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Character association and path analysis for fruit yield and it's contributing traits in muskmelon (*Cucumis melo* L.)

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Abstract
Ninty four diverse genotypes of muskmelon (*Cucumis melo* L.) were evaluated during summer 2024 at Vegetable Research Block, College of horticulture, Bengaluru in Randomized Complete Block Design with two replications to study the relationships among 15 quantitative traits pertaining to growth, earliness and yield characters and to help breeders to determine the selection criteria for breeding programmes for fruit yield improvement. In both phenotypic and genotypic correlation analyses, fruit yield per vine showed strong positive associations with average fruit weight and number of fruits per vine, identifying them as key yield-contributing traits. Traits like sex ratio, shape index and TSS displayed important interactions, indicating the need for balanced selection. Stronger genotypic correlations suggest the predominance of genetic control over environmental influence. Path analysis revealed that average fruit weight exerted the highest positive direct effect on fruit yield per vine at both genotypic and phenotypic levels, indicating it as the most important yield-contributing trait. Number of fruits per vine also showed a strong positive direct effect, further confirming its role in yield improvement. Traits like flesh thickness and cavity diameter contributed indirectly to yield mainly through average fruit weight. These findings highlight that average fruit weight and number of fruits per vine are the most reliable traits for direct selection in muskmelon breeding aimed at yield enhancement.

Keywords: Muskmelon, path analysis, correlation and improvement

Introduction

Muskmelon (*Cucumis melo* L.) (2n=24) belongs to the family Cucurbitaceae. Edible melons belong to either *Cucumis melo* var. *reticulatus* or *Cucumis melo* var. *cantaloupensis*. Plants are either monoecious or andromonoecious annuals with long trailing vines with shallow lobed round leaves. There is considerable variation in fruit size and shape. External appearance may be smooth with netted, the skin colour may be white, yellowish brown or speckles yellow or orange with green or yellow background. Fruits of some cultivars crack when ripe. Upon ripening, fruits soften and fruity aromatic essence are formed in the fruit.

Muskmelon (*Cucumis melo* L.) is an important vegetable crop grown in India. It is popular in North India especially in Uttar Pradesh and Punjab and is grown in almost every place in the plains. Muskmelon has many vernacular names, such as kharbooza (Hindi), kharbuz (Punjabi), sakkartoti (Gujarati), kaling (Sanskrit), velapalam (Tamil) and kekkari kai (Kannada). The species *Cucumis melo* L. is a large polymorphic taxon having large number of botanical and horticultural varieties or groups. It is said to be a native of Tropical Africa more specially in the eastern region and South of Sahara Desert. Central Asia comprising some parts of Southern Russia, Iran, Afghanistan, Pakistan and North West India regarded as a secondary centre of origin (Whitakar and Devis, 1962) [16]. Oriental pickling melon (*Cucumis melo* var. *conomon*) and snap melon (*Cucumis melo* var. *momordica*) are unique and found throughout in India.

Muskmelon occupies an area of 67,000 ha with an annual production of 1541 MT in India. In Karnataka, it is being cultivated in an area of 690 ha with annual production of 11,420 metric tonnes and an average productivity of 18.24 tonnes per hectare (Anon., 2024) [1]. With muskmelon production gaining significance at both national and international levels, there is a growing need to explore and systematically evaluate new germplasm lines. Such studies are essential for the development of improved varieties or hybrids capable of meeting both yield and quality demands in commercial cultivation. The available germplasm ranging from accessions collected from traditional farming systems to hybrids developed by private seed companies offers a wide genetic base and serves as a valuable resource for generating new breeding lines. Hybridization programmes, in particular, hold considerable promise for enhancing productivity in vegetable crops through the identification and use of suitable parents. Previous studies have shown that greater genetic divergence between parents often results in higher heterosis in F1 hybrids and contributes to a broader spectrum of variability in segregating generations (Arunachalam, 1981) [2]. Although correlation studies provide useful information, they alone do not give a complete understanding of the relationships among heritable traits. Relying exclusively on correlation may sometimes result in misinterpretation. Correlation analysis reveals the degree and direction of association between yield and its related characters; however, it does not clarify the direct influence of individual traits on yield or their indirect effects mediated through other attributes. In muskmelon, yield is a complex trait influenced by several interrelated components. The interdependence of these characters often obscures the actual contribution of a single trait to yield. Any alteration in one character can disrupt the entire cause-effect relationship. Therefore, each trait influences yield in two ways through its direct effect and indirectly via other associated traits, which are not apparent from simple correlation estimates. To address this, path coefficient analysis has been employed, as it partitions the correlation into direct and indirect effects. The method of path analysis was originally proposed by Wright (1921) [17] and its first application in plant sciences was reported by Dewey and Lu (1959) [5]

Materials and Methods

The present study carried out Vegetable Research Block, College of horticulture, Bengaluru in Randomized Complete Block Design with two replications during summer 2024. The 94 genotypes were assessed in a field experiment under a randomized complete block design with two replications. Ten plants maintained in each treatment with spacing of 2.0 × 1.0 m between rows and plants, respectively. The data were recorded on three randomly selected plants from each genotype for eighteen growth and yield characters. Observations recorded for days to first male flower apperance, days to first female flower apperance, primary branches per plant, average fruit weight, number of fruits per plant, fruit yield per plant, fruit shape index, flesh thickness, rind thickness, cavity diameter and total soluble solids.

Genotypic and phenotypic direct and indirect effects were estimated following the procedure outlined by Dewey and Lu (1959) [5]. The method used for computing covariance components between different pairs of observations was analogous to the analysis of variance, except that the sum of squares and mean squares were substituted by the sum of products and mean products, respectively. Covariance estimates were derived as described by Singh and Choudhary (1985) [3] and these values, along with variance components, were utilized for calculating genotypic and phenotypic correlation coefficients.

Genotypic correlation primarily arises from pleiotropy and linkage effects of genes and was estimated following the method proposed by Hazel *et al*. (1943) [7]. The combined influence of genetic and environmental factors provides the phenotypic correlation coefficient, which was also derived using the formula suggested by Hazel *et al*. (1943) [7]. Correlation coefficients at both genotypic and phenotypic levels were computed for all possible trait combinations and tested for significance. The standardized tabulated values of *r* with (g-2) and (rg-2) degrees of freedom were used for testing genotypic and phenotypic correlations, respectively, as given by Fisher and Yates (1963) [6]. The significance of the correlation coefficients for *n-2* degrees of freedom was further verified by calculating the *t* value as per the procedure described by Panse and Sukhatme (1985) [10].

Simple correlation analysis does not provide sufficient information to determine the cause, effect and interrelationships between two variables. Hence, the data were analyzed through path analysis, a standardized regression approach, to distinguish whether the associations of different traits with yield arise from their direct effects or are mediated indirectly through other traits. Path coefficient analysis was performed following the procedure proposed by Wright (1921) [17] and later adopted by Dewey and Lu (1959) [5]. Genotypic correlation coefficients of 14 traits with fruit yield per plant were utilized to partition the direct and indirect effects of independent characters on fruit yield per plant.

Path coefficients were derived by solving a set of simultaneous equations that describe the fundamental association between correlation and path analysis. The indirect effects of individual traits via other contributing traits were quantified as the product of their direct effect and the corresponding correlation coefficient. The residual effect, which reflects the unexplained portion of variability in seed yield per plant, encompasses the influence of unmeasured or uncontrolled factors and is assumed to act independently of the variables included in the analysis.

Results and Discussion

The phenotypic and genotypic correlation coefficients were estimated among 15 characters of 94 muskmelon genotypes, to find out the association of fruit yield and other yield contributing characters (Table 1 and Table 2).

The genotypic correlation analysis among various traits in muskmelon revealed significant associations critical for improving yield and related traits. Fruit yield per plant showed a significant positive correlation with average fruit weight (r = 0.353**) and flesh thickness (r = 0.230*), indicating that selection for heavier and thicker-fleshed fruits could enhance yield potential. This finding aligns with earlier studies by Reddy *et al*. (2013) [17], who emphasized fruit weight and quality as primary contributors to yield. A strong and positive correlation was observed between number of male flowers and number of female flowers (r = 0.977**), suggesting that genotypes with greater floral intensity have the potential to produce higher fruit counts. Additionally, number of branches per vine had a positive and significant correlation with fruit yield per vine (r = 0.762**) and average fruit weight (r = 0.512**), highlighting it as an important indirect contributor to yield.

However, traits like sex ratio and number of fruits per vine showed significant negative correlations with average fruit weight (r =-0.769**) and fruit yield per vine (r =-0.561**), respectively. This suggests that correlation between fruit number and fruit size, implying that excessive fruit load may reduce individual fruit weight. The days to male flowering and days to first female flowering was positively correlated with yield-contributing traits such as number of branches per vine, average fruit weight and cavity diameter, but negatively associated with sex ratio and number of fruits per vine, indicating a complex influence of flowering traits on reproductive success. Notably, TSS (total soluble solids), a key quality trait, was negatively correlated with days to first male flower apperance, days to first female flower apperance, shape index and cavity diameter, suggesting that genotypes with higher sweetness may have limited vegetative vigor or delayed flowering. These findings are consistent with Bhimappa *et al*., 2018 [3], who reported inverse relationships between sweetness and growth traits in muskmelon.

In case of correlation at phenotypic level fruit yield per plant showed significant positive correlations with average fruit weight, number of fruits per vine and flesh thickness, indicating these are important direct contributors to yield. Days to male flowering and days to first female flowering were positively correlated with fruit yield per plant indirectly via average fruit weight and number of branches per vine, but showed negative associations with traits like sex ratio and number of fruits per vine. Number of male flowers and number of female flowers were highly correlated (0.977**), suggesting simultaneous selection is feasible. Total Soluble solids showed a strong negative correlation with sex ratio and shape index (SI), suggesting quality traits might inversely relate to certain growth parameters. These findings are consistent with earlier studies that emphasize the role of genotypic correlations in identifying key traits for effective muskmelon improvement (Reddy *et al*. (2017) [17] and Prajapati *et al*., 2022) [11].

At phenotypic level average fruit weight exhibited the highest positive direct effect on fruit yield per plant, indicating it is a key determinant of yield. Similar high direct effects of average fruit weight on yield were also reported by Reddy *et al*. (2017) [17] and Prajapati *et al*. (2022) [11], Priyanka *et al*., 2020 [12] and Choudhary *et al*., 2004 [4] emphasizing its central role in muskmelon breeding. Number of fruits per vine showed a strong direct effect on yield, supporting the notion that both fruit count and fruit size are essential contributors. number of branches per vine also had a moderate positive direct effect suggesting a more branched plant architecture supports better fruit set and yield. Traits like flesh thickness and sex ratio also had considerable positive direct effects, indicating their potential role in enhancing fruit productivity. Tomar *et al*. (2008) [15] Yadav & Ram (2002) [18] and Mehta *et al*. (2009) [9], Karadi *et al*. (2017) [8]

At genotypic level average fruit weight and number of fruits per vine recorded the highest direct effects on fruit yield per plant, in accordance with genotypic trends. Sex ratio had moderate influence, suggesting that female flower ratio plays a role at the observable level. TSS, days to first harvest and rind thickness recorded low or negative direct effects, indicating less influence or possible indirect roles through other traits. At both levels, average fruit weight and number of fruits per vine not only contributed directly to yield but also showed strong indirect effects through traits like number of branches per vine, sex ratio, node at first male flower apperance and node at first female flower apperance, highlighting the complex trait interactions. These associations suggest selecting plants with more branches indirectly increases yield via their positive influence on fruit number and size. Days to first female flower and days to first male flower showed negative direct effects at both levels implying that delayed flowering is undesirable for improving yield. The path analysis confirmed that average fruit weight and number of fruits per vine are the most important traits for improving fruit yield in muskmelon, both directly and indirectly. Selection strategies in muskmelon breeding should emphasize these traits, while also considering supportive characters like number of branches, sex ratio and fruit thickness for holistic improvement.

Table 1: Genotypic correlation coefficients among growth and yield parameters of muskmelon

Traits	DFM	DFF	NFM	NFF	NBV	SR	DFH	NFV	AFW	FYV	SI	FT	RT	CD	TSS
DFM	1.000	0.845 **	0.205 *	0.024	0.674**	-0.624 **	-0.019	-0.575 **	0.568 **	0.042	0.173	0.301**	0.051	0.462 **	-0.377 **
DFF		1.000	0.426 **	0.332 **	1.0812 **	-0.531 **	0.334**	-0.673 **	0.593 **	0.002	0.170	0.211*	0.145	0.408 **	-0.236 *
NFM			1.000	0.977 **	0.544 **	-0.362 **	0.039	-0.483 **	0.528**	0.145	-0.003	0.078	0.141	0.497 **	0.095
NFF				1.000	0.469 **	-0.053	0.088	-0.336 **	0.318 **	0.152	0.027	0.028	0.093	0.336 **	0.101
NBV					1.000	-0.065	-0.223 *	0.170	0.512 **	0.762 **	-0.138	0.231 *	0.058	0.411 **	-0.230 *
SR						1.000	0.071	0.843**	-0.769**	0.193	-0.112	-0.193	0.003	-0.593 **	0.196
DFH							1.000	-0.065	-0.106	-0.179	-0.111	0.113	0.297 **	-0.051	0.151
NFV								1.000	-0.776 **	0.215*	-0.136	-0.231*	-0.119	-0.561 **	0.005
AFW									1.000	0.353 **	0.230 *	0.383 **	0.086	0.586 **	-0.108
FYV										1.000	0.038	0.230 *	-0.033	0.032	0.047
SI											1.000	0.236 *	-0.126	-0.239 *	-0.617**
FT												1.000	-0.073	0.179	-0.196
RT													1.000	0.184	0.305 **
CD														1.000	0.124
TSS															1.000

** Correlation is significant at the 0.01 level. *Correlation is significant at the 0.05 level.

DFM-Days to first male flower appearance	SR-Sex ratio	SI-Shape index
DFF-Days to first female flower appearnace	DFH-Days to first harvest	FT-Flesh thickness
NFM-Node at first male flower appearance	NFV-Number of fruits per vine	RT-Rind thickness
NFF-Node at first female flower appearance	AFW-Average fruit weight	CD-Cavity diameter
NBV-Number of primary branches per vine	FYV-Fruit yield per vine	TSS-Total soluble solids

Table 2: Phenotypic correlation coefficients among growth and yield parameters of muskmelon

Traits	DFM	DFF	NFM	NFF	NBV	SR	DFH	NFV	AFW	FYV	SI	FT	RT	CD	TSS
DFM	1.000	0.618**	0.162*	0.096	0.091	-0.479 **	0.007	-0.416**	0.479**	0.013	0.132	0.236**	0.043	0.396**	-0.285 **
DFF		1.000	0.163 *	0.207 **	-0.023	-0.308 **	0.294 **	-0.374**	0.387 **	0.001	0.101	0.112	0.068	0.269 **	-0.134
NFM			1.000	0.779 **	0.133	-0.256**	0.051	-0.319 **	0.356 **	0.135	-0.010	0.059	0.129	0.385 **	0.077
NFF				1.000	0.119	-0.065	0.038	-0.252 **	0.257 **	0.123	0.045	0.032	0.093	0.290 **	0.114
NBV					1.000	-0.051	-0.019	-0.015	0.082	0.041	-0.033	0.059	0.009	0.133	-0.070
SR						1.000	0.0543	0.708 **	-0.683 **	0.160 *	-0.112	-0.189 **	0.003	-0.508 **	0.181 *
DFH							1.000	-0.087	-0.077	-0.144 *	-0.092	0.089	0.225 **	0.001	0.114
NFV								1.000	-0.643 **	0.334 **	-0.116	-0.197 **	-0.099	-0.470 **	0.009
AFW									1.000	0.337 **	0.209 **	0.352 **	0.087	0.514**	-0.099
FYV										1.000	0.044	0.180 *	-0.028	0.015	0.040
SI											1.000	0.228 **	-0.124	-0.223 **	-0.595**
FT												1.000	-0.053	0.182 *	-0.185 *
RT													1.000	0.174 *	0.301**
CD														1.000	0.113
TSS															1.000

** Correlation is significant at the 0.01 level. *Correlation is significant at the 0.05 level.

DFM-Days to first male flower appearance	SR-Sex ratio	SI-Shape index
DFF-Days to first female flower appearnace	DFH-Days to first harvest	FT-Flesh thickness
NFM-Node at first male flower appearance	NFV-Number of fruits per vine	RT-Rind thickness
NFF-Node at first female flower appearance	AFW-Average fruit weight	CD-Cavity diameter
NBV-Number of primary branches per vine	FYP-Fruit yield per vine	TSS-Total Soluble Solids

Table 3: Genotypic path analysis for fruit yield per vine in muskmelon

Trait	DFM	DFF	NFM	NFF	NBV	SR	DFH	NFV	AFW	SI	FT	RT	CD	TSS	FYV
DFM	0.679	-0.421	0.035	-0.001	-0.036	-0.611	-0.004	-0.431	0.999	-0.025	-0.042	-0.008	-0.062	-0.031	0.042
DFF	0.575	-0.498	0.073	-0.017	-0.058	-0.520	0.060	-0.504	1.041	-0.024	-0.029	-0.023	-0.055	-0.019	0.002
NFM	0.139	-0.212	0.171	-0.050	-0.029	-0.355	0.007	-0.362	0.929	0.000	-0.011	-0.022	-0.066	0.008	0.145
NFF	0.016	-0.166	0.167	-0.051	-0.025	-0.052	0.016	-0.252	0.559	-0.004	-0.004	-0.015	-0.045	0.008	0.152
NBV	0.458	-0.539	0.093	-0.024	-0.054	-0.064	-0.040	0.128	0.899	0.020	-0.032	-0.009	-0.055	-0.019	0.762**
SR	-0.424	0.265	-0.062	0.003	0.003	0.979	0.013	0.632	-1.352	0.016	0.027	0.000	0.079	0.016	0.193
DFH	-0.013	-0.167	0.007	-0.005	0.012	0.070	0.180	-0.049	-0.187	0.016	-0.016	-0.047	0.007	0.012	-0.179
NFV	-0.391	0.335	-0.083	0.017	-0.009	0.826	-0.012	0.749	-1.363	0.019	0.032	0.019	0.075	0.000	0.215*
AFW	0.386	-0.295	0.090	-0.016	-0.028	-0.753	-0.019	-0.581	1.756	-0.033	-0.053	-0.014	-0.078	-0.009	0.353 **
SI	0.118	-0.085	0.000	-0.001	0.007	-0.110	-0.020	-0.102	0.404	-0.141	-0.033	0.020	0.032	-0.050	0.038
FT	0.205	-0.105	0.013	-0.001	-0.012	-0.189	0.020	-0.174	0.673	-0.033	-0.138	0.012	-0.024	-0.016	0.230 *
RT	0.035	-0.072	0.024	-0.005	-0.003	0.003	0.054	-0.090	0.151	0.018	0.010	-0.159	-0.025	0.025	-0.033
CD	0.314	-0.203	0.085	-0.017	-0.022	-0.580	-0.009	-0.420	1.029	0.034	-0.025	-0.029	-0.134	0.010	0.032
TSS	-0.256	0.118	0.016	-0.005	0.012	0.192	0.027	0.004	-0.191	0.087	0.027	-0.049	-0.017	0.081	0.047

** Correlation is significant at the 0.01 level. *Correlation is significant at the 0.05 level. R2-0.9107 Residual effect-0.089

DFM-Days to first male flower appearance	SR-Sex ratio	SI-Shape index
DFF-Days to first female flower appearnace	DFH-Days to first harvest	FT-Flesh thickness
NFM-Node at first male flower appearance	NFV-Number of fruits per vine	RT-Rind thickness
NFF-Node at first female flower appearance	AFW-Average fruit weight	CD-Cavity diameter
NBV-Number of primary branches per vine	FYV-Fruit yield per vine	TSS-Total Soluble Solids

Table 4: Phenotypic path analysis for fruit yield per vine in muskmelon

Trait	DFM	DFF	NFM	NFF	NBV	SR	DFH	NFV	AFW	SI	FT	RT	CD	TSS	FYV
DFM	0.028	-0.005	0.020	-0.001	-0.002	-0.146	0.000	-0.338	0.501	-0.002	0.012	-0.003	-0.020	-0.030	0.013
DFF	0.017	-0.008	0.020	-0.001	0.001	-0.094	-0.005	-0.305	0.405	-0.002	0.005	-0.005	-0.013	-0.014	0.001
NFM	0.004	-0.001	0.125	-0.006	-0.003	-0.078	-0.001	-0.260	0.372	0.000	0.003	-0.010	-0.019	0.008	0.135
NFF	0.003	-0.002	0.097	-0.007	-0.003	-0.020	-0.001	-0.205	0.269	-0.001	0.002	-0.007	-0.014	0.012	0.123
NBV	0.003	0.000	0.017	-0.001	-0.024	-0.016	0.000	-0.013	0.086	0.001	0.003	-0.001	-0.007	-0.007	0.041
SR	-0.013	0.002	-0.032	0.000	0.001	0.304	-0.001	0.575	-0.714	0.002	-0.009	0.000	0.025	0.019	0.160 *
DFH	0.000	-0.002	0.006	0.000	0.000	0.016	-0.015	-0.071	-0.080	0.002	0.004	-0.017	0.000	0.012	-0.144 *
NFV	-0.012	0.003	-0.040	0.002	0.000	0.215	0.001	0.812	-0.672	0.002	-0.010	0.008	0.023	0.001	0.334 **
AFW	0.013	-0.003	0.045	-0.002	-0.002	-0.208	0.001	-0.523	1.045	-0.004	0.017	-0.007	-0.026	-0.011	0.337 **
SI	0.004	-0.001	-0.001	0.000	0.001	-0.034	0.001	-0.095	0.219	-0.017	0.011	0.009	0.011	-0.064	0.044
FT	0.007	-0.001	0.007	0.000	-0.001	-0.058	-0.001	-0.160	0.368	-0.004	0.049	0.004	-0.009	-0.020	0.180 *
RT	0.001	-0.001	0.016	-0.001	0.000	0.001	-0.003	-0.081	0.091	0.002	-0.003	-0.076	-0.009	0.032	-0.028
CD	0.011	-0.002	0.048	-0.002	-0.003	-0.154	0.000	-0.382	0.538	0.004	0.009	-0.013	-0.050	0.012	0.015
TSS	-0.008	0.001	0.010	-0.001	0.002	0.055	-0.002	0.008	-0.104	0.010	-0.009	-0.023	-0.006	0.107	0.040

** Significant at the 0.01 level. * Significant at the 0.05 level. R^2-0.7041 Residual effect-0.295

DFM-Days to first male flower appearance	SR-Sex ratio	SI-Shape index
DFF-Days to first female flower appearnace	DFH-Days to first harvest	FT-Flesh thickness
NFM-Node at first male flower appearance	NFV-Number of fruits per vine	RT-Rind thickness
NFF-Node at first female flower appearance	AFW-Average fruit weight	CD-Cavity diameter
NBV-Number of primary branches per vine	FYV-Fruit yield per vine	TSS-Total Soluble Solids

Conclusion

The study on 94 muskmelon genotypes revealed that fruit yield is strongly governed by average fruit weight and number of fruits per vine, both showing high positive direct and indirect effects at phenotypic and genotypic levels. Number of branches per vine, flesh thickness, and sex ratio also contributed positively, indicating their supportive role in yield enhancement. Conversely, delayed flowering traits exhibited negative direct effects, emphasizing the importance of earliness in muskmelon improvement. Negative correlations between fruit size and fruit number, and between TSS and growth traits, suggest the need for balanced selection strategies to avoid trade-offs. Overall, improvement in muskmelon yield should prioritize fruit weight and fruit number while integrating supportive traits for sustainable breeding progress.

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