



RESEARCH ARTICLE

Variability studies for fruit traits and the inheritance pattern of peel and pulp colour in guava

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Abstract

Guava, an important nutritionally rich fruit crop, exhibits a wide range of variations for peel and pulp colour. The present investigation was carried out during 2022-24 at ICAR-Indian Institute of Horticultural Research (IIHR), Bengaluru, in intervarietal progenies of guava derived from Purple Local × Arka Poorna to know the extent of genetic variability present in various fruit traits and the inheritance of peel and pulp colour based on intervarietal progenies that fruited consistently over two seasons. The result revealed high to low Genotypic Coefficient of Variance (GCV) and Phenotypic Coefficient of Variance (PCV) for the measured traits. The highest PCV and GCV were exhibited for fruit weight (FW) (37.44 % and 21.56 %), number of seeds/100 g of fruit (NS) (42.69 % and 25.58 %) and seed weight/100 g of fruit (SW) (26.08 % and 37.53 %). The high heritability value with high genetic advance was recorded for all the peel and pulp colour traits viz. Peel L^* (0.83 % and 50.55 %), Peel a^* (0.73 % and 100.77 %), Peel h^o (0.89 % and 68.36 %) and Pulp L^* (0.67 % and 26.79 %), Pulp a^* (0.79 % and 84.54 %), Pulp b^* (0.63 % and 44.30 %), Pulp C^* (0.67 % and 41.32 %) and Pulp h^o (0.80 % and 88.29 %). Whereas, the moderate heritability with high genetic advance was recorded for FW (0.33 % and 25.56 %), diameter of calyx cavity (DCC) (0.56 % and 23.19 %), NS (0.36 % and 31.57 %) and SW (0.48 % and 37.34 %). Further, the segregation analysis for peel and pulp colour in intervarietal progenies of guava demonstrated that there is an epistatic interaction between genes and two genes governing the colour characters and the peel colour was inherited with a segregation ratio of 9:7, indicated there is a complimentary gene action whereas, the pulp colour was inherited with 9:3:4 ratio indicated that there is a supplementary gene action. Thus, based on the high heritability with high genetic advance, it can be inferred that fruit peel and pulp colour, along with the fruit weight, could form a selection criterion in the guava improvement program.

Keywords: colour; GCV; guava; heritability; inheritance; intervarietal progenies; variability

Introduction

Guava (*Psidium guajava* L.) is a commercially important, highly nutritious fruit crop that belongs to the family Myrtaceae. It is also known as the super fruit, apple of the tropics and poor mans' apple due to the presence of health-promoting bioactive compounds, with moderate prices, easy availability of fruit throughout the year and hardy nature of the crop (1). It has strong antioxidant, free radical scavenging properties and it possesses an array of medicinal properties such as anti-inflammatory, anti-viral and anti-mutagenic properties (2). The coloured guava is not only known for its higher consumer preferences but also has additional nutritional value as coloured guavas have lycopene, anthocyanin and carotenoid content, which impart colour to its pulp and serve as potential antioxidants (3). Thus, currently, guava improvement is given more focus on the development of coloured varieties with high nutritional values.

In guava, 35 % of the outcrossing occurs which resulting in the variability of the present-day seedling population from which some promising genotypes have been selected (4). This helped to broaden the genetic variability and to develop attractive coloured commercial varieties. The crop improvement program carried out in India has led to the release of several superior guava selections and hybrids. However, the plant breeder usually needs basic information regarding the nature and magnitude of genetic variability that is present in the population of the breeding material and also to what extent the desirable characters are heritable (5-6). The presence of extensive genetic diversity, variability and heritability within the existing guava germplasm forms a crucial basis for enhancing the effectiveness and outcomes of breeding programs, facilitating the development of improved cultivars with superior yield and quality. The presence of high heritability and variability provides extensive scope for further improvement in particular important traits. The

highly heritable value indicates that they were least affected by environmental changes and the selection depending on phenotypic performance would be more valid (7). In guava improvement programs, understanding the genetic basis of important traits is essential for formulating effective selection strategies. Traits exhibiting high heritability along with high genetic advance are primarily governed by additive gene action, allowing efficient improvement through direct selection, whereas traits with high heritability but low genetic advance are governed mainly by non-additive gene effects such as dominance or epistasis, that may require hybridization or recurrent selection methods to realize their genetic potential, where selection based on phenotype becomes less effective (8). Thus, identifying the prevailing gene action and heritability-genetic advance patterns guides breeders in choosing appropriate selection methods. Therefore, a comprehensive study on the understanding of the nature and extent of genetic variation within the population is required to develop the commercially important hybrids. While the variation in the qualitative traits as a result of the segregation in progenies might be helpful for the selection of preferable qualities like colour in the next generation. From, genetic point of view, the variability that is present in the guava segregating population can be utilised to produce the new hybrid lines.

A pivotal aspect of guava enhancement lies in deciphering the inheritance and segregation ratios of peel and pulp colour. The manifestation of these colour traits is influenced by intricate gene interactions. To implement a systematic breeding program in any crop plant, it is crucial to understand the inheritance patterns of morphological traits, which enable the effective management of segregating populations and also help in varietal development, as well as broaden the palette of guava cultivars with market-preferred appearance, enhanced nutritional profiles and greater adaptability. Previous studies exhibited the occurrence of variability, heritability and genetic progress in guava genotypes (9-11). Earlier three studies conducted on the inheritance of pulp colour in guava germplasm and recombinant progenies exhibited dominance of red pulp colour over white pulp colour (12-14). However, to the best of our knowledge to date, very few reports are available on the information of variability study and peel and pulp colour inheritance in guava. Despite considerable progress in guava breeding, there remains a critical gap in understanding and effectively harnessing the genetic variability underlying peel and pulp colour traits. This investigation seeks to advance the understanding of trait inheritance and segregation, providing a foundation for the development of novel guava progenies with enhanced fruit colour and nutritional qualities. Therefore, the present study aimed to investigate the extent of variation in quantitative traits of intervarietal progenies of guava along with the inheritance pattern with respect to peel and pulp colour. Consequently, it will pave the way for developing the new elite progenies with unique fruit traits as per the consumer preferences and promoting sustainable improvement in guava production.

Materials and Methods

Plant material and study site description

The present research was conducted at the ICAR-IIHR, Bengaluru, Karnataka, India (13°7' N, 77°29' E) during 2022-24. The study consisted of 167 intervarietal progenies developed by crossing the

two contrasting guava genotypes, viz. Purple Local and Arka Poorna. The female parent 'Purple Local' is having greyish purple-coloured leaves, purple peel and pulp with soft seeds. Whereas, the male parent 'Arka Poorna' is a cultivar which is obtained from the progeny selection from the cross, 'Purple Local x Allahabad Safeda'. It has green leaves and white-pulped fruits with yellow peel. The seeds recovered after hybridisation were sown in polythene bags (8" x 5") and kept under nursery until they attained the age of 7 to 8 months. Then the intervarietal progeny seedlings were transplanted in the main field during 2020 after attaining six months of age at a spacing of 2 x 1 m and were maintained with due care and under uniform standard crop production techniques. The experimental plot was located at the fruit breeding block IX of the Division of Fruit Crops, which is situated at an altitude of 890 m MSL.

The soil of the experimental plot was sandy loam with a pH of 6.0 to 6.7. ICAR-IIHR, Bengaluru, has a moderately warm climate with mild summer months. The mean maximum temperature varied between 28.5 °C and 31.15 °C with an average temperature of 29.49 °C, while the mean minimum temperature varied between 17.3 °C and 21.17 °C with an average temperature of 19.77 °C.

The evaluation of fruit traits

The 167 intervarietal progenies of guava were studied for segregation ratio for the peel and pulp colour traits based on colour space values and were evaluated for the genetic analysis. A total of 120 progenies, which were fruiting consistently for two seasons during 2022-24, were evaluated for fruit morphological traits as per the standard DUS (distinctiveness, uniformity and stability) descriptors for guava (15).

Determination of fruit morphological traits

In the present investigation, a total of 15 fruit morphological traits and peel and pulp colour coordinate values (L^* , a^* , b^* , C^* and h^*) were evaluated. The fruit morphological traits like fruit weight (FW), diameter of calyx cavity (DCC), fruit length (FLE), fruit width (FWI), ratio of fruit length and width (RFLW), outer pulp thickness (OPT), number of seeds/100 g of fruit (NS), seed weight/100 g of fruit (SW), pulp percent (PP), seed hardness (SH), total soluble solids (TSS), titratable acidity (TA), vitamin C (VIT-C), peel L^* , peel a^* , peel b^* , peel C^* , peel h^* , pulp L^* , pulp a^* , pulp b^* , pulp C^* and pulp h^* of intervarietal progenies were recorded.

Determination of morphological traits

The FW and SW of fruit were estimated by using an electronic balance (Model: Sartoris, BSA 320 d = 0.01 g) and the average values were expressed in g. The DCC, FLE and FWI of each fruit were calculated using the scale and represented in cm. The OPT was also evaluated by using a scale by excluding the seed core. The NS was determined by counting the number of dried seeds extracted from 100 g of fruit pulp. The PP was estimated as per equation 1 and 2. The SH of fruit was measured by using the digital portable tablet hardness tester (Vinsyst Technologies, Model-VTHT, India) and expressed as Kgf.

$$\text{Pulp weight (g)} = \text{Fruit weight (g)} - \text{Seed weight (g)} \quad (\text{Eqn.1})$$

$$\text{Pulp percentage} = \frac{\text{Pulp weight}}{\text{Fruit weight}} \times 100 \quad (\text{Eqn.2})$$

Determination of peel and pulp colour using a colourimeter

The peel and pulp colour were evaluated with the aid of high-quality colourimeter (NR 200, 3NH Technology Co. Ltd, China) and expressed as per the CIELAB (International Commission on Illumination) values and these values include the colour coordinates of L^* measures the intensity of lightness (0 = black to 100 = white), a^* measures the redness (+) and greenness (-) and b^* measures the yellowness (+) and blueness (-), C^* (Colour intensity) and h^p (dominate colour tone) colourimeter values. The readings were taken from the average of three ripe fruits from each of the intervarietal progenies.

Statistical analysis

The present study was carried out during the years 2022 and 2023 and the results for various fruit traits represent the pooled data from the two guava seasons and were tested by two-way ANOVA analysis of variance using SPSS version 17.0 (SPSS Inc., Chicago, IL, USA). From each intervarietal progeny, fruit quality trait was assessed using ten fruits as replication and three replications for colour space values (L^* , a^* , b^* , C^* and h^p). The genetic variability among different fruit morphological and biochemical traits was generated using the variability package by employing the statistical software of R version 4.5.1. The obtained result from the present investigation was subjected to a chi-square test for studying the segregation of peel colour and pulp colour in guava intervarietal progenies. The test on goodness of fit between expected and observed segregation ratio was calculated using R software and statistically significant values were taken at $p < 0.05$.

Results

Genetic variations for fruit and colour traits

Considerable variations were exhibited in intervarietal progenies of guava with respect to the fruit traits (Table 1). The progenies exhibited a wide range of PCV, which ranged from 0.78 % to 42.69 %. The maximum expression of PCV was noted in NS (42.69 %), followed by SW (37.53 %) and FW (37.44 %), TA (27.40 %) and OPT (21.98 %). The moderate PCV was registered for DCC (19.94 %), VIT-C (19.33 %), TSS (18.18 %), FLE (13.68 %) and FWI (12.39 %). Lower PCV values were recorded for RFLW (7.13 %), SH (5.41 %) and PP (0.78 %). The GCV for all the traits ranged from 0.54 % to 26.08 %. Maximum expression of GCV was observed for SW (26.08 %), followed by NS (25.58 %) and FW (21.56 %). The moderate GCV was recorded in TA (15.82 %), DCC (14.98 %), OPT (14.20 %), VIT-C (11.69 %) and TSS (10.42 %). Whereas, lower expression of GCV was registered for FLE (9.10 %), FWI (7.55 %), RFLW (4.65 %), SH (3.33 %) and PP (0.54 %) (Table 1).

A wide range of variation was recorded for the peel and pulp colour values (Table 2). In case of peel and pulp colour, the PCV ranged from 19.30 % to 67.28 % and the GCV ranged from 12.80 % to 57.37 %. The higher PCV and GCV were recorded for colour values of pulp a^* (52.17 % and 46.27 %), b^* (34.36 % and 27.18 %), C^* (29.89 % and 24.49 %) and h^p (53.26 % and 47.78 %) and for peel colour values of L^* (29.63 % and 26.96 %), a^* (67.28 % and 57.37 %), b^* (38.57 % and 33.25 %) and h^p (37.38 % and 35.22 %) indicating high level of variability. However, pulp L^* (19.30 % and 15.84 %) and peel C^* (22.10 % and 12.80 %) recorded moderate PCV and GCV content.

In the present study, all the measured fruit traits recorded moderate heritability, which ranged from 0.33 to 0.56, which is due

to the PCV being significantly greater than GCV in all measured fruit traits (Table 1). With respect to the heritability for peel and pulp colour, it exhibited variation and it was represented in Table 2. However, peel and pulp colour values exhibited heritability in the range of 0.34 to 0.89. The high heritability was recorded for pulp L^* (0.67), a^* (0.79), b^* (0.63), C^* (0.67) and h^p (0.80) and for peel colour values of L^* (0.83), a^* (0.73), b^* (0.74) and h^p (0.89) except for peel C^* which recorded moderate heritability of 0.34.

In the present study, the genetic advance as per cent of the mean was recorded highest in the fruit traits like SW (37.34 %), NS (31.57 %), FW (25.56 %) and DCC (23.19 %). The moderate genetic advances were recorded for OPT (18.90 %), TA (18.80 %), VIT-C (14.56 %), FLE (12.46 %) and TSS (12.31 %). The least genetic advance was noted for PP (0.78 %), SH (4.22 %), RFLW (6.23 %) and FWI (9.47 %) (Table 1). Whereas, the peel and pulp colour recorded the genetic advance except for the peel C^* value, which recorded the moderate genetic advance of 15.28 % (Table 2).

Inheritance pattern of intervarietal progenies

The intervarietal progenies were derived by crossing contrasting parents Purple Local (red peel) with Arka Poorna (yellow peel). Based on the peel colour space values, the intervarietal progenies were broadly grouped into two groups, viz. yellow and red. Out of 167 progenies evaluated for peel colour, 103 intervarietal progenies were segregated into the yellow group and 64 intervarietal progenies into the red group. The resulting intervarietal progenies were segregating in the ratio of 9:7 (yellow: red) with a Chi-square value of 1.99, indicating the complementary gene action (Table 3-5 and Fig. 1A).

Based on the pulp colour space values, the intervarietal progenies were broadly grouped into three groups, viz. red, pink and white. Out of 167 progenies evaluated for pulp colour, 78 intervarietal progenies were segregated into the red group, 40 intervarietal progenies into the pink group and 49 intervarietal progenies into the white group. In this study, the segregation of the red: pink: white pulp colour in the intervarietal progenies of guava was 9:3:4 with a Chi-square value of 1.99, indicating the supplementary gene action (Table 6-8 and Fig. 1B).

Discussion

Genetic variations for fruit and colour traits

The presence of genetic variation and the inheritance of traits of interest are the major factors that determine the success of a crop breeding program. The analysis of genetic variation enables the breeder to determine the most appropriate method and selection criteria for improving the target traits (5). Considerable variations were exhibited in intervarietal progenies of guava with respect to the fruit traits (Table 1). The high PCV and GCV for the traits such as NS, SW and FW suggest the presence of high genetic variation across the intervarietal progenies as well as the suitability of these traits for further improvement through selection. The lower GCV and PCV values indicate that less variability was present in the observed traits. The expression of PCV was higher than that of GCV, demonstrating that the environment influences the expression of the measured fruit traits. Previous studies have reported that PCV was higher than GCV, indicating that the variations in genotypes were caused by both genetic and environmental factors (16, 5). The present

Table 1. Variability, heritability and genetic advance in intervarietal progenies of guava for fruit traits

	Traits												
	FW (g)	DCC (cm)	FLE (cm)	FWI (cm)	RFLW	OPT (cm)	NS	SW (g)	PP (%)	SH (Kgf)	TSS (°B)	TA (%)	VIT-C (mg 100 ⁻¹ g FW)
Seasons	105773 ^{***}	0.44906 [*]	32.213 ^{***}	17.4225 ^{***}	0.122193 ^{***}	0.11	14978.40	1.97109 [*]	1.97109 [*]	0.00	164.759 ^{***}	0.0263761 ^{***}	9706.4 ^{***}
Intervarietal Progenies	4554 ^{***}	0.26766 ^{***}	0.767 ^{***}	0.924 ^{***}	0.004605 ^{***}	0.112402 ^{***}	12281.9 ^{***}	0.86645 ^{***}	0.86645 ^{***}	0.112667 ^{***}	3.692 ^{***}	0.0023726 ^{***}	1243.4 ^{***}
Error	2287.00	0.07	0.30	0.42	0.00	0.05	5792.70	0.30	0.30	6.05	1.87	0.00	577.40
GM	156.19	2.07	5.33	6.63	0.81	1.28	222.68	2.04	97.96	5.28	9.17	0.15	156.10
ECV	30.62	13.15	10.21	9.83	5.41	16.77	34.18	26.98	0.56	4.27	14.90	21.92	15.39
GCV	21.56	14.98	9.10	7.55	4.65	14.20	25.58	26.08	0.54	3.33	10.42	15.82	11.69
PCV	37.44	19.94	13.68	12.39	7.13	21.98	42.69	37.53	0.78	5.41	18.18	27.40	19.33
h ²	0.33	0.56	0.44	0.37	0.42	0.42	0.36	0.48	0.48	0.38	0.33	0.33	0.37
GA	39.93	0.48	0.66	0.63	0.05	0.24	70.31	0.76	0.76	0.22	1.13	0.03	22.73
GA (% Mean)	25.56	23.19	12.46	9.47	6.23	18.90	31.57	37.34	0.78	4.22	12.31	18.80	14.56

*Significant at 0.05 %, ** Significant at 0.01 %, *** significant at 0.001 %. The values which are mentioned for the seasons, Intervarietal progenies and Error indicate the mean square values of two-way ANOVA. FW: fruit weight, DCC: diameter of calyx cavity, FLE: fruit length, FWI: fruit width, RFLW: ratio of fruit length and width, OPT: outer pulp thickness, NS: number of seeds/100 g of fruit, SW: seed weight/100 g of fruit, PP: pulp percent, SH: seed hardness, TSS: total soluble solids, TA: titratable acidity and VIT-C: vitamin C. Whereas, GM: grand mean, ECV: environmental coefficient of variance, GCV: genotypic coefficient of variance, PCV: phenotypic coefficient of variance, h²: heritability (broad sense), GA: genetic advance, GA (%): genetic advance as percentage of mean. PCV & GCV: low (< 10 %), Moderate (10 %-20 %) and high (> 20 %); h²: low (< 30 %), Moderate (30 %-60 %) and high (> 60 %); GA (% Mean): low (< 10 %), Moderate (10 %-20 %) and high (> 20 %).

Table 2. Variability, heritability and genetic advance in intervarietal progenies of guava for peel and pulp colour

	Traits									
	Pulp L*	Pulp a*	Pulp b*	Pulp C*	Pulp h°	Peel L*	Peel a*	Peel b*	Peel C*	Peel h°
Seasons	1409.35 ^{***}	0.58	0.82	13.30	10.72	31115.93 ^{***}	177.548 [*]	1278.95 ^{***}	1680.29 ^{***}	2.39
Intervarietal Progenies	252.88 ^{***}	200.298 ^{***}	44.314 ^{***}	108.513 ^{***}	873.60 ^{***}	607.39 ^{***}	223.616 ^{***}	288.74 ^{***}	103.75 ^{***}	972.87 ^{***}
Error	49.31	23.92	10.20	21.35	94.57	57.08	35.33	42.49	51.59	57.90
GM	63.68	20.30	15.20	26.96	41.31	61.52	16.91	33.37	39.89	60.73
ECV	11.03	24.10	21.01	17.14	23.54	12.28	35.15	19.54	18.01	12.53
GCV	15.84	46.27	27.18	24.49	47.78	26.96	57.37	33.25	12.80	35.22
PCV	19.30	52.17	34.36	29.89	53.26	29.63	67.28	38.57	22.10	37.38
h ²	0.67	0.79	0.63	0.67	0.80	0.83	0.73	0.74	0.34	0.89
GA	17.06	17.16	6.73	11.14	36.47	31.10	17.04	19.71	6.10	41.51
GA (% Mean)	26.79	84.54	44.30	41.32	88.29	50.55	100.77	59.07	15.28	68.36

*Significant at 0.05 %, ** Significant at 0.01 %, *** significant at 0.001 %. The values which are mentioned for the seasons, Intervarietal progenies and Error indicate the mean square values of two-way ANOVA. Whereas, GM: grand mean, ECV: environmental coefficient of variance, GCV: Genotypic coefficient of variance, PCV: phenotypic coefficient of variance, h²: heritability (broad sense), GA: genetic advance, GA (%): genetic advance as percentage of mean. PCV & GCV: low (< 10 %), Moderate (10 %-20 %) and high (> 20 %); h²: low (< 30 %), Moderate (30 %-60 %) and high (> 60 %); GA (% Mean): low (< 10 %), Moderate (10 %-20 %) and high (> 20 %). PCV & GCV: low (< 10 %), Moderate (10 %-20 %) and high (> 20 %).

Table 3. Segregation ratios and Chi-square tests for fruit peel colour based on the colour space values in intervarietal progenies of guava

Population	No. of plant	Observed number		Expected number		Expected ratio	Chi-square tests		Chi-square tests χ^2 (Table)
		Yellow	Red	Yellow	Red		χ^2 (calculated)	p	
Purple Local × Arka Poorna	167	103	64	94	73	9:7	1.99	0.16	3.84 (p < 0.05)

Table 4. Genotypic configuration of fruit peel colour in intervarietal progenies of guava

Gametes	AB	Ab	aB	ab
AB	AABB (Yellow)	AABb (Yellow)	AaBB (Yellow)	AaBb (Yellow)
Ab	AABb (Yellow)	AAbb (Red)	AaBb (Yellow)	Aabb (Red)
aB	AaBB (Yellow)	AaBb (Yellow)	aaBB (Red)	aaBb (Red)
ab	AaBb (Yellow)	Aabb (Red)	aaBb (Red)	aabb (Red)

Phenotypic ratio: 9 Yellow:7 Red (Yellow: Red); Genotypic ratio: 1:2:1:2:4:2:1:2:1 (yellow:yellow:red:yellow:yellow:red:red:red:red); Where, Genotype class: A-B- denotes yellow colour, whereas, the genotype class A-b- or a-B- or a-bb denotes the red colour.

Table 5. Genotype and phenotype class for fruit peel colour in intervarietal progenies of guava

Genotypic ratio	Genotype Class	Phenotypic class	Phenotypic ratio
1	AABB	Yellow	9
2	AABb		
2	AaBB		
4	AaBb		
1	AAbb	Red	7
2	Aabb		
1	aaBB		
2	aaBb		
1	aabb		

Table 6. Segregation ratios and Chi-square tests for fruit pulp colour based on the pigments and colour space values in intervarietal progenies of guava

Population	No. Of Plant	Observed Number			Expected Number			Expected Ratio	Chi-square tests		Chi-square tests χ^2 (Table)
		Red	Pink	White	Red	Pink	White		χ^2	p	
Purple Local × Arka Poorna	167	78	40	49	94	31	42	9:3:4	6.37	0.04	9.210 (P<0.01)

Table 7. Genotypic configuration of fruit peel colour in intervarietal progenies of guava

Gametes	AB	Ab	aB	ab
AB	AABB (Red)	AABb (Red)	AaBB (Red)	AaBb (Red)
Ab	AABb (Red)	AAbb (Pink)	AaBb (Red)	Aabb (Pink)
aB	AaBB (Red)	AaBb (Red)	aaBB (White)	aaBb (White)
ab	AaBb (Red)	Aabb (Pink)	aaBb (White)	Aabb (White)

Phenotypic ratio: 9 Red : 3 Pink: 4 White (Red : Pink: Yellow), where A: denotes pink colour, A and B denote Red colour and aabb or aaB/b denote white colour.

Table 8. Genotype and phenotype class for fruit peel colour in intervarietal progenies of guava

Genotypic ratio	Genotype Class	Phenotypic class	Phenotypic ratio
1	AABB	Red	9
2	AABb		
2	AaBB		
4	AaBb		
1	AAbb	Pink	3
2	Aabb		
1	aaBB	White	4
2	aaBb		
1	aabb		

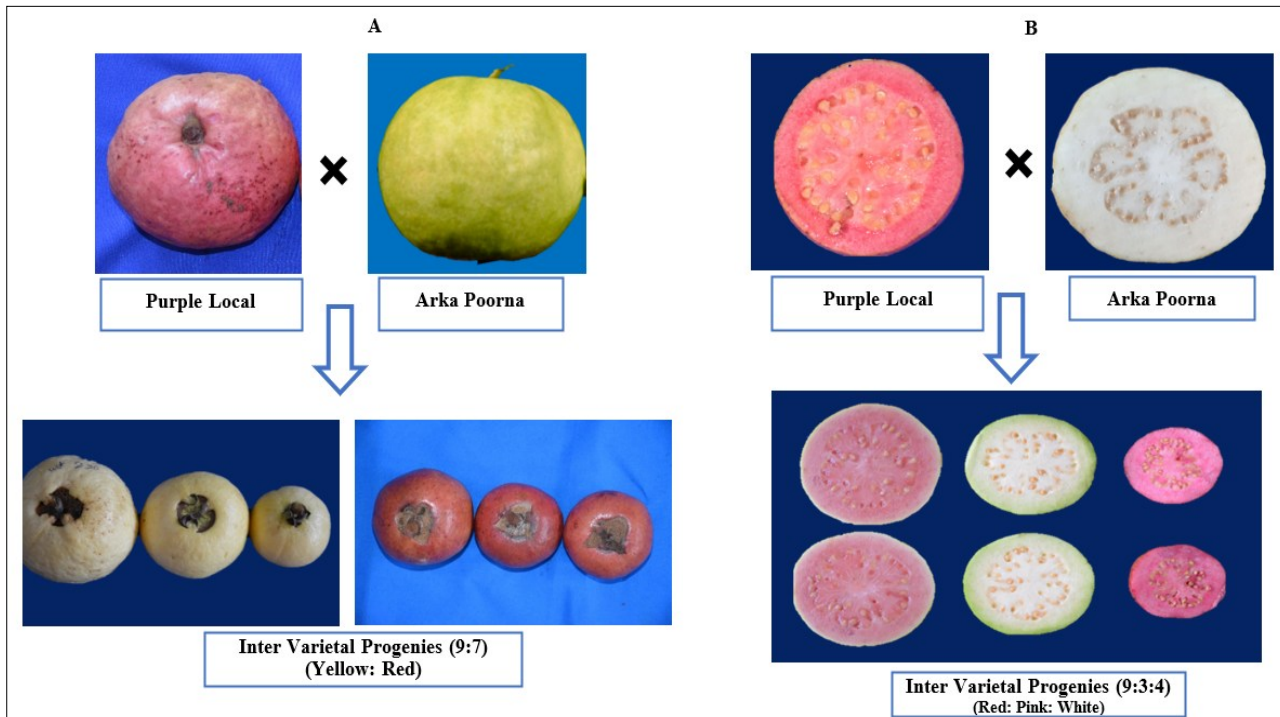


Fig. 1. Inheritance pattern in intervarietal progenies of guava: A. peel colour, B. pulp colour.

study is in agreement with the findings in guava fruit, where a higher PCV of 20.93 % were observed for FW and moderate variance was noted for SH and TSS (17). However, in the present, the PCV for FW was 37.44 % which was comparatively higher than the earlier study report. The PCV values for colour traits were higher compared with the GCV, indicating the influence of traits by environment. Similar findings were obtained in guava, where they also recorded higher PCV and GCV except for the pulp L^* (18).

The heritability is a reliable measure of the transmission of characters from parents to their progeny. The estimation of the heritability and genetic advance helps breeders in the selection of genotypes from diverse populations that predict the gain under the selection (5). The high heritability values indicate that these traits were less influenced by environment and selection based on these traits would be reliable (19). Previous study reported higher heritability for the peel and pulp L^* and a^* value, except for the peel a^* and pulp b^* value, which recorded moderate to low heritability in guava (18). The high heritability, which is accompanied by the high genetic advance in the present study for the peel and pulp colour traits, shows that the expression of these traits was governed by the additive gene effect and the selection based on these traits is effective. The moderate heritability with low genetic advance was recorded for the fruit traits like FWI, RFLW, PP and SH, which shows that these traits are most probably governed by non-additive gene action. The fruit traits like FW, DCC, NS and SW showed moderate heritability, with the high GA exhibiting the traits governed by the additive gene effect; however, slight environmental effects were present on these traits and selection is also useful. Our results are concurrent with the findings of previous research, which also noted high GA for FW and for NS (20). Similarly, research indicates that the moderate GA coupled with the high heritability showing the revealing a slightly lower amount of environmental influence on the trait D/L index (21).

Inheritance pattern of intervarietal progenies

The intervarietal progenies were derived by crossing contrasting parents Purple Local (red peel) with Arka Poorna (yellow peel). Based on the peel colour space values, the intervarietal progenies were broadly grouped into two groups, viz. yellow and red. The resulting intervarietal progenies were segregated to the yellow and red peel groups in a 9:7 ratio, indicating the complementary gene action. Further, The Chi-square test suggested that peel colour is controlled by two genes, each with two alleles and displays complementary gene action. The probable genotypes of the progenies are 1: AABB (yellow), 2: AABb (yellow), 1: AAbb (red), 2: AaBB (yellow), 4: AaBb (yellow), 2: Aabb (red), 1: aaBB (red), 2: aaBb (red) and 1: aabb (red) (9: 7 that is yellow: red) indicating yellow peel colour is dominant over the red peel colour and two dominant gene are required for the expression of yellow peel colour, if anyone of the two gene are in recessive condition red peel colour was expressed in intervarietal progenies of guava. Peel colour in guava is explained by complementary gene action in the present study, where two non-allelic genes must both present dominant alleles for the development of a specific colour (yellow). This fits classical complementary gene interaction (9:7), only individuals with both dominant alleles display the colour phenotype, while the absence of either results in a default (red) phenotype. Peel colour is controlled by the interplay of several candidate genes, indicating that gene complementation drives peel colouration. This is the first report stating peel colour inheritance in guava.

The progenies were classified based on the pulp colour space values for the inheritance study. Since both carotenoid and anthocyanin pigments have a role in determining the pulp colour of guava, the progenies were categorised as red, pink and white pulp colour. The anthocyanin pigment governs the red pulp colour of guava, while lycopene governs the pink pulp colour and carotenoid defines the white pulp colour. In this study, the segregation of the red: pink: white pulp colour in the intervarietal progenies of guava was 9:3:4, demonstrating the supplementary gene action (Table 4). The pulp colour in guava is controlled by two genes that display

supplementary gene action, the gene 'A' in dominant condition produces pink pulp, the gene 'B' in dominant/recessive condition (B/b) do not have its own effect but when two genes are in dominant condition the gene 'B' supplements the effect of the 'A' and produces the red pulp colour. Thus, the genotypes class 9A-B produce the Red pulp colour that is 1 AABB, 2 AABb, 2 AaBB, 4 AaBb. The genotype class 3A-bb (1 AABb, 2 Aabb) produces the pink pulp colour that is in the absence of dominant B, it produces the pink colour. Further, the genotype class 3 aaB (1 aaBB, 2 aaBb) produces the white pulp colour and genotype class 1 aabb also produces white pulp colour, together producing 4 white pulp colours. The predicted genotypes of progenies were AABB, AABb, AaBB, AaBb, AaBb, AAbb, Aabb, aaBB, aaBb and aabb. In the earlier study, it was observed that the F₂ population of rice segregated in 9:3:4 for grain colour of rice (black purple: brown: white), indicating the purple colour of grain was controlled by two dominant complementary genes and also suggesting that the additional genes may probably play a role in the colour expression (22). The chi-square test indicates that the dominant gene action controls pulp colour. Also suggest that multiple genes are involved in determining pulp colour, with dominant genes controlling the coloured pulp and the recessive gene controlling colourless pulp. Pulp colour in guava is governed by supplementary gene action, where one gene alone is sufficient to produce colour, but the presence of a second gene modifies the intensity or shade, resulting in a 9:3:4. The present result was concurrent with the earlier findings that recorded the polygenic nature of pulp colour inheritance in guava and also found white pulp colour inheritance was homozygous recessive in nature and red colour was dominant (14). As revealed from the present study, gradations of variation were recorded for pulp colour (with respect to red and pink groups) among the progenies, which ranged from the red group to the red-purple group as per the RHS colour chart.

Conclusion

This study demonstrates the presence of significant genetic variability among the intervarietal progenies of guava. The presence of high heritability with high genetic advance was noted for peel colour, pulp colour and moderate heritability with high genetic advance for fruit traits like FW, DCC, NS and SW, which indicates that selection would be effective for these traits and helpful in future breeding programs. The segregation analysis for peel and pulp colour demonstrated that the peel colour was governed by complementary gene action, whereas the pulp colour was governed by the polygenic nature, which is influenced by carotenoid and anthocyanin genes. Thus, the present investigation recorded a significant genetic variability with respect to fruit, peel and pulp colour traits, which can be utilised further in the guava breeding program to get a desired elite variety with enhanced pulp pigment. Since the study has resulted in high heritability for the traits like fruit weight, peel and pulp colour, six progenies were identified which will be used in the guava crop improvement program.

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Authors' contributions

MM was involved in the investigation, formal analysis, data curation and writing of the original draft. VC contributed to conceptualisation, supervision, visualisation, reviewing and editing. AS, KC and HBK participated in reviewing and editing the manuscript. RKV provided resources and contributed to reviewing. SKS was responsible for resources, methodology and reviewing. SRDV also contributed through resources, methodology and review. All authors read and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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