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RESEARCH ARTICLE

Genetic evaluation of muskmelon hybrids using performance, correlation and path analysis for yield and quality traits in Kashmir

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Abstract

The present muskmelon hybrid study was carried out during the *Kharif* season of 2021–2022 in the experimental field of the vegetable science division, SKUAST, Kashmir, Shalimar. The experimental design employed was a randomized complete block design (RCBD) with three replications, evaluating twenty muskmelon hybrids for various quantitative and qualitative traits. Significant genotypic differences were observed across all the traits. Madhusree hybrid exhibited the highest fruit yield per plant (11.52 kg), followed by Tipu-50 (8.63 kg) and Punjab hybrid (7.87 kg). In terms of quality attributes, hybrid VS-8989 demonstrated the highest total soluble solids (TSS) (11.55 °B), followed by Sawarna hybrid (10.58 °B) while highest vitamin C content was found in Mahima (31.55 mg/100 g), followed by Punjab hybrid (31.08 mg/100 g) and Shelf life was longest in LHM-Masti (10.86 days), followed by Madhuraj (10.27 days). The average yield per plant demonstrated a significant positive correlation at both genotypic and phenotypic levels with several yield-contributing traits, including weight of fruit (g), number of fruits/plant, Vitamin C content (mg/100 g), flesh thickness (cm) and fruit length (cm). Path coefficient analysis further revealed that the highest positive direct effect on average yield per plant was observed for the number of fruits per plant, average fruit weight (g), fruit length (cm), flesh thickness (cm), phenol content (mg/g), days to first fruit harvest and internodal length (cm). These traits showed significant positive correlations and high positive direct effects on yield per plant, suggesting that direct selection based on these traits would be effective for yield improvement.

Keywords: correlation; muskmelon hybrids; path coefficient; quality traits; yield traits

Introduction

Muskmelon (*Cucumis melo* L.) is among the world's most significant commercial fruit crops. It is well-known for its distinctive flavour, taste and rich phytonutrient content. Melon fruit is a valuable source of essential nutrients, including potassium, vitamin C and provitamin A (beta-carotene) (1). In Kashmir, melons are considered one of the most expensive fruits due to the complexities involved in their cultivation. Achieving high-quality and abundant fruit production necessitates optimal growing conditions, which include selecting appropriate varieties, accounting for climatic factors, ensuring suitable soil types and quality, implementing proper irrigation techniques and managing diseases. In India, various melon genotypes are cultivated across different regions. These genotypes often originate from imports and have been developed through breeding programs. Despite the diversity in melon cultivation, there is a notable lack of comprehensive research on melon breeding and genetics. This gap highlights the need for more in-depth studies to enhance our understanding and improvement of melon crops.

Muskmelon is a cross-pollinated crop with a chromosome number 2n = 2x = 24 and exhibiting significant genetic variation due to its monoecious nature (2). To enhance both yield potential and quality traits, as well as to improve resistance to pests and diseases, a comprehensive investigation of local germplasm variation is highly recommended. Muskmelon productivity in India remains low compared to other vegetable crops. This low productivity can be attributed to factors such as premature flower drop, insufficient initiation of female flowers relative to male flowers, inadequate source-sink relationship and poor translocation of photo-assimilates during the later stages of crop growth. Muskmelon thrives in dry, warm weather with ample sunshine. Optimal growth occurs within a temperature range of 18 °C to 28 °C, although the plant can tolerate temperatures up to 40 °C. Growth significantly slows at temperatures below 12 °C. Additionally, muskmelon plants are extremely susceptible to frost, which can cause severe mortality. High humidity is also detrimental, as it hinders plant development, reduces fruit quality and increases disease incidence. The Kashmir Valley, characterised by its temperate agro-climatic conditions, experiences lower temperatures compared to other regions of India, with daytime and nighttime temperatures averaging 27.5 °C and 12.2 °C, respectively, during the limited growing season from May to September. Given these conditions, there is a need to either improve locally preferred cultivars or identify suitable cultivars and hybrids that offer high yield, superior quality and better adaptation to the region. Improving muskmelon cultivation in the Kashmir Valley and similar regions lies in leveraging genetic diversity, understanding environmental influences and applying targeted breeding strategies (3). By focusing on traits that enhance yield, quality and adaptability, the productivity and profitability of muskmelon cultivation can be significantly increased, meeting both consumer demands and agricultural sustainability goals. The objectives of this study were identify the mean performance of different genotypes and investigate the correlation, path analysis among twenty commercially available melon varieties. The findings of this research could be valuable for breeders, researchers and farmers, providing insights for future studies and practical applications.

Materials and Methods

Twenty hybrids of muskmelon were evaluated using a randomized block design with three replications at the vegetable experimental farm, Division of Vegetable Science, SKUAST-K, Shalimar, during 2021-2022, with the objective to find out the suitable hybrids of muskmelon for the temperate conditions of the Kashmir valley. Initially, seeds were sown in plug trays within a shade net house nursery in the *Kharif* season. The main field was prepared through ploughing, harrowing, levelling and subsequently divided into growing units (single-row plots). Each hybrid was cultivated in a separate growing unit, with rows spaced 1.5 m apart and plants spaced 1.5 m apart, resulting in respective hybrid being characterised by one row with six plants.

Twenty-five-day-old seedlings and after attaining considerable growth, were transplanted onto the main field. Throughout the investigation, standard cultural and plant protection practices were followed. Five randomly plants from each line in each replication were chosen for observation recording, with a focus on twenty-five quantitative and qualitative attributes *viz*., days to first male flower anthesis, days to first female flower anthesis, days to first fruit harvest, days to last fruit harvest, number of primary branches/plant, number of nodes/vine, node at which first male flower appeared, node at which first female flower appeared, node at which first branched tendril appeared, inter nodal length (cm), fruit length (cm), rind thickness (mm), flesh thickness (cm), average fruit weight (g), fruit yield/plant (kg), number of fruits/plant, fruit yield (t/ha), seed cavity length (cm), seed cavity width (cm), vine length (m), TSS/ total soluble solids (°B), vitamin C content (mg/100 g), moisture content (%), dry matter content (%) and shelf life (Days).

Observations on days to the emergence of the first staminate flower, days to the appearance of the first pistillate flower, node numbers of the first pistillate flower, days to first fruit harvest, days to last fruit harvest and total yield/plant were recorded from the whole plot. At the final harvest, traits such as the length of the vine and the number of primary branches/plant were measured. During the blooming stage, the earliest qualities, such as days to the emergence of the first staminate flower, days to the appearance of the first pistillate flower and first pistillate flower node numbers, were recorded. Days to first fruit harvest and days to last fruit harvest were recorded at the half-slip stage. Fruit length, average fruit weight, fruit cavity length, breadth, rind thickness, pulp thickness and seed yield were recorded from five randomly harvested at the half-slip stage in each replication. During the first harvest, five fruits were selected at the half-slip stage and total soluble solids were measured in °B with a hand refractometer. The total number of fruits/plants was calculated by adding the number of fruits taken from all pickings of each line in each replication and dividing it by the total number of plants/plot. Similarly, the total yield/plant was estimated by adding the weight of all fruits taken from each line in each replication and dividing by the total number of plants in the plot. Statistical studies, including analysis of variance, which is correlation and path coefficient analysis, were undertaken using standard and established approaches to determine the significance level between lines, i.e. hybrids (4-6), including the software used.

Results and Discussion

The success of selection in any crop improvement program depends not only on the variability present in yield and other economically important traits but also on the interrelationships among these traits within the population.

Means performance of muskmelon hybrids

Muskmelon breeders globally have been utilizing the available genetic resources to develop varieties that align with the evolving needs of society. To make muskmelon an ideal vegetable crop for sustainable agriculture, both producers and consumers must focus on high fruit yield and superior quality, respectively. In muskmelon breeding programs, certain traits should be prioritized, such as medium to tall vine height, moderate branching, lower position of the first male and female flowering nodes, early maturity and an extended fruiting period to enhance productivity. Additionally, medium-sized fruits with thin skin, thick pulp, high total soluble solids, a small seed cavity and few seeds are desirable for improved fruit quality and consumer appeal (Table 1). Tolerance to biotic stresses is also essential for stable and sustainable production. Therefore, muskmelon germplasm must be thoroughly evaluated for these traits to identify suitable accessions for breeding programs. Therefore, in the present investigation, different promising hybrids were evaluated under Kashmir Valley weather conditions to identify a suitable and superior hybrid for the region. The performance of these hybrids was assessed by studying different parameters, which are further discussed below:

Table 1. Path coefficient analysis showing phenotypic and genotypic contributions to fruit yield

		Phenotypic and Genotypic Path Matrix												
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Days to first fruit harvest (1)	**(P)**	0.0771	0.0047	-0.0039	-0.0195	-0.0023	0.0195	-0.008	0.0036	0.0272	-0.0267	0.0087	-0.0024	0.1121
	(G)	0.078	0.0041	-0.0042	-0.0204	-0.0035	0.0196	-0.008	0.0033	0.0274	-0.027	0.0092	-0.0024	0.1108
Internodal length (cm) (2)	**(P)**	0.0001	0.0009	-0.0002	-0.0001	-0.0001	0.0001	-0.0002	-0.0002	-0.0001	0.0001	-0.0003	-0.0002	-0.0726
	(G)	0.0001	0.0025	-0.0004	-0.0002	-0.0003	0.0003	-0.0005	-0.0005	-0.0004	0.0004	-0.0008	-0.0006	-0.0712
Flesh thickness (cm) (3)	**(P)**	-0.006	-0.0204	0.1194	0.029	0.0332	0.0086	0.0242	0.0475	-0.006	0.0065	0.044	0.0278	0.306*
	(G)	-0.0066	-0.0199	0.1208	0.03	0.0341	0.0087	0.0243	0.0482	-0.0061	0.0066	0.0441	0.0282	0.306*
Fruit length (cm) (4)	**(P)**	-0.0668	-0.0283	0.0642	0.264	0.227	0.0543	0.0094	0.0344	0.0245	-0.0236	0.0254	-0.0197	0.303*
	(G)	-0.0701	-0.0246	0.0665	0.2679	0.2311	0.0547	0.009	0.0364	0.0244	-0.0235	0.0233	-0.0195	0.301*
Fruit Diameter (cm) (5)	**(P)**	0.0052	0.0222	-0.0485	-0.1499	-0.1744	-0.0489	0.0075	-0.0391	-0.0379	0.0372	-0.0329	-0.0036	0.2434
	(G)	0.008	0.0186	-0.0496	-0.1518	-0.176	-0.0486	0.0077	-0.0405	-0.0374	0.0367	-0.0304	-0.0037	0.2411
Average fruit weight (g) (6)	**(P)**	0.2321	0.1032	0.0659	0.1886	0.2572	0.918	-0.4277	0.0204	-0.0368	0.0385	0.0177	-0.0818	0.503**
	(G)	0.2306	0.103	0.0659	0.1872	0.2533	0.9168	-0.427	0.0207	-0.0368	0.0385	0.0173	-0.0817	0.503**
Number of fruits / plant (7)	**(P)**	-0.0962	-0.1911	0.1879	0.0331	-0.0399	-0.4318	0.9268	0.2801	0.0626	-0.0601	0.3477	0.2877	0.474**
	(G)	-0.0952	-0.1908	0.1861	0.0312	-0.0407	-0.4315	0.9264	0.2794	0.0628	-0.0601	0.3459	0.287	0.474**
TSS (°B) (8)	**(P)**	-0.0066	0.0274	-0.0552	-0.0181	-0.0311	-0.0031	-0.0419	-0.1386	-0.0353	0.0348	-0.0293	-0.0249	0.1957
	(G)	-0.0059	0.0265	-0.0553	-0.0189	-0.0319	-0.0031	-0.0418	-0.1386	-0.0352	0.0347	-0.0286	-0.0249	0.1959
Moisture content (%) (9)	**(P)**	-0.4814	0.2088	0.0684	-0.127	-0.2966	0.0548	-0.0923	-0.3475	-1.366	1.3655	-0.0375	0.1942	-0.0265
	(G)	-0.5182	0.225	0.0744	-0.1344	-0.3129	0.0592	-0.0999	-0.3741	-1.4742	1.4737	-0.0404	0.2097	-0.0266
Dry matter content (%) (10)	**(P)**	0.4713	-0.2093	-0.0735	0.1217	0.2905	-0.0571	0.0881	0.3412	1.3593	-1.3598	0.0349	-0.1944	0.0305
	(G)	0.5074	-0.2256	-0.0798	0.1289	0.3065	-0.0616	0.0952	0.3673	1.4671	-1.4676	0.0378	-0.2099	0.0306
Vitamin C content (mg/100g) (11)	**(P)**	-0.0134	0.0363	-0.0436	-0.0114	-0.0223	-0.0023	-0.0444	-0.025	-0.0033	0.003	-0.1184	-0.075	0.327*
	(G)	-0.014	0.037	-0.0435	-0.0104	-0.0206	-0.0022	-0.0445	-0.0246	-0.0033	0.0031	-0.1192	-0.0753	0.325*
Phenol content (mg/g) (12)	**(P)**	-0.0032	-0.027	0.0244	-0.0078	0.0022	-0.0094	0.0326	0.0189	-0.0149	0.015	0.0665	0.105	0.2127
	(G)	-0.0033	-0.027	0.0247	-0.0077	0.0022	-0.0094	0.0328	0.019	-0.0151	0.0151	0.0669	0.1059	0.2128
Fruit yield/plant (13)	**(P)**	0.1121	-0.0726	0.306*	0.303*	0.2434	0.503**	0.474**	0.1957	-0.0265	0.0305	0.327*	0.2127	
	(G)	0.1108	-0.0712	0.306*	0.301*	0.2411	0.503**	0.474**	0.1959	-0.0266	0.0306	0.325*	0.2128	

Growth parameters

The number of primary branches/plants is a crucial growth parameter in muskmelon. In this study, the Sawarna Hybrid exhibited the highest number of primary branches (13.317), followed by the Punjab Hybrid (13.283), Sunrise Hybrid (12.873) and Madhusree (12.320). Conversely, LHM-Munna had the least number of branches/vines (6.897). The Sawarna Hybrid also recorded the highest number of nodes/vine (33.653), followed by the Punjab Hybrid (33.637), Sunrise Hybrid (33.553) and Madhusree (32.487), with LHM-Munna again having the fewest nodes/vine (24.663). The lowest node number for the first male flower was observed in Punjab Hybrid (2.310), followed by Madhuraj (2.653) and LHM-Mahak (2.663). In contrast, the Mahima Hybrid recorded the highest node number (3.653), followed by Mahak (3.652). The Raseela Hybrid was the earliest to produce a female flower (3.7733 nodes), followed by Muskmelon Madhuri-2 (4.110) and the Punjab Hybrid (4.333). Madhuraj was the latest (6.220 nodes) for the first female flower, followed by NMMH-203 (5.443). The LHM-Munna Hybrid was the earliest (4.330 nodes) to produce a tendril, followed by LHM-Mahak (4.553) and Tipu-50 (4.643). Madhusree was the latest (6.220 nodes), followed by Madhulika (6.283). The maximum internodal length was recorded in LHM-Mahak (5.8867 cm), followed by Raseela (5.553 cm) and Sawarna Hybrid (5.552 cm). The shortest internodal lengths were found in Mahima (3.997 cm), VS-8989 (74.86 cm), Madhuraj (4.663 cm) and Muskmelon Madhuri-2 (4.663 cm). The longest vine length was observed in Tipu-50 (1.7100 m), followed by LHM-Masti (1.657 m) and LHM-Mahak (1.627 m), while the shortest vine lengths were in Raseela (1.2133 m), Mahima (1.237 m) and Madhulika (1.257 m) (Table 1). Similar findings for growth and flowering behaviour of muskmelon hybrids were also reported (7, 8).

Flowering and fruit set

The first flower was recorded in hybrid Tipu-50 (34.75 days), followed by Madhuraj (35.00 days) and Madhura Diamond (35.75 days). In contrast, hybrid Mahima (40.50 days), Mahak (40.00 days) and Madhusree (39.83 days) took the longest time to flower among the 20 hybrids. For the first fruit harvest, hybrid Madhuraj was the earliest (64.31 days), followed by LHM-Masti (64.56 days) and Sunrise Hybrid (67.16 days). Whereas Muskmelon Madhuras (77.35 days), LHM-Medha (76.65 days) and Madhusree (76.24 days) took the longest. Madhuraj was also the earliest (73.30 days) for the last fruit harvest, followed by LHM-Masti (74.92 days) and Muskmelon Madhuri-2 (78.75 days), while Madhusree (92.15 days), Sawarna Hybrid (89.83 days) and Muskmelon Madhuras (89.14 days) were the latest (Table 1). Similar results were obtained for growth and flowering behaviour of muskmelon (*Cucumis melo* L.) hybrids, and bitter gourd, water melon and *Cucurbita* spp (7-11).

Fruit characteristics

Among different fruit characteristics studied, the highest fruit length was recorded in hybrid Sawarna Hybrid (16.46 cm), followed by NMMH-203 (16.16 cm) and Mahima (15.93 cm), whereas the smallest was found in LHM-Madhura (10.83 cm), followed by Punjab Hybrid (11.66 cm) and LHM-Mahak (11.80 cm). The highest fruit diameter was recorded in Sawarna Hybrid (14.36 cm), followed by Mahima (13.43 cm) and NMMH-203 (13.40 cm), while the smallest were in LHM-Madhura (9.33 cm), Punjab Hybrid (10.06 cm) and VS-8989 (10.76 cm). The Mahima Hybrid had the thinnest rind (1.44 mm), followed by LHM-Masti (1.99 mm) and Madhusree (1.99 mm), while Madhura Diamond had the thickest (5.33 mm), followed by NMMH-203 (4.66 mm) and Punjab Hybrid (4.21 cm). Madhusree recorded the highest flesh thickness (3.997 cm), followed by Mahima (3.663 cm) and Madhuraj (3.667 cm), with the lowest found in VS-8989 (2.00 cm), LHM-Munna (2.233 cm) and LHM-Madhura (2.330 cm). The smallest seed cavity length was in Madhura Diamond (2.846 cm), followed by Muskmelon Madhuri-2 (3.130 cm) and LHM-Madhura (4.860 cm), while the largest was in Sawarna Hybrid (10.806 cm), followed by Raseela (9.290 cm) and Madhuraj (8.770 cm). The narrowest seed cavity width was in LHM-Munna (3.500 cm), followed by LHM-Mahak (3.520 cm) and Muskmelon Madhuri-2 (3.810 cm), with the widest in Muskmelon Madhuras (7.746 cm), NMMH-203 (7.153 cm) and Punjab Hybrid (6.60 cm) (Table 1). The similar fruit characteristics were observed in melon fruits (8, 13, 14).

Yield contributing parameters

Yield of a crop is not an independent parameter; it is a complex expression influenced by the harmonious interaction of several other contributing characters. Among the parameters recorded, the highest average fruit weight was recorded in Sawarna Hybrid (1.633 kg), followed by Madhusree (1.457 kg), Muskmelon Madhuras (1.400 kg) and Tipu-50 (1.327 kg), while the lowest was in Muskmelon Madhuri-2 (0.517 kg), Madhulika (0.730 kg) and Mahak (0.853 kg). Madhulika had the highest number of fruits (10.887), followed by Muskmelon Madhuri-2 (9.663) and Madhusree (8.023), with the least in Sawarna Hybrid (4.513), Madhura Diamond (4.627) and LHM-Madhura (4.663). The highest fruit yield/plant was observed in Madhusree hybrid (11.523 kg/plant), followed by Tipu-50 hybrid (8.627 kg/plant) and Madhulika hybrid (7.870 kg/plant), while the lowest was in LHM-Munna hybrid (4.300 kg/plant), Mahak hybrid (4.587 kg/plant) and LHM-Medha hybrid (4.860 kg/plant). The highest fruit yield/hectare was in Madhusree (51.213 t/ha), followed by Tipu-50 (38.330 t/ha) and Madhulika (34.973 t/ha), while the lowest was in LHM-Munna (4.300 t/ha), Mahak (19.103 t/ha) and LHM-Medha (21.593 t/ha) (Table 2). These findings agree with those of earlier studies (13, 14).

Quality parameters

The taste, flavour and texture of muskmelon are governed by a multitude of quality attributes, which are discussed hereafter. Among all the hybrids, the highest TSS content was observed in Muskmelon Madhuri-2 (11.57 °B), followed by Sawarna Hybrid (10.58 °B) and Madhusree (10.50 °B), while the lowest was in VS-8989 (6.35 ° B), LHM-Medha (6.70 °B) and LHM-Munna (7.33 °B). The highest Vitamin C content was recorded in Muskmelon Madhuri-2 (91.44 mg/100 g), followed by Madhura Diamond (90.86 mg/100 g) and NMMH-203 (90.77 mg/100 g), with the lowest in Madhuraj (86.89 mg/100 g), LHM-Masti (87.33 mg/100 g) and LHM-Madhura (87.33 mg/100 g). Further, hybrid Madhuraj exhibited the highest moisture content (13.11 %), followed by LHM-Madhura (12.66 %) and LHM-Masti (12.66 %), with the lowest in Muskmelon Madhuri-2 (8.55 %), Madhura Diamond (9.13 %) and NMMH-203 (9.22 %). The highest dry matter content was in Mahima (31.55 %), followed by Punjab Hybrid (31.08 %) and Madhusree (24.04 %), with the lowest in Madhulika (20.51 %), VS-8989 (20.53 %) and Muskmelon Madhuri-2 (20.53 %). The longest shelf life was exhibited by Sawarna Hybrid (10.86 days), followed by Madhusree (10.27 days) and Punjab Hybrid (10.09 days), while the shortest was in LHM-Masti (3.26 days), LHM-Medha (4.06 days) and NMMH-203 (4.49 days) (Table 3). Similar results of quality parameters were found in melon fruits (15, 16).

Correlation analysis among yield and quality traits

Most of the growth, yield and quality attributes in muskmelon are controlled by one or a few genes and are generally less influenced by other traits. However, these traits are directly or indirectly interrelated and their relationships are studied through correlation and path analysis. The relationships between various traits in muskmelon are generally determined by both phenotypic and genotypic correlations. Phenotypic correlation measures the degree of association between two variables, influenced by both genetic and environmental factors. In contrast, genotypic correlation represents the genetic component of phenotypic correlation and is inheritable, making it particularly useful for guiding breeding programs. Correlation coefficients can also help identify traits that are less important for selection programs. Correlation can arise due to genetic linkage, pleiotropic gene effects, physiological and developmental relationships, environmental influences, or a combination of these factors. A detailed examination of simple correlation coefficients showed that different traits were variably associated with each other. Generally, genotypic correlation coefficients were higher than their corresponding phenotypic correlation coefficients. This kind of stronger genetic association between different traits indicates a robust genetic linkage among the traits, while the phenotypic correlation is moderated by significant environmental interactions. Here, in the present investigation, the smaller difference between genotypic and phenotypic correlation indicates that the muskmelon lines under study are relatively stable and less influenced by environmental variations.

Yield exhibited positive and significant, genotypic and phenotypic correlation for the yield contributing traits such as average fruit weight (g), number of fruits/plant, vitamin C content (mg/100 g), flesh thickness (cm) and fruit length (cm) while positively non-significant with phenol content (mg/g), TSS (°B), days to first fruit harvest and dry matter content (%). The above outcomes are consent with the findings for fruit width in muskmelon and the total number of fruits per plant (17-22). Days to first fruit harvest is positively correlated with moisture content (r_g = 0.354, r_p 0.352) while negatively correlated with fruit length (r_g = -0.262* = -0.275) and dry matter content (r_g = -0.346*, r_p -0.347*). Internodal length negatively correlated with phenolic content (r_g = -0.255, r_p = 0.257) and ascorbic acids (r_g = -0.307, r_p = 0.311). Flesh thickness (cm) is positively correlated with TSS (r_g = 0.399, r_p 0.398), Vit. C (r_g = 0.369, r_p= 0.368), fruit yield/plant (r_g = 0.307, r_p= 0.306) and fruit diameter (r_g = 0.282, r_p= 0.278). In muskmelon, fruit traits such as fruit length, average fruit weight and the number of fruits/vine are critical for evaluation. Fruit length demonstrated a significantly positive correlation with fruit diameter (r_g = 0.863, r_p= 0.860) and fruit yield/plant (r_g = 0.304, r_p= 0.303), whereas fruit diameter was positively correlated with fruit length (r_g = 0.863, r_p= 0.860), flesh thickness (r_g = 0.282, r_p= 0.278) and

Table 2. Mean performance of hybrids for yield and quality attributing traits

Genotypes	Days to first Male flower anthesis	Days to first female flower Anthesis	Days to first fruit harvest	Days to last fruit harvest	Number of Primary branches/plant	Number of nodes/vine	Node at which the first male flower appeared	Node at which the first female flower appeared	Node at which first branched tendril appeared	Inter nodal length (cm)	Vine length (m)	Rind thickness (mm)	Flesh thickness (cm)	Fruit length (cm)	Average fruit weight (g)	Number of fruits/plant	Fruit yield/plant (kg)	Fruit yield t/ha)	Seed Cavity Length (cm)	Seed Cavity Width (cm)	TSS (°B)	Moisture content (%).	Dry matter content (%)	Vitamin C content (mg/100g)	Shelf life (Days)
F1-Tipu-50	34.75	40.41	70.11	80.86	9.98	31.50	3.00	5.00	4.64	5.44	1.71	3.28	2.44	14.80	1.33	6.52	8.63	38.33	7.09	4.54	8.21	89.03	10.97	20.87	6.19
F1-VS-8989	38.50	45.76	73.34	85.68	9.08	27.29	3.00	5.11	5.11	4.66	1.46	2.39	2.00	14.43	1.02	6.48	6.47	28.75	6.72	4.63	6.35	88.82	11.18	20.54	7.21
F1-LHM-Munna	39.17	44.22	74.42	83.25	6.90	24.66	2.88	4.55	4.33	5.33	1.31	3.00	2.23	12.73	0.90	4.80	4.30	19.10	7.16	3.50	7.33	89.94	10.06	21.66	7.66
F1-LHM-Mahak	37.75	44.69	75.74	86.65	8.66	27.69	2.66	5.22	4.55	5.89	1.63	3.77	2.50	11.80	1.05	6.17	6.51	28.95	7.11	3.52	7.91	90.44	9.56	21.12	5.77
F1-LHM-Medha	38.17	43.97	76.65	84.89	9.95	30.23	3.33	5.11	4.67	5.33	1.59	2.29	3.00	13.83	1.00	4.89	4.86	21.59	6.70	4.17	6.71	89.33	10.67	21.07	4.07
F1-LHM-Masti	36.25	39.67	64.56	74.92	8.60	30.26	3.32	5.22	5.61	5.66	1.66	2.00	3.00	14.33	0.98	5.74	5.59	24.84	6.81	5.37	8.18	87.33	12.67	21.44	3.26
F1-Madhuraj	35.00	37.52	64.32	73.31	11.55	32.00	2.65	6.22	4.66	4.66	1.50	2.66	3.33	13.63	0.98	6.23	6.05	26.91	8.77	6.32	7.94	86.89	13.11	20.80	5.23
F1-Mahima	40.50	45.36	72.63	84.21	11.59	30.97	3.65	4.66	5.33	4.00	1.24	1.44	3.66	15.93	1.17	6.07	7.01	31.15	6.73	4.68	9.20	90.33	9.67	31.55	8.17
Muskmelon Madhuri-2	39.58	44.36	70.62	78.75	11.76	32.01	3.32	4.11	5.66	4.66	1.52	3.00	3.00	13.00	0.52	9.66	4.96	22.04	3.13	3.81	11.78	91.44	8.56	20.54	6.92
F1-Raseela	39.00	44.71	72.84	84.23	9.15	27.92	2.75	3.77	4.67	5.55	1.21	3.66	3.00	14.20	0.97	5.33	5.13	22.80	9.29	5.04	9.67	89.11	10.89	22.55	9.18
F1-Mahak	40.00	41.84	71.45	80.68	9.15	27.56	3.65	4.33	4.66	4.66	1.29	4.00	3.22	13.40	0.85	5.33	4.59	20.38	7.08	5.55	10.37	88.94	11.06	21.13	9.38
Madhusree	39.83	43.95	76.25	92.15	12.32	32.49	3.10	4.44	6.33	4.77	1.39	2.00	4.00	14.70	1.46	8.02	11.52	51.21	6.17	5.19	10.50	88.94	11.06	24.05	10.27
Punjab Hybrid	38.00	43.23	73.72	86.51	13.28	33.64	2.31	4.33	5.64	4.66	1.53	4.22	3.00	11.67	0.73	10.89	7.87	34.98	6.17	6.60	9.75	88.22	11.78	31.08	10.09
LHM-Madhura	36.50	44.00	73.39	84.38	11.37	30.32	3.43	5.28	5.00	4.78	1.41	4.00	2.33	10.83	1.27	4.66	5.81	25.83	4.86	5.45	9.23	87.33	12.67	21.70	5.58
F1-Sawarna Hybrid	37.78	42.46	72.93	89.83	13.32	33.65	2.89	5.11	4.66	5.55	1.59	4.11	3.11	16.47	1.63	4.51	7.30	32.46	10.81	5.67	10.58	89.50	10.50	22.88	10.86
Madhura Diamond	35.75	44.17	75.13	86.74	10.94	29.17	3.00	5.33	5.55	4.77	1.37	5.33	2.66	11.90	1.30	4.63	6.08	27.01	2.85	4.88	9.59	90.87	9.13	22.78	7.09
F1-NMMH-203	38.67	43.18	68.85	79.12	10.11	29.15	3.55	5.44	4.70	4.22	1.50	4.66	3.00	16.17	0.92	6.51	6.02	26.77	8.30	7.15	9.75	90.78	9.22	21.40	4.49
Muskmelon Madhuras	36.17	45.49	77.35	89.15	12.05	31.81	3.22	5.22	4.92	5.00	1.45	3.66	2.88	11.83	1.40	4.55	6.36	28.28	5.44	7.75	9.10	90.33	9.67	21.44	5.47
Madhulika	38.33	43.50	75.93	86.43	10.48	27.29	3.32	4.78	6.28	5.00	1.26	3.00	2.89	12.43	0.90	5.78	5.21	23.17	6.36	6.02	8.99	88.84	11.16	20.51	5.82
Sunrise F1-Hybrid	37.67	40.55	67.16	84.60	12.87	33.55	3.15	5.22	5.22	4.89	1.44	3.00	2.66	12.13	0.95	5.26	5.01	22.24	5.56	5.54	8.18	88.72	11.16	21.71	9.47
Mean	37.87	43.15	72.37	83.82	10.66	30.16	3.11	4.92	5.11	4.97	1.45	3.27	2.90	13.51	1.07	6.10	6.26	27.84	6.66	5.27	8.97	89.26	10.74	22.54	7.11
SeM±	0.72	0.85	1.06	1.32	0.64	1.08	0.24	0.39	0.22	0.35	0.07	0.23	0.21	0.59	0.07	0.63	0.61	2.70	0.44	0.28	0.29	0.47	0.47	0.43	0.37
CD0.05	2.08	2.44	3.05	3.82	1.85	3.13	0.69	1.13	0.64	1.02	0.19	0.65	0.60	1.70	0.21	1.82	1.75	7.79	1.27	0.81	0.84	1.36	1.35	1.24	1.06
CD0.01	2.80	3.29	4.11	5.14	2.49	4.22	0.93	1.53	0.87	1.37	0.26	0.88	0.80	2.29	0.28	2.45	2.36	10.49	1.71	1.09	1.14	1.83	1.82	1.67	1.43
CV	3.29	3.40	2.53	2.73	10.41	6.23	13.33	13.81	7.57	12.29	8.02	11.94	12.33	7.55	11.89	17.89	16.78	16.78	11.45	9.18	5.65	0.91	7.56	3.29	8.94
Max.	40.50	45.76	77.35	92.15	13.32	33.65	3.65	6.22	6.33	5.89	1.71	5.33	4.00	16.47	1.63	10.89	11.52	51.21	10.81	7.75	11.78	91.44	13.11	31.55	10.86
Mini.	34.75	37.52	64.32	73.31	6.90	24.66	2.31	3.77	4.33	4.00	1.21	1.44	2.00	10.83	0.52	4.51	4.30	19.10	2.85	3.50	6.35	86.89	8.56	20.51	3.26

Table 3. Phenotypic and genotypic correlation matrix among yield and yield-contributing traits

		Phenotypic and genotypic correlation matrix												
		(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**	**(11)**	**(12)**	**(13)**
Days to first fruit harvest (1)	**(P)**	1	0.061	-0.0505	-0.275*	-0.0299	0.2529	-0.1038	0.0473	0.352*	-0.347*	0.113	-0.0307	0.1121
	(G)	1	0.0521	-0.0542	-0.262*	-0.0453	0.2515	-0.1028	0.0423	0.352*	-0.346*	0.1178	-0.0307	0.1108
Internodal length (cm) (2)	**(P)**		1	-0.1705	-0.1074	-0.1272	0.1124	-0.2062	-0.1976	-0.1529	0.1539	-0.307*	-0.257*	-0.0726
	(G)		1	-0.1644	-0.0918	-0.1058	0.1124	-0.206	-0.191	-0.1526	0.1537	-0.311*	-0.255*	-0.0712
Flesh thickness (cm) (3)	**(P)**			1	0.2432	0.278*	0.0718	0.2028	0.398*	-0.0501	0.0541	0.368*	0.2329	0.306*
	(G)			1	0.2481	0.282*	0.0719	0.2009	0.399*	-0.0505	0.0543	0.365*	0.2333	0.307*
Fruit length (cm) (4)	**(P)**				1	0.860**	0.2055	0.0358	0.1302	0.093	-0.0895	0.0961	-0.0745	0.303*
	(G)				1	0.863**	0.2042	0.0336	0.136	0.0912	-0.0878	0.0871	-0.0728	0.304*
Fruit diameter (cm) (5)	**(P)**					1	0.280*	-0.0431	0.2245	0.2171	-0.2136	0.1884	0.0206	0.2434
	(G)					1	0.290*	-0.044	0.2303	0.2123	-0.2088	0.173	0.0209	0.2411
Average fruit weight (g) (6)	**(P)**						1	-0.466**	0.0223	-0.0401	0.042	0.0192	-0.0891	0.503**
	(G)						1	-0.467**	0.0225	-0.0401	0.042	0.0188	-0.0891	0.504**
Number of fruits/plant (7)	**(P)**							1	0.302*	0.0676	-0.0648	0.375*	0.310*	0.474**
	(G)							1	0.304*	0.0678	-0.0649	0.376*	0.311*	0.476**
TSS (°B) (8)	**(P)**								1	0.253*	-0.2509	0.2116	0.1798	0.1957
	(G)								1	0.255*	-0.2503	0.2066	0.1794	0.1959
Moisture content (%) (9)	**(P)**									1	-0.843**	0.0275	-0.1421	-0.0265
	(G)									1	-0.832**	0.0274	-0.1422	-0.0266
Dry matter content (%) (10)	**(P)**										1	-0.0257	0.143	0.0305
	(G)										1	-0.0258	0.143	0.0306
Vitamin C content (mg/100g) (11)	**(P)**											1	0.633**	0.327*
	(G)											1	0.636**	0.329*
Phenol content (mg/g) (12)	**(P)**												1	0.2127
	(G)												1	0.2128
Fruit yield/plant (13)	**(P)**													1
	(G)													1

average fruit weight (r_g = 0.290, r_p= 0.280). Average fruit weight significantly positively correlated with fruit yield/plant (r_g = 0.504, r_p 0.503) and fruit diameter (r_g = 0.290, r_p 0.280) and significantly negatively correlated with number of fruits/plant (r_g = -0.476, r_p = 0.466). Number of fruits/plant was positively significant with fruit yield/plant (r_g = 0.476, r_p 0.474), vit. c content (r_g = 0.376, r_p= 0.375) phenol content (r_g = 0.311, r_p= 0.310) and TSS (r_g = 0.304, r_p= 0.302) while negatively correlated with average fruit weight (r_g = -0.476, r_p= -0.466). TSS is responsible for sweetness in muskmelon and is significantly positively correlated with flesh thickness (r_g = 0.399, r_p 0.398) and number of fruits/plants (r_g = 0.304, r_p 0.302). Moisture content in muskmelon positively correlated with days to first fruit harvest (r_g = 0.399, r_p 0.398), TSS (r_g = 0.255, r_p 0.253) and negatively correlated with dry matter content in fruit (r_g = -0.832, r_p 0.843). Vit. C is responsible for antioxidant and it is positively correlated with phenol content (r_g = 0.636, r_p= 0.633), no. of fruits/plant (r_g = 0.376, r_p= 0.375), flesh thickness (r_g = 0.369, r_p= 0.368) and fruit yield/plant (r_g = 0.329, r_p= 0.327), whereas phenol content positively correlated with vit C (r_g = 0.636, r_p= 0.633) and number of fruits/plant (r_g = 0.311, r_p= 0.310). Yield is an important trait for crop improvement and it is highly significantly correlated with average fruit weight. (r_g = 0.504, r_p= 0.503) followed by number of fruits/plant (r_g = 0.476, r_p= 0.474), Vit. C Content (r_g = 0.329, r_p= 0.327), flesh thickness (r_g = 0.307, r_p 0.306) and fruit length (r_g = 0.304, r_p 0.303) all the traits are all significantly positive and negatively correlated at genotypic and phenotypic levels (Table 1 and Fig. 1-2). These results align with the association between fruit length, fruit width and fruit weight but differ in terms of the relationship between fruit length and pulp thickness. A similar outcome was presented in muskmelon (23-26).

Path analysis

Following the results from the correlation analysis, a path coefficient analysis was conducted to ascertain the direct and indirect effects of various traits on fruit yield. While the correlation coefficients provided insights into the relationships between yield and its associated traits, they did not explain the direct and indirect impacts of individual traits on fruit yield itself. Path coefficient analysis revealed that average yield/plant showed the highest positive direct effect on number of fruits/plant, average fruit weight (g), fruit length (cm), flesh thickness (cm), phenol content (mg/g), days to first fruit harvest and internodal length (cm) whereas vitamin C content (mg/100 g), TSS (°B), dry matter content (%) and moisture content (%) showed indirect effects on yield fruit/plant at genotypic and phenotypic level. Dry matter content (%) exerted the highest positive indirect effect on fruit yield/plant through average fruit weight followed by days to first fruit harvest, fruit diameter and internodal length whereas negative indirect effect on phenol content, TSS (°B), flesh thickness, vitamin C content (mg/100 g), fruit length, number of fruits/plant and moisture content on yield at genotypic and phenotypic level. Internodal length (cm) showed the significantly positively indirect effect on yield moisture content, followed by average fruit weight, vitamin C content, TSS (°B), days to first fruit harvest, while negative indirect effect on yield through flesh thickness, phenol content, fruit length, fruit yield/plant, number of fruits/plant and dry matter content on yield. The indirect effects of Flesh thickness were highest and positive on fruit yield/vine through number of fruits, moisture content, average fruit weight, fruit length, phenol content, negative indirect effect through yield on internodal length, days to first fruit harvest, vitamin C content, TSS (°B) and dry

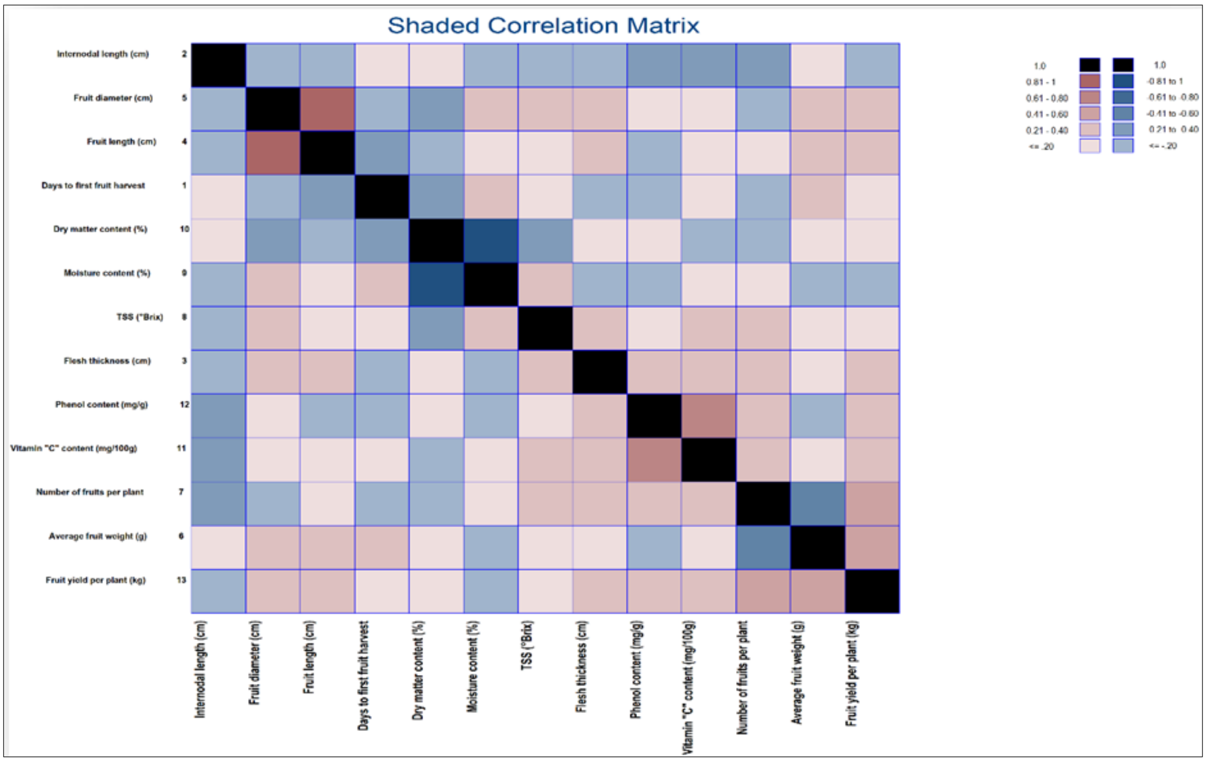

Fig. 1. Phenotypic correlation matrix among yield and morphological traits.

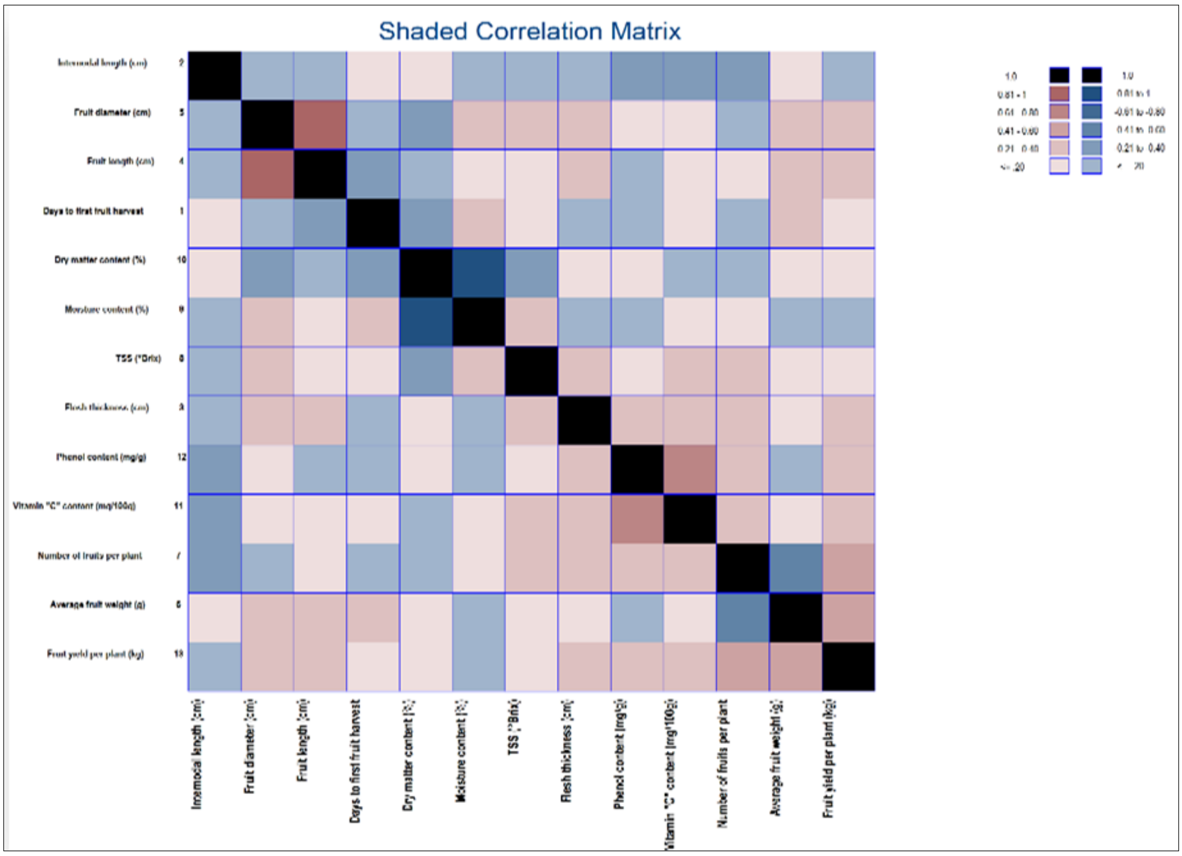

Fig. 2. Genotypic correlation matrix among yield and yield-contributing traits.

matter content. The highest negative indirect effect of fruit length on fruit yield/vine was observed through internodal length followed by phenol content, vitamin C content, TSS (°B), days to first fruit harvest, moisture content and fruit diameter whereas average fruit weight, dry matter content, number of fruits/plant and flesh thickness showed positive indirect effect on yield at genotypic and phenotypic level.

Fruit diameter had a significantly positive association with dry matter content, average fruit weight, fruit yield/plant, fruit length, flesh thickness and phenol content, whereas internodal length, days to first fruit harvest, vitamin C content, TSS (°B), number of fruits/plant and moisture content on yield. The average fruit weight had a significantly positive association with fruit yield/plant, moisture content, fruit length, days to first fruit harvest, flesh thickness and internodal length. Indirect negative effect showed by vitamin C content, TSS (°B), phenol content, dry matter content and number of fruits/plant. A similar association of average fruit weight with vine length, fruit length and fruit yield (23-25). The highest negative indirect effect of the number of fruits/vine on fruit yield/vine was observed through internodal length, days to first fruit harvest, TSS (° B), vitamin C content, moisture content and average fruit weight and a positive association was observed by dry matter content, phenol content, flesh thickness, fruit length and fruit diameter. TSS (° B) had a significantly positive association with dry matter content, number of fruits/plant, fruit yield/plant, flesh thickness, fruit length, average fruit weight, phenol content, days to first fruit harvest and negatively correlated with internodal length, vitamin C content, fruit diameter and moisture content (Table 3 and Fig 3 & 4).

Moisture content showed a negative association with internodal length, vitamin C content, flesh thickness, phenol content, fruit yield/plant, TSS (°B), average fruit weight and fruit diameter, while a positive indirect effect on dry matter content, number of fruits/plant, days to first fruit harvest and fruit length (23). The vitamin C content showed negligible indirect effects on fruit yield/vine through other characters as moisture content, average fruit weight, TSS (°B), fruit yield/plant, phenol content, flesh thickness, internodal length, fruit length, days to first fruit harvest, number of fruits/plant and dry matter content, both in positive and negative directions. Phenol content in fruit was positively indirectly affected on yield/vine through number of fruits/plant, moisture content and flesh thickness, whereas internodal length, days to first

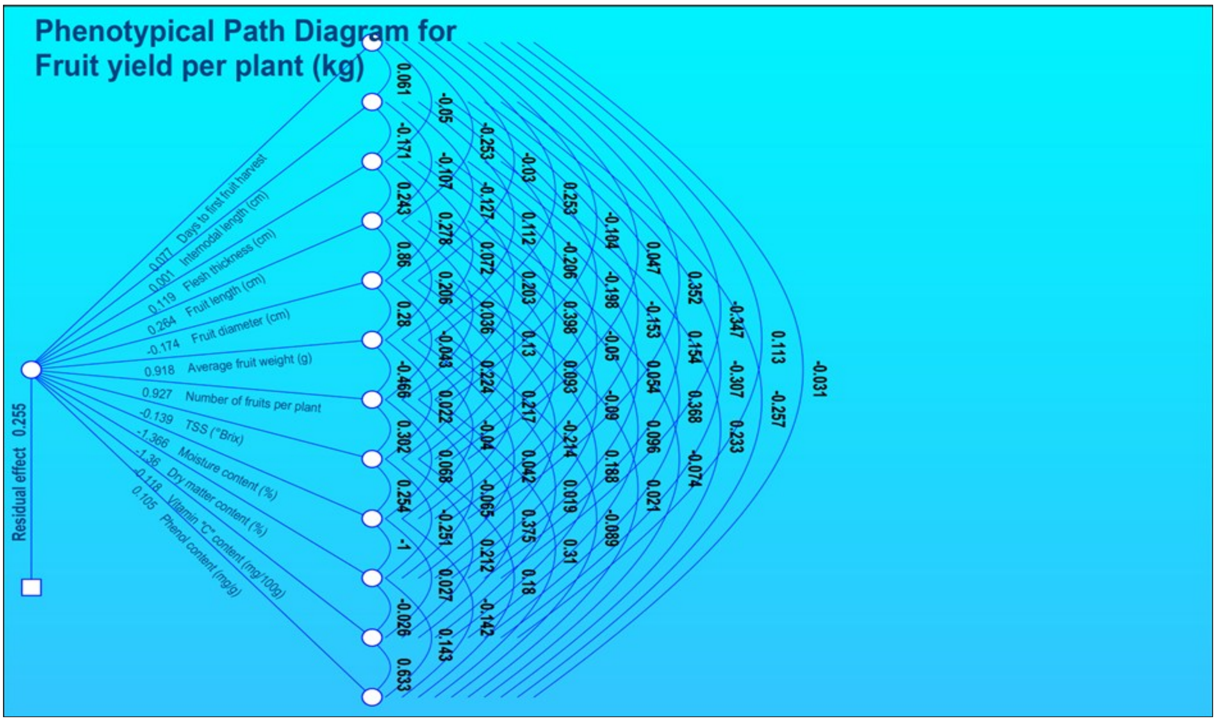

Fig. 3. Phenotypic path diagram for fruit yield/plant.

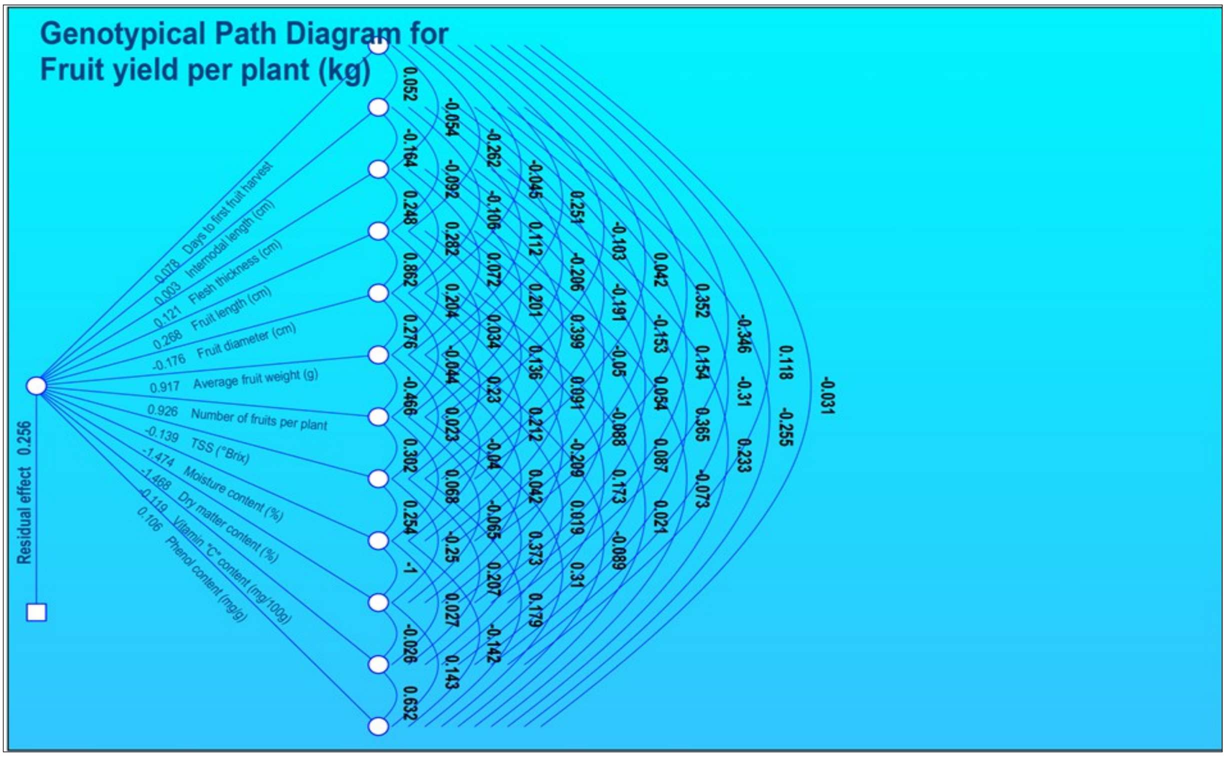

Fig. 4. Genotypic path diagram for fruit yield/plant.

fruit harvest, fruit length, TSS (°B), vitamin C content, average fruit weight and dry matter content on yield at genotypic and phenotypic levels. Consequently, enhancing fruit yield can be achieved by selecting genotypes characterised by higher fruit weight, fruit length, fruit girth, number of fruits/plant and moisture percentage, while maintaining lower TSS (26-31).

Conclusion

Fruit yield is a complex trait influenced by multiple interrelated components. Based on the mean performance of the genotypes evaluated, the highest fruit yield/hectare (t/ha) was observed in the genotype Madhusree, followed by Tipu-50 and Madhulika. In contrast, the lowest yield was recorded in LHM-Munna, followed by Mahak and LHM-Medha. Correlation analysis revealed that fruit yield exhibited a positive and significant association both at the genotypic and phenotypic levels with key yield-contributing traits, including average fruit weight (g), number of fruits/plant, vitamin C content (mg/100 g), flesh thickness (cm) and fruit length (cm). Path coefficient analysis further demonstrated that average yield/plant exerted the highest positive direct effects on number of fruits/plant, average fruit weight, fruit length, flesh thickness, phenol content (mg/g), days to first fruit harvest and internodal length. Notably, the number of fruits/plants showed both a significant positive correlation and a strong direct effect on fruit yield, suggesting that direct selection for this trait could be particularly effective in enhancing overall productivity.

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Authors' contributions

MF, SN, AK, A and HK contributed to laboratory experiments, methodology, formal analysis, original draft writing, review and editing. IA and PS contributed to conceptualization, methodology, investigation, review, editing, visualization and supervision. DA, TFJ AS and DK contributed to formal analysis, review, editing and visualization. RN and IAT contributed to formal analysis, methodology, investigation and visualization. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors declare that they have no known competing interests.

Ethical issues: None

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