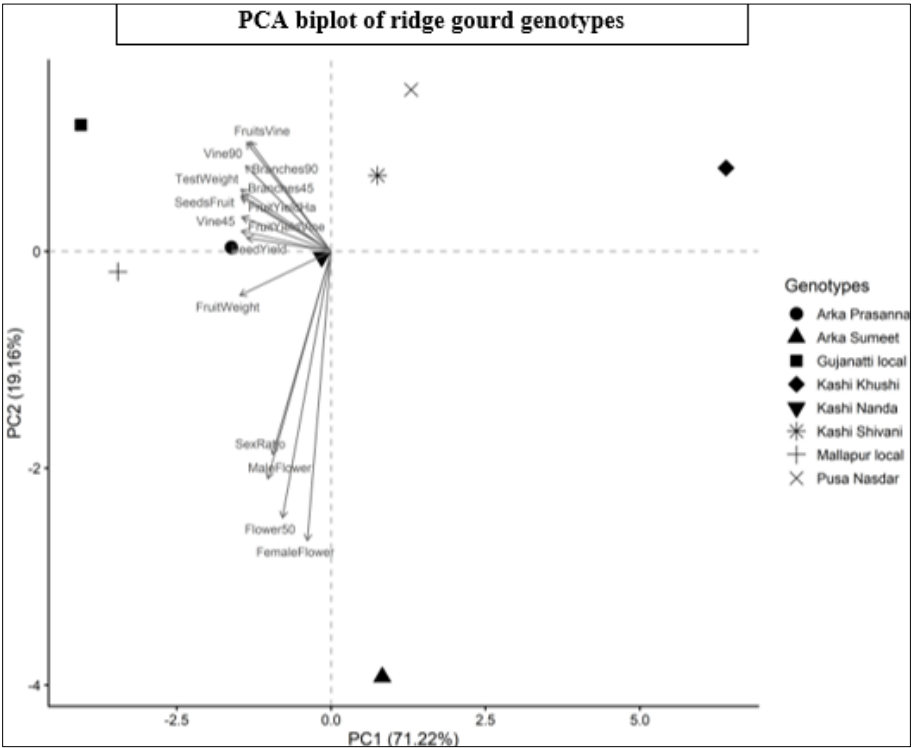


Fig 2: Principal component biplot (PC1 = 71.22%, PC2 = 19.16%) of eight ridge gourd genotypes based on all 15 growth, flowering, fruit and seed yield traits.

Genetic divergence and cluster analysis

Genetic divergence analysis using Tocher's method (Table 6, 7 and Fig. 3) grouped the eight genotypes into four clusters. Cluster I comprised four genotypes (Arka Prasanna, Kashi Nanda, Kashi Shivani and Pusa Nasdar) and Cluster II comprised two genotypes (Gujanatti Local and Mallapur Local), while Arka Sumeet and Kashi Khushi each formed distinct single genotype clusters (III and IV), indicating that both genotypes were sufficiently divergent from the remaining panel and from each other, to preclude grouping despite the sequential clustering procedure adopted. The separation of Gujanatti Local and Mallapur Local from the remaining genotypes, already indicated by principal component analysis, was confirmed by the maximum inter-cluster distance (104.81) recorded between Cluster II and Cluster IV and the minimum inter-cluster distance (20.29) recorded between Clusters I and II. Among the four clusters, Cluster II also recorded the highest mean fruit yield (23.22 t/ha), fruit weight (229.22 g) and seed yield (1.75 t/ha), while Cluster IV (Kashi Khushi) recorded the lowest values for these traits, reflecting its poor performance. Despite being the genotype with the lowest performance in this panel, the strong genetic divergence of Kashi Khushi from Cluster II suggests that genetic divergence and yield

performance operate as separate selection criteria (Mohammadi and Prasanna, 2003) [21].

Table 6: Distribution of eight ridge gourd genotypes into clusters based on Tocher's method and average intra- (diagonal) and inter-cluster D² values

Cluster	No. of genotypes	Genotypes included
I	4	Arka Prasanna, Kashi Nanda, Kashi Shivani, Pusa Nasdar
II	2	Gujanatti Local, Mallapur Local
III	1	Arka Sumeet
IV	1	Kashi Khushi

Cluster	I	II	III	IV
I	7.61	20.29	23.99	45.25
II		6.10	42.53	104.81
III			NA	54.29
IV				NA

D², Standardized squared Euclidean distance computed on standardized genotype mean values across 15 traits; cluster-formation threshold = 9.84 (mean of each genotype's minimum D² to its nearest neighbour). NA-Not applicable (singleton cluster).

Table 7: Pairwise standardized squared Euclidean distance (D²) among eight ridge gourd genotypes

Genotype	Arka Prasanna	Arka Sumeet	Gujanatti Local	Kashi Khushi	Kashi Nanda	Kashi Shivani	Mallapur Local	Pusa Nasdar
Arka Prasanna	0.00							
Arka Sumeet	25.19	0.00						
Gujanatti Local	10.15	58.28	0.00					
Kashi Khushi	75.18	62.05	125.71	0.00				
Kashi Nanda	4.22	20.52	23.15	52.78	0.00			
Kashi Shivani	11.23	29.00	36.41	43.65	6.10	0.00		
Mallapur Local	5.79	38.92	6.98	113.84	15.49	24.04	0.00	
Pusa Nasdar	14.24	34.98	37.13	35.25	9.47	6.90	33.34	0.00

D², Standardized squared Euclidean distance between genotype pairs, computed across all 15 traits (the same values underlie the intra- and inter-cluster averages reported in Table 6).

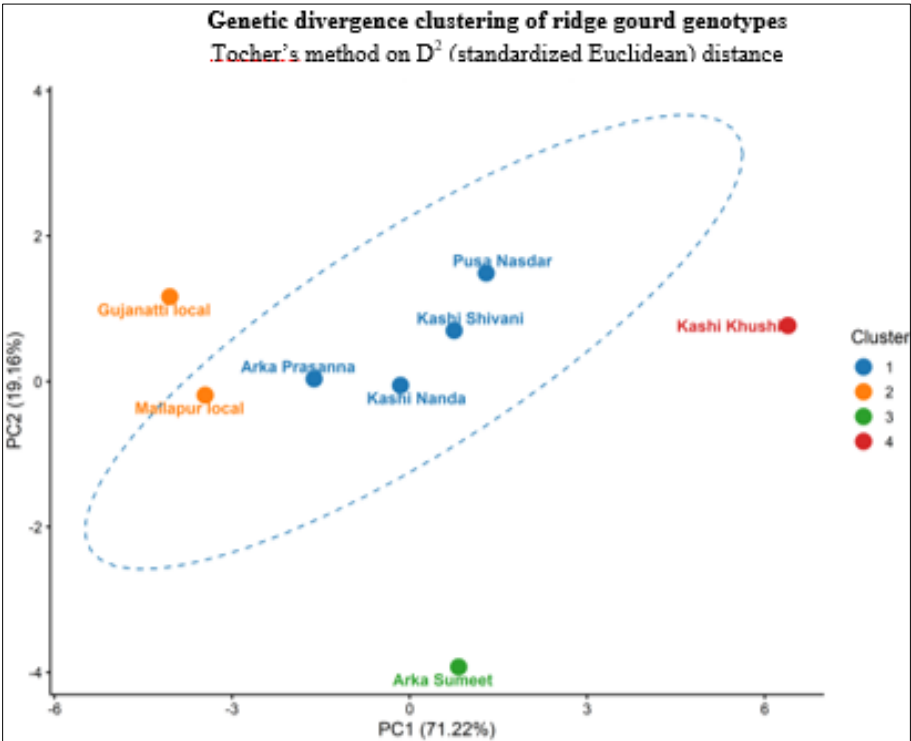


Fig 3: Principal component scatter of eight ridge gourd genotypes overlaid with cluster membership from Tocher's D² clustering. Cluster I (blue): Arka Prasanna, Kashi Nanda, Kashi Shivani, Pusa Nasdar; Cluster II (orange): Gujanatti Local, Mallapur Local; Cluster III (green): Arka Sumeet; Cluster IV (red): Kashi Khushi.

Composite rank-sum multi-trait selection index

A composite rank-sum index computed across the seven yield-determinant traits (Table 8) placed Gujanatti Local (rank-sum = 9, mean rank = 1.3) and Mallapur Local (rank-sum = 12, mean rank = 1.7) clearly as the two strongest all-round performers, with Arka Prasanna (rank-sum = 23, mean rank = 3.3) a distant third; Kashi Khushi recorded the maximum possible rank-sum (56), a

direct arithmetic consequence of ranking last for every one of the seven traits considered. That this simple, assumption-free index reproduces the same leading genotypes already identified through correlation, path, principal component and divergence analyses provides a further, independent line of convergent evidence for Gujanatti Local and Mallapur Local as the better performers in this panel.

Table 8: Composite rank-sum multi-trait selection index across seven yield determinant traits in ridge gourd genotypes

Genotype	FY/V	FY/ha	SY	F/V	FW	TW	VL45	Rank-sum	Mean rank
Gujanatti Local	1	1	1	2	1	1	2	9	1.3
Mallapur Local	2	2	2	1	2	2	1	12	1.7
Arka Prasanna	3	3	4	4	3	3	3	23	3.3
Kashi Nanda	4	4	3	5	5	5	6	32	4.6
Arka Sumeet	5	5	5	7	4	7	5	38	5.4
Kashi Shivani	7	7	6	3	6	4	7	40	5.7
Pusa Nasdar	6	6	7	6	7	6	4	42	6.0
Kashi Khushi	8	8	8	8	8	8	8	56	8.0

Note: FY/V-Fruit yield per vine; FY/ha-Fruit yield/h per ctare; SY-Seed yield; F/V-Fruits per vine; FW-Fruit weight; TW-Test weight; VL45-Vine length @ 45 DAS. Genotypes ranked 1 (best) to 8 (poorest) for each trait; rank-sum = sum of ranks across all seven traits (lower = superior overall performance).

The correlation, path coefficient, principal component, divergence and composite rank-sum analyses together revealed broadly consistent patterns of trait association and genotype differentiation across the panel. Given the eight genotype, single environment design of the present study, these estimates should be regarded as indicative of the patterns observed within this panel rather than as precise population parameters and validation across larger, multi-location trials is recommended. Heritability and path coefficient estimates in particular may be influenced by genotype × environment interaction under a single-environment design and should therefore be interpreted with appropriate caution pending confirmation through multi-location trials with larger germplasm panels.

Conclusion

This study identified Gujanatti Local, Mallapur Local and Arka Prasanna as the most promising ridge gourd genotypes for the Northern transition zone of Karnataka, combining high fruit and seed yield with desirable vegetative vigour. Sex ratio, fruits per vine and seed yield emerged as the most important direct contributors to fruit yield and are recommended as primary selection criteria, with vine length and fruit weight as useful correlated traits. Despite its poor mean performance, Kashi Khushi proved to be the most genetically divergent genotype from the high yielding Cluster II, highlighting the value of divergence based characterization in capturing genetic variability that is not reflected in mean performance alone.

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Conflict of Interest: The authors declare that they have no conflict of interest.

Author Contributions: Vridulashree V conceptualized and conducted the field experiment, performed the data analysis and drafted the manuscript. Mangi V L supported implementation of the research programme and field experimentation at ARS, Kallolli and provided technical guidance. Badiger B A provided technical support, guidance and assisted in revising the manuscript. Harsha B assisted with manuscript editing and use of analytical tools. Manu B contributed to conceptualization, provided technical support, guidance and assisted in revising the manuscript. Hosamani J supervised the research, provided technical guidance and critically revised the manuscript. All authors read and approved the final manuscript.

Ethical Matters: This study involved field evaluation of plant (ridge gourd) genotypes only and did not involve human participants or experimental animals; approval from an ethics committee was therefore not applicable.

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