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Analyzing Genetic Variability and Heritability of Yield Related Traits in Papaya (*Carica papaya* L.) via Line Tester Method

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ABSTRACT

This study evaluates the genetic variability, heritability, and correlation among 41 diverse papaya genotypes across 15 traits to identify potential avenues for crop enhancement. Significant variation was observed in traits such as plant height (ranging from 90.97 cm to 177.33 cm), flowering initiation (196.67 to 228 days), and flowering duration (210.27 to 235.33 days). High heritability values were noted for plant height at flowering (98.39%), fruit yield per plant (98.22%), and fruit length (95.26%), indicating these traits are predominantly influenced by genetic factors and are suitable targets for breeding programs. Genetic advance calculations showed substantial potential for improvement in traits like plant height at flowering (70.68%) and fruit yield per plant (62.69%). Correlation analyses revealed significant positive associations between fruit yield per plant and traits such as fruits per plant (0.8406) and plant height (0.612). These findings underscore the potential for effective selection and hybrid breeding programs to enhance papaya yield and quality. Negative significant effects were observed in certain crosses, suggesting the complexity of heterosis effects and the importance of selecting compatible parental lines. Overall, this research highlights the rich genetic variability in papaya and provides valuable insights for breeding programs aimed at improving crop yield and quality.

INTRODUCTION

Papaya, scientifically classified under the Caricaceae family and commonly referred to as 'papaya,' originally hails from tropical America. It holds significance in tropical and subtropical regions due to its economically valuable edible fruits and latex (Niklas & Marler, 2007) and (Carvalho & Renner, 2012). Papaya exhibits a broad spectrum of natural genetic diversity, offering opportunities for crop enhancement. Variations in flowering and fruiting behaviors are observed, and insights into genetic variability, heritability, and genetic advance serve as the foundation for selecting desirable fruit traits and identifying suitable parental plants. Understanding genetic variability alongside heritability provides a reliable estimation of the genetic progress required for selection, as elucidated (Burton & Devane, 1953) (Jambhale, 2014). Determining the traits influencing yield involves examining genetic variability, heritability, and correlation coefficients. Correlation analysis reveals the genetic relationships among various traits, as outlined by Bhatt in 1973. Utilizing heritability alongside genetic advance assists in making informed decisions for effective selection based on phenotypic performance, as highlighted by Johenson et al. in 1955. Understanding the correlation between yield and its contributing characteristics is crucial for hybridization programs. Considering the significance of papaya and these factors, the current study has commenced.

However, more research is needed on this topic; at the same time, it is important to value the genetic variability present in papaya plants. This information can help guide the selection of suitable parents for future breeding programs, greatly impacting the quality and yield of the crop.

Material and Methods

The present study was conducted at the Horticulture Research Centre of Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, during season 2019 & 2021. The research study utilized a total of 11 inbred lines of the 2nd generation, namely Pusa Dwarf, Pusa Nanha, Pant Papaya 1, PS 1, and Pusa

Giant, which were taken as female parents. Additionally, each of these lines was crossed with six male parents, including Surya, Pusa Delicious, Pusa Majesty, Red Lady, Washington, and Ultra Dwarf 1. These selections of inbred lines and male parents aimed to represent a diverse range of genotypes for assessing combining ability in papaya.

The seeds of these selected parent genotypes were obtained from various reputed sources representing different geographical regions. Pant Papaya 1 was sourced from Govind Ballabh Pant University of Agriculture and Technology, Pantnagar; Pusa Delicious, Pusa Majesty, Pusa Giant, Pusa Dwarf, and Pusa Nanha were obtained from IARI, Regional Station Pusa, Samastipur, Bihar; Surya was acquired from IIHR, Bangalore; PS 1 was sourced from SVPUA&T, Meerut. Additionally, other varieties/lines such as Red Lady and Ultra Dwarf 1 were included in the study. With utilizing selected genotype the following Cross combination have been made like Pusa Dwarf x Pusa Majesty, Pusa Dwarf x Surya, Pusa dwarf x Red Lady, Pusa Dwarf x Washington, Pusa dwarf x Pusa Delicious, Pusa dwarf x Ultra Dwarf 1, Pusa Nanha x Pusa Majesty, Pusa Nanha x Surya, Puisa Nanha x Red Lady, Pusa Nanha x Washington, Pusa Nanha x Pusa Delicious, Pusa Nanha x Ultra Dwarf 1, PS 1 x Pusa Majesty, PS 1 x Surya, PS 1 x Red Lady, PS 1 x Washington, PS-1 x Pusa Delicious, PS-1 x Ultra Dwarf 1, Pant Papaya 1 x Pusa Majesty, Pant Papaya-1 x Surya, Pant Papaya 1 x Red Lady, Pant papaya 1 x Washington, Pant papaya 1 x Pusa Delicious, Pant papaya 1 x Pusa dwarf 1, Pusa Giant x Pusa Majesty, Pusa Giant x Surya, Pusa Giant x Red Lady, Pusa Giant x Washington, Pusa Giant x Pusa Delicious and Pusa Giant x Pusa dwarf 1.

Standard horticultural practices were employed throughout the study to ensure optimal growth and development of the papaya plants. The crops were grown for consecutive years, and observations were recorded for various parameters, including Stem Diameter, Number of Leaves at Flowering, Number of Fruit Per Plant, Fruit Diameter, Weight of Fruit, Pulp Thickness, Fruit Length, Days to Flowering, Breadth of Central Cavity, Plant Height at Flowering, Plant Height at Harvesting, Fruit Yield Per Plant, and Total Soluble Solids (TSS).

Mean values of the recorded parameters were subjected to one-way analysis of variance (ANOVA) to determine the significance of differences among genotypes. Phenotypic and genotypic variations were computed following the methodology proposed by Burton (1953). Heritability estimates were calculated for each trait and categorized as high (above 90 percent), moderate (60 to 90 percent), or low (below 60 percent). Heritability in the broad sense was determined using the approach outlined by Lush (1949). Expected genetic advance for different characters under selection was estimated based on the methods described by Lush (1949) and Johnson et al. (1955). These statistical analyses provided insights into the genetic variability and heritability of the traits evaluated in the study.

Results and Discussion

The study evaluated 41 diverse genotypes across 15 characteristics, presenting the range of mean performance in Table 2.0. Notably, substantial variation existed across the traits examined. Plant height ranged from 90.97 cm to 177.33 cm, with Pusa Nanha x Ultra Dwarf-1 exhibiting the smallest and Red Lady the largest. Flowering initiation spanned from 196.67 to 228 days, with Pusa Nanha x Ultra Dwarf-1 initiating earliest and Red Lady taking the longest. Flowering duration ranged from 210.27 to 235.33 days, with Pusa Nanha x Ultra Dwarf-1 displaying the shortest and Pant Papaya 1 x Red Lady the longest duration. Various other parameters such as plant height at flowering, petiole length, plant girth, number of leaves at flowering, fruit characteristics including length, girth, central cavity size, pulp thickness, total soluble solids (TSS), as well as fruits per plant, fruit weight, and fruit yield per plant, exhibited considerable diversity across the genotypes studied, indicating potential avenues for further investigation and breeding efforts.

Heritability estimates were categorized into high (above 90 percent), moderate (60 to 90 percent), and low (below 60 percent). Heritability (h^2b) varied from 60.72% to 98.39%, (Table: 2.0) with high heritability values recorded for plant height at flowering (98.39%), fruit yield per plant (98.22%), fruit plant-1 (97.94%), fruit length (95.26%), petiole length (92.08%), central cavity (92.74%), plant height (93.09%), and fruit weight (89.4%). Moderate to high heritability was observed for plant girth (89.74%), flowering initiation (88.22%), and leaves at flowering (84.39%). However, lower heritability values were noted for pulp thickness (80.9%) and TSS (°Brix) (60.72%). These findings suggest that certain traits such as plant height at flowering, fruit yield per plant, and fruit length are predominantly influenced by genetic factors, making them potentially suitable targets for breeding programs aimed at improving yield and quality in papaya. Singh and Kumar (2010), Cynthia et al. (2000), and Dash et al. (1998) also reported similar findings. The high estimate of heritability primarily stems from additive gene effects, suggesting the potential for significant genetic progress through effective selection (Panse, 1957).

Notably, traits such as plant height at flowering, fruit yield per plant, and fruits per plant exhibited high GCV and PCV, with values of 34.59, 30.71, and 27.38, respectively, indicating substantial genetic variability. On the other hand, traits like flowering at days and total soluble solids (TSS) showed low GCV and PCV, with values of 3.08 and 4.77, respectively. Genetic advance calculations revealed significant potential for improvement in traits like plant height at flowering (70.68%), fruit yield per plant (62.69%), and fruit length (37.83%). Furthermore, correlation analyses at genotypic and phenotypic levels elucidated associations between traits, with fruit yield per plant showing significant positive correlations with fruits per plant (0.8406), plant height (0.612), and pulp thickness (0.583). These findings, supported by numerical data, provide valuable insights for selection programs and breeding efforts in papaya cultivation.

At the **genotypic level**, the study revealed significant positive correlations among various traits in papaya cultivation presented in Table: 3.0. Fruit yield per plant displayed strong associations with fruits per plant (0.8406), plant height (0.612), pulp thickness (0.583), days of flowering (0.561), petiole length (0.527), flower initiation (0.439), fruit weight (0.435), and plant girth (0.197). Fruit weight exhibited notable correlations with central cavity (0.334), TSS (0.326), pulp thickness (0.311), and fruit girth (0.258). Fruits per plant showed significant associations with plant height (0.677), petiole length (0.634), days at flowering (0.596), flower initiation (0.529), plant girth (0.205), and plant height at flowering (0.211). These correlations highlight key trait relationships essential for papaya breeding programs, offering valuable insights for genetic improvement strategies.

At the **phenotypic level**, significant positive correlations were observed among various traits in papaya cultivation presented in Table: 4.0. Yield per plant showed strong associations with fruit per plant (0.840), plant height (0.576), pulp thickness (0.541), and other traits. Fruit weight correlated significantly with central cavity (0.328) and pulp thickness (0.303). Fruits per plant displayed notable correlations with plant height (0.656), petiole length (0.588), and other attributes. Total soluble solids (TSS) exhibited significant associations with leaves at flowering (0.1401) and pulp thickness (0.122). Pulp thickness showed strong correlations with plant height (0.465) and other traits. Central cavity displayed significant associations with plant height (0.575) and plant height at flowering (0.542). Fruit girth correlated notably with plant height (0.238) and other characteristics. Fruit length exhibited significant correlations with flower initiation (0.539) and days at flowering (0.499). Leaves at flowering showed strong associations with plant height (0.376) and days at flowering (0.203). These correlations provide insights into trait relationships crucial for papaya breeding programs.

At the **environmental** level, notable correlations were observed among various traits in papaya cultivation presented in Table: 5.0. Yield per plant showed significant positive associations with fruit length (0.620), pulp thickness (0.362), and plant girth (0.288). Fruit weight displayed significant positive correlations with petiole length (0.544), leaves at flowering (0.371), and flower initiation (0.280), among others. Fruits per plant exhibited notable correlations with plant height at flowering (0.470), plant girth (0.449), and central cavity (0.326). Total soluble solids (TSS) showed significant associations with leaves at flowering (0.567) and fruit girth (0.395). The central cavity displayed a significant positive correlation with plant height (0.774), while fruit girth exhibited notable correlations with leaves at flowering (0.224) and petiole

length (0.222). Fruit length showed significant positive associations with plant girth (0.420) and plant height at flowering (0.358). Leaves at flowering exhibited notable associations with flower initiation (0.192), while plant girth displayed significant correlations with plant height at flowering (0.400). Petiole length showed significant positive associations with leaves at flowering (0.404) and initiation of flowering (0.328), indicating complex interrelationships among environmental factors and papaya traits. Plant height at flowering exhibited the highest values of PCV, GCV, and genetic advance associated with high heritability, followed by fruit per plant and fruit yield per plant. This aligns with the observations made by Dwivedi et al. (1995), Ghanta and Mondal (1992), and Alonso et al. (2008), who similarly noted related to PCV, GCV, genetic advance, and heritability in papaya.

Conversely, negative significant effects were also observed in certain crosses, highlighting the complexity of heterosis effects. For instance, crosses like Pusa Nanha x Pusa Delicious showed reductions in traits like plant height (-36.23 cm) and fruit yield per plant (-31.60 kg), suggesting the presence of genetic incompatibilities or unfavorable interactions between parental lines.

These findings underscore the importance of understanding heterosis effects for effective hybrid breeding programs in papaya, allowing for the selection of superior crosses with improved traits and yield potential.

CONCLUSION

The study evaluated 41 diverse papaya genotypes across 15 characteristics, revealing substantial variation in traits such as plant height, flowering initiation, flowering duration, and fruit characteristics. High heritability estimates for traits like plant height at flowering (98.39%), fruit yield per plant (98.22%), and fruit length (95.26%) suggest these traits are primarily influenced by genetic factors, making them suitable targets for breeding programs. Significant positive correlations among traits, such as fruit yield per plant with fruits per plant, plant height, and pulp thickness, provide valuable insights for genetic improvement strategies. The findings highlight the rich genetic variability in the genotypes studied, underscoring the potential for effective selection and hybrid breeding programs to enhance yield and quality in papaya. Understanding heterosis effects further aids in identifying superior crosses, paving the way for significant advancements in papaya cultivation.

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Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used Chat GPT in order to set language modulation. After using this tool/service, the author(s) reviewed and edited the content as needed and take (s) full responsibility for the content of the publication.

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Table 1.0 ANOVA for parents and hybrids

Characters	d.f	Flower initiation (days)	Flowering at days	Plant height (cm)	Plant height at flowering (cm)	Leaves at flowering	Plant girth (cm)	Petiole length (cm)	Fruit length (cm)
Replication	2	35.79	5.72	9.22	15.46	7.00	3.22	10.62	2.08
Genotype	40	148.71**	141.08**	1347.91**	1082.45**	25.06**	60.23**	90.52**	48.17**
Parent	10	230.02**	147.64**	2293.05**	2486.57**	26.46**	194.53**	162.76**	18.59**
Line(p)	4	223.89**	123.07**	2533.91**	4186.87**	46.36**	99.15**	170.49**	21.63**
Tester(p)	5	278.82**	193.51**	2438.56**	1261.11**	12.77**	274.10**	188.61**	19.53**
L(P) × T(P)	1	10.45	16.58	601.99**	1812.71**	15.29**	178.17**	2.63	1.70
Crov s PAR	1	153.06**	0.05	801.38**	5262.06**	28.99**	66.86**	74.28**	136.56**
ERROR	80	7.27	9.07	35.07	5.89	1.44	2.18	2.59	0.81
TOTAL	122	54.11	52.30	465.08	359.02	9.27	21.23	31.55	16.36

Characters	d.f.	Fruit girth (cm)	Central cavity (cm)	Pulp thickness (cm)	TSS (°Brix)	Fruits/plant	Fruit weight (g)	Fruit yield/plant(kg)
Replication	2	1.77	0.022	0.001	0.496	1.09	25.96	1.31
Genotype	40	46.45**	4.067**	0.104**	0.725**	287.80**	53024.52**	528.04**
Parent	10	55.68**	7.104**	0.189**	0.690**	246.16**	70720.20**	326.63**
Line(p)	4	28.31**	11.834**	0.225**	0.665**	334.32**	11098.70**	195.12**
Tester(p)	5	52.84**	4.705**	0.196**	0.589**	203.93**	111081.39**	471.87**
L(P) × T(P)	1	179.34**	0.176	0.014	1.292**	104.72**	107400.21**	126.50**
Crov s PAR	1	335.19**	1.088**	0.007	0.006	227.74**	42711.48**	674.68**
ERROR	80	2.50	0.104	0.008	0.139	2.25	2038.48	3.44
TOTAL	122	16.90	1.402	0.039	0.337	95.85	18722.22	175.40

***Significant at 5%, ** significant at 1 %**

Table 2.0 Variability of parents and hybrids

Charecters	Mean	Minimum	Maximum	Heritability	GA	GA % Mean	GCV	PCV	ECV
Flower initiation (days)	215.93	196.67	228.00	88.22	14.33	6.63	3.43	3.65	1.25
Flowering at days	226.20	210.27	235.33	83.74	13.13	5.80	3.08	3.36	1.36
Plant height (cm)	139.86	90.97	177.33	93.09	42.73	30.55	15.37	15.93	4.19
Plant height at flowering (cm)	54.29	29.55	122.78	98.39	38.37	70.68	34.59	34.87	4.43
Leaves at flowering	29.97	23.04	35.03	84.39	5.24	17.50	9.25	10.06	3.98
Plant girth (cm)	35.24	30.00	53.00	89.74	8.55	24.25	12.43	13.12	4.20
Petiole length (cm)	40.45	31.00	50.33	92.08	10.80	26.70	13.51	14.07	3.96
Fruit length (cm)	21.52	14.83	33.67	95.26	8.14	37.83	18.82	19.28	4.20
Fruit girth (cm)	38.76	29.83	43.50	85.15	7.18	18.53	9.75	10.57	4.07
Central cavity (cm)	8.04	5.77	11.30	92.74	2.27	28.19	14.21	14.76	3.98
Pulp thickness (cm)	2.19	1.79	2.53	80.90	0.33	15.04	8.12	9.03	3.95
TSS (^{o}Brix)	12.35	11.40	13.40	60.72	0.74	5.96	3.71	4.77	2.99
Fruits/plant	37.52	15.00	55.33	97.94	20.94	55.82	27.38	27.67	3.97
Fruit weight (g)	1185.69	821.98	1368.00	89.40	253.80	21.41	10.99	11.62	3.78
Fruit yield/plant (kg)	44.39	19.18	72.87	98.22	27.83	62.69	30.71	30.99	4.14

Table 3.0 Estimates of Genotypic correlation coefficients for different characters in papaya

characters	Flower initiation (days)	Floweringat days	Plant height (cm)	Plant height at flowering (cm)	Leaves at flowering	Plant girth (cm)	Petiole length (cm)	Fruit length (cm)	Fruit girth (cm)	Central cavity (cm)	Pulp thickness (cm)	TSS (°Brix)	Fruits/plant	Fruit weight (g)	Fruit yield/plant(kg)
Flower initiation (days)	1.000	0.736**	0.625**	0.418**	-0.011	0.351**	0.345**	0.610**	0.172	0.416**	0.200	-0.241**	0.529**	0.057	0.439**
Flowering at days			0.649**	0.421**	0.219*	0.406**	0.708**	0.577**	0.225*	0.510**	0.585**	-0.067	0.596**	0.028	0.561**
Plant height (cm)				0.575**	0.414**	0.491**	0.679**	0.441**	0.321**	0.559**	0.592**	-0.094	0.677**	0.103	0.612**
Plant height at flow (cm)					0.242**	0.015**	0.249**	0.276**	-0.202*	0.571**	0.403**	-0.131	0.211*	0.160	0.173
Leaves at flowering						0.052	0.412**	0.085	-0.054	0.179*	0.266**	0.196*	0.329**	0.083	0.390**
Plant girth (cm)							0.481**	0.306**	-0.090	0.341**	0.456**	0.158	0.205*	0.060	0.197*
Petiole length (cm)								0.286**	0.223*	0.401**	0.498**	-0.066	0.634**	-0.101	0.527**
Fruit length (cm)									0.260**	0.217*	0.191*	-0.084	0.388**	-0.013	0.312**
Fruit girth (cm)										0.316**	0.144	-0.054	0.321**	0.258**	0.387**
Central cavity (cm)											0.468**	0.125	0.440**	0.334**	0.434**
Pulp thickness (cm)												0.331**	0.475**	0.311**	0.583**
TSS (°Brix)													-0.062	0.326**	0.156
Fruits/plant														0.109	0.864**
Fruit weight (g)															0.435**
Fruit yield/plant(kg)															1.000

*Significant at 5%, ** significant at 1 %

Table 4.0 Estimates of Phenoypic correlation coefficients for different characters in papaya

Characters	Flower initiation (days)	Flowering at days	Plant height	Plant height at flowering (cm)	Leaves at flowering	Plant girth (cm)	Petiole length (cm)	Fruit length (cm)	Fruit girth (cm)	Central cavity(cm)	Pulp thickness(cm)	TSS (°Brix)	Fruits/plant	Fruit weight(g)	Fruit yield/plant(kg)
Flower initiation (days)	1.000	0.591**	0.541**	0.378**	0.016	0.275**	0.343**	0.539**	0.157	0.351**	0.201*	-0.151	0.481**	0.082	0.402**
Flowering at days			0.586**	0.370**	0.203*	0.365**	0.625**	0.499**	0.200*	0.459”*	0.449**	-0.061	0.543**	0.031	0.501**
Plant height (cm)				0.543**	0.376**	0.467**	0.613**	0.421**	0.238**	0.575**	0.465**	-0.126	0.656**	0.103	0.576**
Plant height at flowering (cm)					0.186*	0.500**	0.222*	0.277**	-0.185*	0.542*”	0.370**	-0.126	0.216*	0.134	0.173
Leaves at flowering						-0.028	0.408**	0.039	-0.011	0.149	0.160	0.280**	0.281**	0.120	0.343**
Plant girth (cm)							0.376**	0.312**	-0.113	0.338**	0.377**	0.019	0.213*	0.021	0.198*
Petiole length (cm)								0.230**	0.222*	0.359”*	0.454**	-0.044	0.588**	-0.042	0.487**
Fruit length (cm)									0.194*	0.208*	0.171	-0.068	0.371**	-0.041	0.320**
Fruit girth (cm)										0.229”*	0.114	0.057	0.304**	0.180*	0.341**
Central cavity (cm)											0.358**	0.020	0.432**	0.328**	0.398**
Pulp thickness (cm)												0.122	0.405**	0.303**	0.541**
TSS (°Brix)													-0.075	0.184*	0.130
Fruits/plant														0.088	0.840**
Fruit weight (g)															0.394**
Fruit yield/plant(kg)															1.000

*Significant at 5%, ** significant at 1 %

Table 5.0 Estimates of Environmental correlation coefficients for different characters in papaya

Characters	Flower initiation (days)	Flowering at days	Plant height (cm)	Plant height at flowering (cm)	Leaves at flowering	Plant girth (cm)	Petiole length (cm)	Fruit length (cm)	Fruit girth (cm)	Central cavity (cm)	Pulp thickness (cm)	TSS (Brix)	Fruits/plant	Fruit weight (g)	Yield/plant (kg)
Flower initiation (days)	1.000	-0.298**	-0.283**	-0.268**	0.192*	-0.342**	0.328**	-0.272**	0.060	-0.272**	0.215*	0.115	-0.221*	0.280**	-0.139
Flowering at days			0.117	-0.231**	0.119	0.106	0.026	-0.186*	0.066	0.087	-0.183*	-0.054	0.068	0.058	-0.155
Plant height (cm)				-0.210*	0.091	0.221*	-0.214*	0.108	-0.473**	0.774**	-0.421**	-0.332**	0.257**	0.112	-0.267**
Plant height at flowering (cm)					-0.687**	0.400**	-0.437**	0.358**	-0.014	-0.108	0.186*	-0.307**	0.470**	-0.404**	0.125
Leaves at flowering						-0.578**	0.404**	-0.433**	0.224*	-0.093	-0.345**	0.567**	-0.321**	0.371**	-0.236**
Plant girth (cm)							-0.679**	0.420**	-0.283**	0.315**	-0.086	-0.484**	0.449**	-0.314**	0.288**
Petiole length (cm)								-0.626**	0.222*	-0.145	0.192*	0.027	-0.355**	0.544**	-0.375**
Fruit length (cm)									-0.481**	0.080	0.028	-0.028	-0.136	-0.401**	0.620**
Fruit girth (cm)										-0.492**	-0.029	0.395**	0.190*	-0.357**	-0.243**
Central cavity (cm)											-0.403**	-0.438**	0.326**	0.273**	-0.437**
Pulp thickness (cm)												-0.399**	-0.295**	0.272**	0.362**
TSS (Brix)													-0.298**	-0.275**	0.109
Fruits/plant														-0.310**	-0.389**
Fruit weight (g)															-0.311**
Yield/plant															1.000

*Significant at 5%, ** significant at 1 %