Research Article

ISAH Indian Journal of Arid Horticulture

Year 2025, Volume-7, Issue-1 (January - June)

Optimizing guava (*Psidium guajava* L.) breeding programs: The role of genotype selection in enhancing growth, yield and nutrient content

Daya Shankar Mishra[1*], Vikas Yadav[1], L. P. Yadav[1], V.V. Apparao[1], Prakashbhai Ravat[1], Prakash Kumar[2] and Jagadish Rane[3]

[1]ICAR-Central Horticultural Experiment Station, Vejalpur-389340, Panchmahal, Gujarat, India
[2]ICAR-Indian Agricultural Statistics Research Institute (IASRI), New Delhi-110012, India
[3]ICAR-Central Institute for Arid Horticulture, Beechwal, Bikaner-334006, Rajasthan, India

ARTICLE INFO

Received: 12 March 2025
Accepted: 07 April 2025

Keywords: Guava, genetic variability, cross combination, yield

doi:10.48165/ijah.2025.7.1.5

ABSTRACT

This study examines genetic variation and its impact on key growth, yield, and quality traits in guava genotypes through analysis of variance and *per se* performance of cross combinations. The results indicate significant genetic effects on most traits, with the highest variations observed for days to first flowering (DTFF), days to first harvest (DTFH), number of seeds per fruit (NSPF), total phenols (TPH), and total antioxidant activity (TAA), highlighting the potential for selection based on these traits. The study also identifies traits with lower genetic variability, such as acidity (Acid) and pulp thickness (PT), suggesting their dependence on environmental or management factors. The ANOVA results revealed significant impacts of genotypes on key traits related to growth, yield, and fruit quality, with extremely high F-values ($p< 0.0001$) for most traits, suggesting that genotype plays a dominant role in the expression of these characteristics. Notably, the cross combinations, including G-28 × Lalit and G-15 × VL, showed strong potential for improving growth and quality parameters. G-28 × Lalit demonstrated superior growth and nutrient content, while G-15 × VL excelled in quality traits such as sugar content, total soluble solids (TSS), and antioxidant properties. Additionally, other cross combinations like VL × G-15 and G-31 × TP offered promising results for increasing biomass, yield, and fruit quality. Further multi-generational evaluations and environmental studies are essential to assess the stability and heritability of these traits under diverse conditions. The study highlights the importance of genotype selection for developing high-performing guava cultivars, emphasizing the need for further research to optimize breeding strategies for improved yield, quality, and resilience.

Introduction

Guava (*Psidium guajava* L.) is known as a ‘super fruit’ and the ‘apple of the tropics’ (Bishnoi *et al.*, 2024) because of its significant nutritional benefits. The agro-food sector currently exhibits significant interest in plant sources abundant in phytochemicals (Paras *et al.*, 2024). Guava ranks as the third-highest source of vitamin C (299 mg/100 g) and is also a provider of vitamin A (0.46 mg/100 g), calcium (17.8-30 mg/100 g), iron (200-400 IU/100 g), and phosphorus (0.30–0.70 mg/100 g). Its seeds are abundant in omega-3, omega-6, polyunsaturated fatty acids, and dietary fiber (0.9-1.0 g/100 g) (Kamath *et al.*, 2008). Because of these factors, along with the low farming expenses and improved

Corresponding author’s Email: dsmhort@gmail.com (Dr. D.S. Mishra)

suitability for less productive areas (Bezerra *et al.*, 2019), the guava farming is economically significant in numerous tropical and sub-tropical nations (Singh *et al.*, 2015; Mishra and Singh, 2022).

Coloured pulp guava is more nutritious than white pulp guava because it contains various pigments. These pigments offer appealing color as well as numerous health advantages (Bishnoi *et al.*, 2024, Speer *et al.*, 2020; Woodside *et al.*, 2015). Lycopene and/or anthocyanins, in conjunction with carotenoids, contribute to the pink pulp color of guava (Bose *et al.*, 2019; Kumari *et al.*, 2020; Shukla *et al.*, 2021; Singh *et al.*, 2019; Thakre *et al.*, 2016). Lycopene and anthocyanins are possible antioxidants and possess anti-cancer, anti-inflammatory, and heart-protective properties (Naseer *et al.*, 2018). Thus, we can explore superior and essential genotypes that exhibit high yields along with favorable quality traits, benefiting developed nations globally.

Guava demonstrates out-crossing levels of 35-40% (Singh and Sehgal, 1968; Nakasone and Paull, 1998; Mishra *et al.*, 2024), leading to heterozygous open-pollinated seedling populations that possess significant genetic diversity for important horticultural traits (Mishra *et al.*, 2019). Accurate characterization of genetic diversity is essential for creating enhanced guava cultivars. An adequate understanding of the gene pool applicable in genetic enhancement initiatives, together with morpho-genetic profiling of specific accessions/cultivars, can significantly assist in choosing the parental lines for genetic advancements (Singh *et al.*, 2015; Kumari *et al.*, 2018).

One of the primary objectives of current guava enhancement programs in various nations is the creation of high-yielding, nutrient-rich cultivars that feature fewer and softer seeds, along with improved shelf-life (Correa *et al.*, 2012; Pommer, 2012, Mishra *et al.*, 2019).

Only few improved and released varieties like Lalit, Shweta, Arka Kiran etc. are available, while different seedling selections like L-49, Apple colour and other local varieties are still under cultivation (Sarkar and Sarkar, 2022). Therefore, we presumed that new improved guava genotypes could be developed with the introgression among the widespread locally available genotypes/varieties with desirable traits. The aim of enhancing guava crops by utilizing various breeding techniques, such as hybridization, selection, and introduction, was to develop new cultivars with superior traits (Paras *et al.*, 2023). Efforts in plant breeding for guava fruit crops aim to increase fruit yield, improve fruit quality, and boost resistance to major pests and diseases. For high-yielding guava genotypes, it is essential to have high output, uniform size and shape, and superior quality fruit. Uniform guava genotypes, whether homozygous or heterozygous, can yield uniform traits. Pure genotypes consist of homozygotes, whereas hybrid germplasm includes heterozygotes. Cross hybrid genotypes are chosen for their enhanced traits, appeal, and greater yield, rendering them more sought after than pure guava genotypes. By executing a random cross among various parental genotypes that are distinct in their attributes, it becomes feasible to develop guava hybrid cultivars with preferred characteristics and identify the most innovative combinations (Badami *et al.*, 2020). This study represents the initial research conducted under semi-arid tropical conditions using superior guava genotypes in random hybridization to create improved guava genotypes.

Material and Methods

This study was conducted at the ICAR-CIAH Central Horticultural Experiment Station (CHES), Vejalpur, Panchmahal, Gujarat, India (22°41'N, 73°33'E with altitude 113 m above sea level) The climate of the experimental site is hot semi-arid with a mean annual precipitation of about 750 mm, and the soil is derived from basic rocks, calcareous in nature, clay loam to clay in texture and has a pH of about 6.5 with organic matter content 0.45-0.73%. Ten guava parental genotypes (Table 1) which were already established at CHES, Godhra experimental farm were used for crossing program. Crosses were made among the genotypes, 50 flowers in each female parent were crossed with the selected male parent. Flower buds, which were expected to open the following day, were selected from female and male parents. All the anthers of the female buds were emasculated and bagged and flower buds of male parent were also bagged. Pollination was done the following morning between 6.30-8.30 am. Pollinated flowers were bagged and kept until fruits were formed. Single fruit from each cross combination was taken (Harvested during Dec.) and all the seeds of that fruit were used for raising the seedlings (sown in the month of January 2017-18). Number of seedlings per fruit representing a progeny in each cross varied 60-120. Finally healthy seedlings of different crosses were planted at 5 m x 2.5 m spacing during July, 2017-18. Fifteen plants were kept in each replication (blocks) which was replicated thrice. In each block all progenies were randomly arranged. These were observed for 2-3 years and data on growth, yield and quality parameters were taken, winter season crop was used for recording the data on fruit yield and quality parameters.

Tree growth and yield parameters, including tree height (TH), stem girth (SG), trunk cross-sectional area (TCSA), tree spread (SPD), number of fruits per tree (FNP), fruit yield per plant (YP), production efficiency (PE), other physical and bio-chemical quality parameters and mineral contents on fresh weight basis (FW) were recorded following standard procedures (Mishra *et al.*, 2022). Fruit yield per plant observation were recorded on 3 replication of each guava cross combination on randomly selected 2-3 trees. For experimental design and analysis of variance (ANOVA), the "proc glm" procedure in SAS was utilized. This procedure assesses the significance of differences among group means and generates an ANOVA table detailing the sources of variation in the data. Post hoc tests, such as the Least Significant Difference (LSD) test, were performed using the "means" statement with the "LSD" option in the "proc glm" procedure, allowing for pairwise comparisons of treatment means to identify significant differences (Tripathi *et al.*, 2025). The variation among the crosses was partitioned further into sources attributable to Analysis of variance (ANOVA) and *per se* performance of cross combinations.

Result and Discussion

Analysis of variance (ANOVA) for cross combinations

The results of the analysis of variance (ANOVA) for various traits in guava genotypes are presented Table 1 to Table 3. The mean sum of squares for genotypes revealed significant genetic effects on most traits. The highest values were observed for DTFH (39599.86) followed by DTFF (36411.02), NSPF (17214.37), TAA (16015.43) and TPH (8104.38) suggesting that these traits are strongly influenced by genetic variation. Other traits, such as PT (0.03), PE (0.06), FSI (0.02), and Acid (0.02) showed smaller mean sum of squares, indicating that these traits are less influenced by genotype differences, but still exhibit some genetic variability. Replication mean sum of squares shows the environmental influence on the traits. Traits like FWt (14354.20), NSPF (17050.90), TPH (5406.56), had relatively high replication mean sum of squares, indicating that environmental or management factors might play a substantial role in these traits, while Acid (0.02), FSI (0.01) and PT (0.05) had relatively smaller replication effects, reflecting less environmental variability for these traits (Mishra *et al.*, 2022; Chiveu *et al.*, 2019). The R-square values, representing the proportion of variability explained by the model, were generally high, especially for RF (0.95), WF (0.94), Mg (0.92) and K (0.87), indicating that the genotypes contribute substantially to the observed variation in these traits. Traits like FL (0.43), TSS (0.43), Acid (0.43) and TA (0.44) had somewhat lower R-squares, suggesting that other factors may also contribute to the variability in these traits. The coefficient of variation (CV) values indicates the degree of variability in the traits. Traits such as PE (52.43%), WF (33.14%), Btaoy (32.40%), Lyc (27.73%) and Asc (21.24%) showed higher coefficients of variation, indicating greater variability between genotypes. In contrast, Btaty (7.91%), K (8.20%), FW (9.07%), TS (9.80%) and PT (9.85%), had lower coefficients of variation, indicating more consistent performance across genotypes for these traits. The extremely notable F-values for every trait ($p< 0.0001$) indicated that genotype explained a considerable portion of the variance in the dependent variables (Table 1). The F-values were significantly high for all traits ($p< 0.0001$) with the exception of DTFF (F = 8.61, p=<0.0001), RF (F = 31.61, p=<0.0001), WF (F = 26.85, p=<0.0001), K (F = 11.85, p=<0.0001), Mg (F = 17.96, p=<0.0001) and Lyc (F = 7.85, p=<0.0001) (Kumari *et al.*, 2018). The analysis of variance (ANOVA) results reveals significant genetic variability across guava genotypes, influencing key growth, yield, and quality traits. The observed extremely high F-values ($p<0.0001$) for most traits, such as TCSA, TSS, and Lycopene content, indicate that genotype plays a pivotal role in shaping these characteristics. The exceptions, including DTFF, RF, and WF, still show a notable influence of genotype on trait expression but with somewhat lower F-values compared to others, which suggests the possibility of environmental or management factors playing a larger role in these particular traits (Kherwar and Usha, 2016).

Per se performance of cross combinations

The *per se* performance of cross combinations further emphasizes the potential for breeding programs aimed at improving specific agronomic or quality traits (Table 4 to 6 and Fig. 1). G-28 × Lalit strong performance across multiple traits, including SG (8.29), DTFF (550.67), DTFH (664.33), FNP (104.10), P (24.24), Ca (29.40) and Mg (49.48), while showing decreased levels in traits such as Btaoy (30.52) and TA (20.53). These results suggest that G-28 × Lalit may be a valuable combination for enhancing growth and nutrient content, albeit with a trade-off in traits like Btaoy and TA. The high values for essential growth parameters such as SG (8.29) and P (24.24) suggest that this cross may be ideal for cultivating guava with high productivity and quality (Kumari *et al.*, 2018). In contrast, the G-15 × VL combination demonstrated superiority for quality-related traits, such as TSS (13.56), Acid (0.66), Asc (266.20), TS (9.82) and K (289.94), along with enhanced yield potential TPH (375.14), TCSA (56.88) and TAA (454.83), while displaying the lowest for FSI (0.92), P (16.00) and Flav (15.45). These findings suggest that G-15 × VL may be particularly useful for breeding guava varieties with higher sugar content and overall quality, making it an attractive candidate for improving the fruit's organoleptic properties (Chiveu *et al.*, 2019).

The VL × G-15 cross combination, with the highest Btaoy (95.55), YP (20.01), PE (0.56) and Lyc (12.16) values, highlights the potential of this combination for increasing biomass and yield potential, although this comes at the expense of earlier fruit maturity DTFF (149.67) and DTFH (233.67). This finding supports the notion that selecting for both early-maturing genotypes and high-yielding genotypes requires balancing various traits to meet the diverse objectives of guava breeding programs.

Similarly, the G-31 × TP combination exhibited promising results for FSI (1.19), RF (100) and quality, Flav (26.32), but with lower performance in traits like FW (6.57), SCD (3.66), WF (0.00), K (168.81) and Fe (22.19). This combination may be beneficial for improving fruit characteristics such as flavor and texture, but breeders would need to account for the lower levels of potassium in the resulting progeny (Kherwar and Usha, 2016; Kumari *et al.*, 2020).

The combination of VL × G-31 also displayed substantial potential for FWt (287.29), FL (8.82), SCD (4.63) as well as the number of seeds per fruit (277) making it valuable for increasing fruit size and yield per tree, However, it showed lower values for FNP (28.67), Asc (88.81) which may limit its potential for enhancing antioxidant properties and fruit fertility. VL × SP is greater for FW (8.02), SH (12.46) and TA (29.14), but lesser for NSPF (122.33) and Acid (0.38). VL × MP-2 exhibited the highest TH (3.28), SPD (3.24), HSW (1.55), WF (100) and Fe (40.23), while recording the lowest in RF (0.00), Ca (13.98), Mg (10.87), Lyc (0.12) and TPH (202.20). Several crosses, such as SP × G-28 and MP-2 × G-15, presented varying degrees of strengths and weaknesses across traits. While SP × G-28 exhibited higher PT (1.69), indicating potential for enhancing postharvest quality, it showed decreased growth parameters like TCSA (26.42) and SG (5.75). Conversely, the MP-2 × G-15 combination exhibited reduced performance for certain traits, such as Btaty (80.00), FWt (196.27), FL (7.02), PT (1.49), YP (5.39), PE (0.16) and TSS (9.87), but may have value in terms of other agronomic or postharvest traits not captured in this study. The BL × SP combination had consistently lower values for certain traits, including TH (2.23), SPD (2.35), HSW (1.01) and SH (9.51), indicating that it may not be as promising for improving overall plant stature and growth in comparison to other combinations. Nonetheless, this combination might still be valuable for specific breeding goals focused on improving traits like flower density or fruit size, even if other areas of performance are less robust (Kumari *et al.*, 2020).

The cross combinations analyzed demonstrate the potential for improving various growth, yield, and quality parameters by selecting appropriate genotypes that complement each other's strengths. However, further research, including multigeneration evaluations and environmental studies, will be necessary to fully understand the stability and heritability of these traits in different agro-climatic conditions. Such information is critical for developing high-performing guava cultivars suited for diverse production environments and consumer preferences.

Table 1. Analysis of variance for different characters in guava

Source	df	Mean Sum of Square											
		TH	SPD	SG	TCSA	DTFF	DTFH	Btaoy	Btaty	FWt	FL	FW	FSI
Genotypes	9	0.21	2.47	0.29	348.57	36411.02	39599.86	1084.94	122.25	3067.01	0.75	0.68	0.02
Replication	2	0.58	9.11	0.45	1098.57	31922.50	23798.53	286.37	10.75	14354.20	0.86	1.83	0.01
R-Square		0.59	0.69	0.70	0.68	0.84	0.82	0.55	0.51	0.52	0.43	0.55	0.48
Coeff. of Var.		12.46	14.75	10.60	30.69	21.90	17.31	32.40	7.91	22.30	10.13	9.07	11.14
F- value		2.37	3.58	3.79	3.45	8.61	7.25	2.02	1.73	1.79	1.24	1.96	1.53
Pr>F		0.050	0.010	0.006	0.010	<.0001	0.0001	0.099	0.150	0.131	0.328	0.190	0.210

TH-Tree height (m), SPD-Spread (m), SG-Stem girth (m), TCSA-Trunk cross sectional area, DTFF-Days to 1st flowering, DTFH- Days to 1st harvest, Btaoy- Bearing trees after 1 year (%), Btaty- Bearing trees after 2 year (%), FWt- Fruit weight (g), FL- Fruit length (cm) FW- Fruit width (cm), FSI- Fruit shape index

Table 2. Analysis of variance for different characters in guava

Source	df	Mean Sum of Square											
		SCD	PT	NSPF	HSW	SH	RF	WF	FNP	YP	PE	TSS	Acid
Genotypes	9	0.30	0.03	17214.37	0.10	4.19	2451.87	2442.24	1712.07	61.01	0.06	3.84	0.02
Replication	2	0.20	0.05	17050.90	0.11	7.25	81.23	113.23	180.03	9.85	0.05	2.90	0.02
R-Square		0.51	0.44	0.68	0.55	0.48	0.95	0.94	0.72	0.65	0.48	0.43	0.43
Coeff. of Var.		9.92	9.85	29.06	18.20	15.00	10.78	33.14	31.39	33.29	52.43	15.23	28.52

F- value	1.68	1.30	3.45	1.97	1.54	31.61	26.85	4.24	3.00	1.51	1.23	1.22
Pr>F	0.160	0.298	0.0098	0.0971	0.2018	<.0001	<.0001	0.0034	0.019	0.210	0.334	0.343

SCD-Seed core diameter (cm), PT-Pulp thickness (cm), NSPF-No. of seed/ fruit, HSW-100 seed weight (g), SH-Seed hardness (kg/ cm^2), RF-Red fleshed (%), WF-White fleshed (%), FNP-Fruits number/plant, YP-Yield/ plant (kg), PE-Production efficiency (kg/ cm^2), TSS-Total soluble solids, Acid-Acidity (%)

Table 3. Analysis of variance for different characters in guava

Source	df	Mean Sum of Square											
		TA	Asc	TS	K	P	Ca	Mg	Fe	Lyc	TPH	Flav	TAA
Genotypes	9	19.59	6806.63	3.85	4657.78	27.29	80.09	336.70	103.66	33.97	8104.38	48.88	16015.43
Replication	2	8.14	2633.17	0.74	640.82	16.84	5.94	19.43	1.00	8.58	5406.56	7.51	1092.88
R-Square		0.44	0.76	0.77	0.87	0.75	0.80	0.92	0.77	0.83	0.80	0.80	0.82
Coeff. of Var.		14.88	21.24	9.80	8.20	11.95	14.55	16.36	14.72	27.73	11.57	13.42	11.50
F- value		1.29	5.07	5.62	11.35	4.92	6.71	17.96	5.34	7.85	6.66	6.51	7.42
Pr > F		0.3034	0.0012	0.0007	<.0001	0.0015	0.0002	<.0001	0.0009	<.0001	0.0002	0.0003	0.0001

TA-TSS: Acidity, Asc-Ascorbic acid (mg/100g), TS-Total sugar (%), K-Potassium (mg/100g FW), P-Phosphorus (mg/100g), Ca-Calcium (mg/100g), Mg-Magnesium (mg/100g), Fe-Iron (ppm FW), Lyc-Lycopene (mg/100g). TPH-Total phenols (GAE/100g), Flav-Flavonoids (CE/100g), TAA-Total antioxidant activity (AAE/100g)

Table 4. *Per se* performance of cross combinations for different characters in guava

Genotypes	TH	SPD	SG	TCSA	DTFF	DTFH	Btaoy	Btaty	FWt	FL	FW	FSI
G-28 × Lalit	2.88ab	2.75ab	8.29a	55.69ab	550.67a	664.33a	30.52c	98.25a	230.27a	7.86ab	7.32ab	1.08a-c
G-15 × VL	2.66bc	2.48b	8.23a	56.88a	225.67de	345.67d-e	80.11ab	100.00a	248.69a	7.19b	7.84a	0.92c
VL × G-15	2.79a-c	3.11a	6.77ab	36.02bc	149.67e	233.67e	95.55a	100.00a	271.45a	7.73ab	7.63ab	1.01a-c
G-31 × TP	2.88ab	3.08a	7.23ab	42.17a-c	349.00bc	459.67bc	60.00a-c	100.00a	199.52a	7.74b	6.57b	1.19a
VL × G-31	2.84ab	2.74ab	6.58ab	34.38c	270.33b-d	462.33bc	86.67a	100.00a	287.29a	8.82a	7.98a	1.11a-c
VL × SP	2.73a-c	2.82ab	5.99b	28.17c	265.00b-d	381.00b-d	66.67a-c	93.33a	273.20a	7.90ab	8.02a	0.98bc
SP × G-28	2.55bc	2.39b	5.75b	26.42c	291.00b-d	400.00b-d	66.67a-c	100.00a	222.95a	7.72ab	7.21ab	1.07a-c
VL × MP-2	3.28a	3.24a	7.44ab	43.48a-c	220.33de	336.33de	73.33ab	100.00a	251.78a	7.47b	7.72ab	0.97c
MP-2 × G-15	2.79a-c	2.56b	6.49b	33.47c	369.00b	475.00b	46.67bc	80.00b	196.27a	7.02b	7.16ab	1.00a-c
BL × SP	2.23c	2.35b	5.97b	29.93c	245.33c-e	354.33b-e	60.00a-c	100.00a	213.06a	8.11ab	6.95ab	1.17ab

TH-Tree height (m), SPD-Spread (m), SG-Stem girth (m), TCSA-Trunk cross sectional area, DTFF-Days to 1st flowering, DTFH- Days to 1st harvest, Btaoy- Bearing trees after 1 year (%), Btaty- Bearing trees after 2 year (%), FWt- Fruit weight (g), FL- Fruit length (cm) FW- Fruit width (cm), FSI- Fruit shape index

Table 5. *Per se* performance of cross combinations for different characters in guava

Geno-types	SCD	PT	NSPF	HSW	SH	RF	WF	FNP	YP	PE	TSS	Acid
G-28 × Lalit	4.23a-c	1.56a	220.33b-d	1.24a-c	11.64a-c	60.00e	40.00b	104.10a	14.87a-c	0.37ab	11.83ab	0.58ab
G-15 × VL	4.03a-c	1.67a	198.33b-d	1.23a-c	12.01a-c	92.67ab	7.33ef	78.67ab	18.32ab	0.46ab	13.56a	0.66a
VL × G-15	4.26a-c	1.75a	258.67a-c	1.14bc	10.25bc	92.33ab	7.67ef	80.53ab	20.01a	0.56a	12.08ab	0.44ab
G-31 × TP	3.66c	1.55a	235.00a-d	1.04c	12.07a-c	100.00a	0.00f	46.33c-e	9.63cd	0.22ab	9.93b	0.40b
VL × G-31	4.63a	1.74a	277.00ab	1.46ab	13.59a	76.67dc	23.33cd	28.67e	7.94cd	0.23ab	10.37b	0.41b
VL × SP	4.06a-c	1.77a	122.33d	1.33a-c	12.46a-c	71.67de	28.33bc	53.00b-e	13.68a-c	0.49a	11.02ab	0.38b
SP × G-28	3.73bc	1.69a	151.67cd	1.22a-c	11.50a-c	78.33cd	21.67c-e	42.67c-e	10.01cd	0.38ab	11.31ab	0.45ab
VL × MP-2	4.22a-c	1.74a	259.33a-c	1.55a	12.74ab	0.00f	100.00a	60.67b-d	12.49b-d	0.29ab	12.11ab	0.48ab
MP-2 × G-15	4.38ab	1.49a	355.33a	1.07c	11.35a-c	90.00a-c	10.00d-f	29.67de	5.39d	0.16b	9.87b	0.45ab
BL × SP	3.74bc	1.54a	352.00a	1.01c	9.51c	80.00b-d	23.33cd	61.67bc	12.29b-d	0.51a	11.17ab	0.49ab

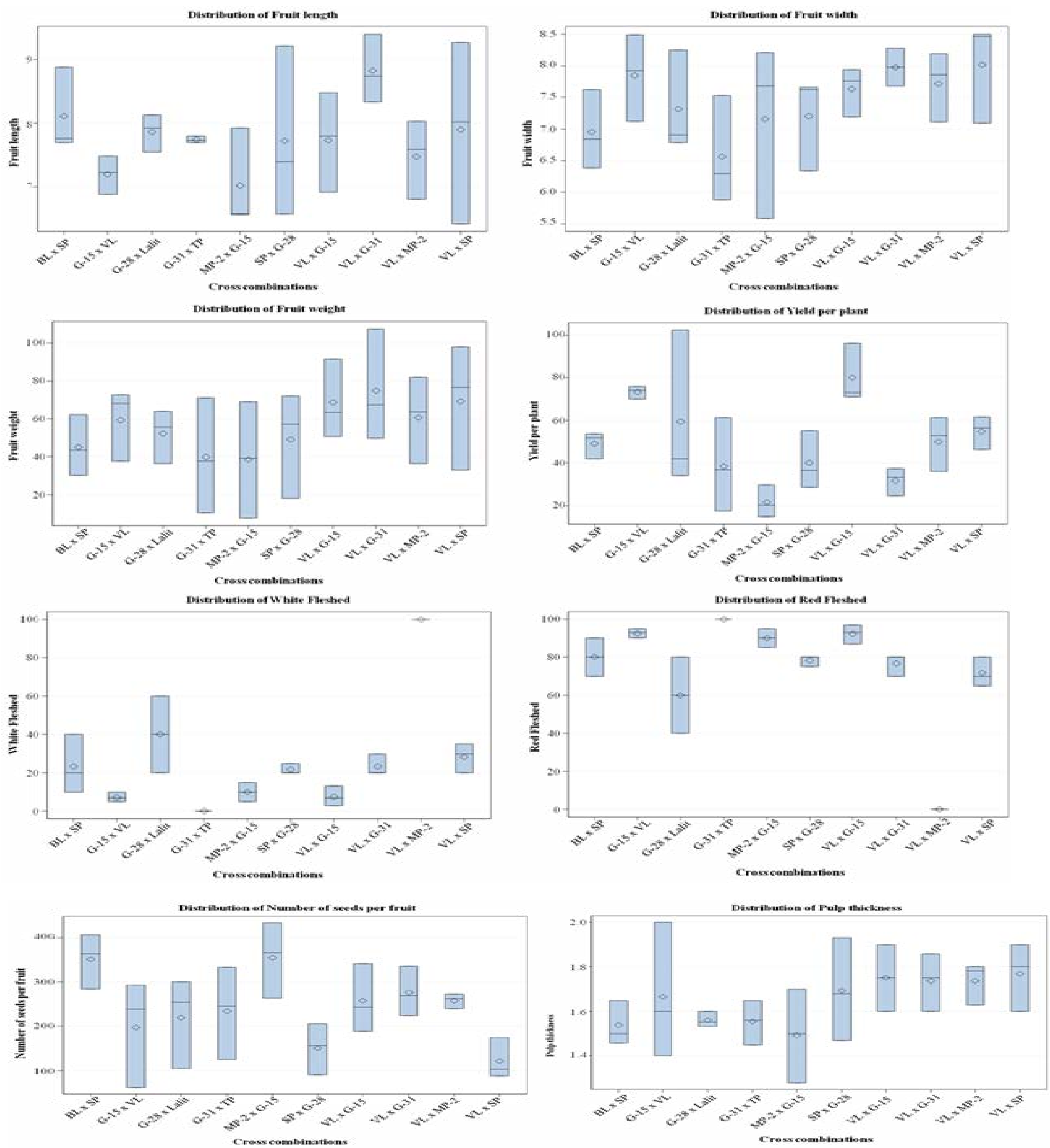
SCD-Seed core diameter (cm), PT-Pulp thickness (cm), NSPF-No. of seed/ fruit, HSW-100 seed weight (g), SH-Seed hardness (kg/cm^2), RF-Red fleshed (%), WF-White fleshed (%), FNP-Fruits number/ plant, YP-Yield/ plant (kg), PE-Production efficiency (kg/cm^2), TSS-Total soluble solids, Acid-Acidity (%)

Table 6. *Per se* performance of cross combinations for different characters in guava

Geno-types	TA	Asc	TS	K	P	Ca	Mg	Fe	Lyc	TPH	Flav	TAA
G-28 × Lalit	20.53c	156.64bc	7.96b-d	214.55de	24.24a	29.40a	49.48a	25.80cd	5.23de	266.21cd	15.81e	369.37b
G-15 × VL	21.83bc	266.20a	9.82a	289.94a	16.00c	22.83bc	22.87bc	29.09bc	9.96ab	375.14a	15.45e	454.83a
VL × G-15	27.49ab	175.39b	7.64cd	241.62b-d	19.36bc	25.29ab	26.19b	23.43cd	12.16a	357.66ab	15.58e	379.80b
G-31 × TP	24.94a-c	114.83cd	7.10c-e	168.81f	16.16c	18.74cd	23.04b	22.19d	6.88bc-e	305.69b-d	26.32a	258.21d
VL × G-31	25.48a-c	88.81d	6.77de	170.55f	20.55ab	26.06ab	28.32b	23.75cd	6.41c-e	261.85cd	20.86bc	283.08cd
VL × SP	29.14a	143.25b-d	7.68cd	215.11de	19.05c	25.09ab	22.55bc	22.53cd	7.41b-d	316.47bc	20.35b-d	353.10bc
SP × G-28	25.56a-c	147.26b-d	7.31c-e	232.41c-e	18.10bc	16.88d	14.39d	22.53cd	3.98e	316.39bc	24.54ab	407.36ab
VL × MP-2	25.03a-c	195.18b	8.40bc	256.16bc	16.06c	13.98d	10.87d	40.23a	0.12f	202.20e	16.36de	473.80a

MP-2 × G-15	22.68bc	166.83bc	6.01e	268.65ab	17.03bc	15.17d	16.25cd	33.55ab	8.89a-c	266.59cd	16.84c-e	289.95cd
BL × SP	24.58a-c	171.10bc	9.23ab	209.25e	23.64a	23.16bc	26.90b	28.03b-d	8.69bc	254.24de	15.62e	413.23ab

TA-TSS: Acidity, Asc-Ascorbic acid (mg/100g), TS-Total sugar (%), K-Potassium (mg/100g FW), P-Phosphorus (mg/100g), Ca-Calcium (mg/100g), Mg-Magnesium (mg/100g), Fe-Iron (ppm FW), Lyc-Lycopene (mg/100g). TPH-Total phenols (GAE/100g), Flav-Flavonoids (CE/100g), TAA-Total antioxidant activity (AAE/100g)



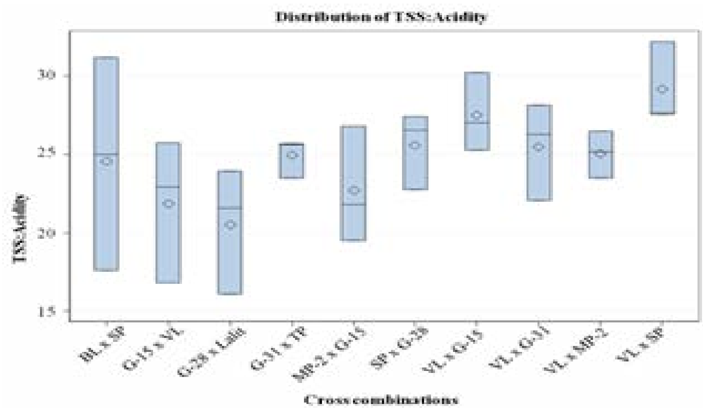


Fig 1. Mean value (Mean ± SD) distribution between major growth, yield and quality parameters and cross-combination genotypes of guava

Conclusion

The findings from this study underline the significant genetic variability among guava genotypes which showed that genotype plays a key role in determining important traits related to growth, yield, and fruit quality. The extremely high F-values across most traits emphasize the importance of genetic factors in influencing these characteristics, although environmental factors may also contribute, as seen in some traits such as DTFF, RF and WF. The *per se* performance of the cross combinations further reinforces the potential of targeted breeding strategies aimed at enhancing specific traits.

Several cross combinations demonstrated notable strengths, including G-28 × Lalit, which showed promise in terms of growth and nutrient content, and G-15 × VL, which excelled in quality-related traits and yield. These combinations indicate that strategic crosses can significantly improve guava cultivars for both agronomic performance and fruit quality. Conversely, some crosses, such as BL × SP, showed less potential for growth improvements, but may still offer value for specific breeding objectives. The trade-offs between growth, yield, and quality parameters highlight the need for a balanced approach in breeding programs to meet diverse goals. For future use, breeding efforts should consider genotypes like G-28 × Lalit for high productivity and nutrient enrichment, and G-15 × VL for superior fruit quality, particularly in flavor and sugar content. It is suggested that breeders further refine these crosses by balancing early maturity with high yield, ensuring adaptability to various agro-climatic conditions. Overall, this study contributes valuable insights into the genetic diversity and potential of guava genotypes for breeding high-performance cultivars. However, further investigations, including multigeneration studies and environmental assessments, are essential to evaluate the stability and heritability of these traits under different growing conditions. Such knowledge will be crucial for developing guava varieties that meet both agricultural needs and consumer demands.

Acknowledgements

The authors express gratitude to the ICAR, New Delhi and Director, ICAR-CIAH, Bikaner for providing the financial support, necessary facilities with constant encouragement and guidance to undertake this research program.

Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

References

Azam, M.G., Uddin, M.S., Chowdhary, S.M.K., Rashid, Hasan, Harunor, A.S.M., Barua, H., Chhanda, R.A., Rahman, S., Bagum, S.A., Shamsunnahar, M., Islam, M.N. 2020. Variability studies of guava (*Psidium guajava* L.) genotypes for growth, yield and quality attributes in Chattogram region of *Bangladesh Journal of Agricultural Science & Engineering Innovation (JASEI)*, 1(2): 3-9.

Badami, K., Daryono, B. S., Amzeri, A. and Khoiri, S. 2020. Combining ability and heterotic studies on hybrid melon (*Cucumis melo* L.) populations for fruit yield and quality traits. *SABRAO Journal of Breeding and Genetics*, 52 (4): 402-417.

Bishnoi, P., Thakre, M., Maurya, P., Jagga, S., Gangappa, N. D., Nagaraja, A., Verma, M.K., Krishnan, S.G., Varghese, E. and Mithra Sevanthi, A. 2024. Pulp colour and pigment composition have no genetic correlation with seed hardness in guava (*Psidium guajava* L.). *The Journal of Horticultural Science and Biotechnology,* 1-14. https://doi.org/10.1080/14620316.2024.2392090

Bose, S. K., Ahmed, S., Howlader, P. and Ali, M. 2019. Flowering, fruiting behavior and nutritional quality of selected guava genotypes. *International Journal of Horticultural Science and Technology*, 6(1): 11-25.

Chiveu, J., Naumann, M., Kehlenbeck, K. and Pawelzik, E. 2019. Variation in fruit chemical and mineral composition of Kenyan guava (*Psidium guajava* L.): Inferences from climatic conditions, and fruit morphological traits. *Journal of Applied Botany and Food Quality*, 92: 151–159.

Correa, L.C., Santos, C.A.F. and Lima, G.P.P. 2012. Chemical and biochemical characterization of guava and araca fruits from different regions of Brazil. *Acta Horticulturae*, 959: 103-109.

Kamath, J. V., Rahul, N., Kumar, C. A. and Lakshmi, S. M. 2008. *Psidium guajava* L: A review. *International Journal of Green Pharmacy*, 2(1): 9-12. https://doi.org/10.4103/0973-8258.39155

Kherwar, D. and Usha, K. 2016. Genetic variations, character association and path analysis studies in guava (*Psidium guajava* L.) for bioactive and antioxidant attributes. *Indian Journal of Plant Physiology*, 21:355-361.

Kumari, P., Mankar, A., Karuna, K., Homa, F., Meiramkulova, K. and Siddiqui, M. W. 2020. Mineral composition, pigments, and postharvest quality of guava cultivars commercially grown in India. *Journal of Agriculture and Food Research*, 2: 100061. https://doi. org/10.1016/j.jafr.2020.100061

Kumari, S., Arumugam, N., Singh, R., Srivastav, M., Banoth, S., Mithra, A.C., Arun, M.B., Goswam, A.K. and Khan, Y.J. 2018. Diversity analysis of guava (*Psidium guajava*) germplasm collection. *Indian Journal of Agricultural Sciences*, 88 (3): 489-497.

Mishra, D. S., Berwal, M. K., Singh, A., Singh, A. K., Rao, V. A., Yadav, V. and Sharma, B. D. 2022. Phenotypic diversity for fruit quality traits and bioactive compounds in red-fleshed guava: Insights from multivariate analyses and machine learning algorithms. *South African Journal of Botany*, 149: 591-603.

Mishra, D.S. and Singh, A.K. 2022.Crop regulation in guava: a review. *Annals of Arid Zone*, 61(2): 75-82.

Mishra, D.S., Singh, A.K. and Rane, J. 2024. Guava breeding for future challenges. In: Dwibedi *et al*. (Eds.), Frontiers in Horticultural Technologies, Daya Publishing House, New Delhi. Pp. 87-112.

Mishra, D.S., Singh, S., Singh, A.K., Appa Rao, V.V. and Saroj, P.L. 2019. Assessment of genetic diversity in guava. *Indian Journal of Horticulture*, 75(3): 362-368.

Nakasone, H.Y. and Paull, R.E., 1999. Tropical fruits. Crop production in Science in Horticulture. CAB International, Wallingford, UK. P. 159.

Naseer, S., Hussain, S., Naeem, N., Pervaiz, M. and Rahman, M. 2018. The phytochemistry and medicinal value of (*Psidium guajava*) guava. *Clinical Phytoscience*, 4: 32-34. https://doi. org/10.1186/s40816-018-0093-8

Paras, Kaur, K., Kaur, G., Singh, D. and Brar, J. S. 2024. Heritability and principal component analysis of phytochemical traits in guava under Indian subtropics. *Applied Fruit Science*, 66(1): 193-202.

Pathak, R.K. and Ojha, C.M. 1993. Genetic resources of guava. In: Chadha, K.L., Pareek, O.P. (Eds.), Advance in Horticulture. Fruit Crops, Part 1, vol. I. Malhotra Publishing House, New Delhi. Pp. 143-147.

Pommer, C.V. 2012. Guava world-wide breeding: major techniques and cultivars and future challenges. *Acta Horticulturae*, 959: 81-88.

Sarkar, T.and Sarkar, S.K. 2022. Pollination characteristics and intervarietal hybridization of *Psidium guavaja*. *Journal of Crop and Weed*, 18(1): 96-103.

Shukla, S., Kushwaha, R., Singh, M., Saroj, R., Puranik, V., Agarwal, R. and Kaur, D. 2021. Quantification of bioactive compounds in guava at different ripening stages. *Food Research*, 5(3): 183-189. https://doi.org/10.26656/ fr.2017.5(3).554

Singh, D., Gill, M. I. S., Boora, R. S. and Arora, N. K. 2015. Estimates of genetic variability, heritability, genetic advance, correlation coefficients and their prospects for crop improvement in guava (*Psidium guajava* L.). *Journal of Applied Horticulture*, 17(1): 76-78.

Singh, R. and Sehgal, O.P. 1968. Studies on blossom biology of *Psidium guajava* L. (guava). II. Pollen studies, stigma receptivity, pollen and fruit set. *Indian Journal of Horticulture*. 25: 52-59.

Speer, H., D'Cunha, N. M., Alexopoulos, N. I., McKune, A. J. and Naumovski, N. 2020. Anthocyanins and human health-a focus on oxidative stress, inflammation and disease. Antioxidants, 9(5): 366. https://doi. org/10.3390/antiox9050366

Thakre, M., Hanamant, S., Ramkumar, M. K., Senapati, R., Rudra, S. G., Saha, S., Nagaraja, A., Verma, M. K., Krishnan, G. S., Varghese, E. and Amitha Mithra, S. V. 2023. Pigment composition analysis of fruit pulp in the recombinant progenies reveals the polygenic nature of pulp color inheritance in guava (*Psidium guajava* L.). *Tree Genetics and Genomes*, 19: 20. https://doi. org/10. 1007/s11295-023-01595-w

Tripathi, P.C., Sane, A., Kumar, P, Kanupriya, C., Mishra, D.S. and Ravat, P. 2025. Phenotypic and genetic characterization of *Cordia myxa* L. using multivariate analysis. *Flora*, 323:15263. https://doi.org/10.1016/j.flora.2025.152673

Woodside, J. V., McGrath, A. J., Lyner, N. and McKinley, M. C. 2015. Carotenoids and health in older people. *Maturitas*, 80(1): 63-68. https://doi.org/10. 1016/j.maturitas.2014.10.012