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Research Article

Phenotypic and genotypic association of yield and yield-related traits in eggplant (*Solanum melongena* L.) evaluated for two seasons

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ABSTRACT

Research on phenotypic and genotypic and associations between traits of eggplants provide valuable insights into the intricate dynamics of breeding programs. By understanding the relationships between different traits, breeders can effectively plan, evaluate, and establish selection criteria to cultivate desired characteristics in eggplant. The aim of this experiment was to determine the correlation coefficients, both phenotypic and genotypic, among various characters related to yield and to analyse the direct and indirect effects of these traits on yield per plant using path analysis. A randomized complete block design (RCBD) was used to arrange the plants and replicated three times. The results across the seasons indicated significant variations ($p \leq 0.05$) of all the traits examined. Research on correlation has indicated a significant and strong relationship between the main traits that contribute to crop yield (fruit length and fruit weight) at both the phenotypic and genotypic levels. Furthermore, several traits including the number of fruits, fruit weight, fruit length, stomata conductance, transpiration rate, and photosynthetic rate have demonstrated a significant and positive correlation with yield per plant. These traits have also exhibited a direct influence on yield. Conversely, traits such as fruit diameter and stomata conductance have displayed a strong and positive indirect impact on yield through their influence on fruit weight, number of fruits, and number of branches. In tropical conditions, the variables of yield component and physiological traits have been found to be positively correlated with higher eggplant yields. Consequently, these variables can serve as reliable indicators for indirect selection for yield in eggplant cultivation.

INTRODUCTION

Eggplant (*Solanum melongena* L.), also known as brinjal or aubergine, is a significant crop that thrives in sub-tropical, tropical, and warm temperate regions. It belongs to the Solanaceae family, which is widely distributed and includes various domesticated species like tomato, pepper, potato and tobacco [1, 2]. It is believed that eggplant originated in Indo-Burma, with China being a secondary center of origin. A complex trait like Yield depends on a variety of characteristics. It is essential to understand the significance of each component and how it relates to yield and to other components before beginning a successful selection procedure [3, 4]. Earlier research on this topic was conducted by a number of researchers. The relative contribution of causal factors to the final yield cannot be quantified using a simple measure of character correlation. Due to their interdependence, component qualities frequently alter their direct relationship with yield, which limits the validity of selection indices based on correlation coefficients.

Correlation refers to the ongoing relationship between traits, while path analysis dissects this relationship into direct and indirect effects of each trait on yield [5]. Research on the correlations between genotypic and phenotypic traits in crop plants holds significant value in the context of planning, evaluating, and establishing selection criteria within breeding programs [6]. Genetic relationships provide simple selection criteria and facilitate the development of a directional model centered on yield and its components in field trials. To design appropriate breeding strategies aimed at improving yield through selection, conducting correlation and path analysis studies is desirable. These studies contribute to a better understanding of the relationship between yield and yield traits [7, 8]. Correlation studies examines the mutual relationships between various traits and identifies the component traits that can be relied upon for advancement. It plays a significant role in determining effective breeding processes [6]. Path coefficient analysis quantifies the inter-relationships of different components on yield and is a statistical technique specifically designed for this purpose. It assists in the selection and development of eggplant yield by manipulating quantitative characters that influence yield and have correlations among themselves. Path analysis studies provides a comprehensive investigation of the associations among yield components, aiding in the development of reliable selection criteria and reducing the risks of component compensation in yield improvement [9]. The objective of this research is to determine the direct and indirect relationships among yield and yield-contributing traits, and the relative contributions of each trait to fruit yield in eggplant through association and path analysis.

MATERIALS AND METHODS

The 32 accessions of eggplant were obtained from China, Bangladesh, Malaysia, and Thailand for the first (May to September 2021) and second (November to March 2022) trials (Table 1, Figure 1). The seeds were sown in 48-holes germination trays with two seeds per cell planted in peat moss growing medium. The seedlings began germination within 3 – 8 days after sowing and healthy plantlet were transplanted to the experimental field six weeks after sowing, in an open field cropping system. The experiment was conducted in Field 15, which is situated within the Faculty of Agriculture, Universiti Putra Malaysia (UPM) Serdang, Selangor, Malaysia. The geographical coordinates of the field are approximately 3º02` N latitude and 101º42` East longitude, with an altitude of 31 meters above sea level. The experiment was laid out in a randomized complete block design with five plant of each genotype in three replications. Plants were spaced 50 cm between the plant and 70 cm between rows. Fertilization was applied based on the standard horticultural practices for vegetables production in Malaysia from the Department of Agriculture (DOA, Malaysia). Daily visit to the study site was conducted to examine for insect, pest and disease incidence, crop maintenance, to observe crop performance and irrigate them when necessary using a rain port sprinkler system. Data were collected from growth, physiological and yield traits. The observations have been recorded on randomly five tagged plants in each entry for all traits studied. The studied traits are; days to 50% flowering (DF), branches number (NB), plant height (PH) in cm, photosynthetic rate (PR), stomata conductance (SC), transpiration rate (TR), chlorophyll content (CC), fruit number (NF), fruit length (FL) in cm, fruit diameter (FD) in mm, fruit weight (FW) in g and yield per plant (Y/P) in kg.

Correlation and path coefficient analysis

The genotypic and phenotypic correlation coefficients were computed using SAS, version 9 (SAS Institute Inc., Cary, NC, USA). Subsequently, the phenotypic associations were decomposed into direct and indirect effects components through path analysis, employing the approach outlined by Wright [10]. The path coefficients were computed using the methodology outlined by Usman et al. [11].

Fig. 1. Some of the varieties used in this studies.

Table 1. Eggplant (*Solanum melongena*) accessions used in this study.

New code	Original name	New code	Original name
CE1	Changza 8	ME5	Little Nyonya 313
CE2	Changza 218	ME6	Super Naga 312 F1 hybrid eggplant
CE3	Yuanza 471	ME7	MTe 2
CE4	Chua young seng seed (Long eggplant)	ME8	Eggplant-Purple Dream (302)
BE1	Long purple eggplant Pahuja seeds	ME9	Mardi Terung Telunjuk (415)
BE2	F1 hybrid eggplant Pahuja seeds	ME10	Mardi Terung Telunjuk (384)
BE3	BARI BEGUN 04	ME11	Green world Biocolor Eggplant 321
BE4	BARI 311	ME12	Mardi NTH 08-0077
BE5	BARI BEGUN 05	ME13	Mardi NTH 08-0111
BE6	BARI BEGUN 02	ME14	Mardi NTH 08-0031
BE7	BARI BEGUN 07	TE1	East west seed 1371/2560
BE8	Plate Brush Eggplant	TE2	East west seed 01513/2554
ME1	Green world Round Purple 311	TE3	Eggplant 1253/2561
ME2	Green world white eggplant shining 330	TE4	Eggplant El ryu
ME3	F1 418 purple king	TE5	Round eggplant 01451/2551
ME4	Nyonya eggplant F1 428	TE6	Round eggplant 01452/2551

RESULTS

Analysis of variance

Analysis of variance across the two seasons for the growth, physiological, yield, and yield traits for all the genotypes studied is presented in Table 2. The results showed that all growth, physiological and yield traits studied in these trials recorded a highly significant (p≤0.05) differences among the genotypes and the genotype by season interaction.

Phenotypic and genotypic association

There is a complex relationship between different plant traits, as they are not independent but rather associated with one another. This association ultimately affects the overall yield. In our study, we observed strong and highly significant correlations between yield per plant and most of the traits examined (see Table 3). These correlations were evident at both the phenotypic and genotypic levels. At the phenotypic level, the correlation coefficients ranged from 0. 02 to 0. 89, while at the genotypic level, they ranged from 0. 12 to 0. 29. These results indicate that the magnitudes of the genotypic coefficients were higher compared to the corresponding estimates of the phenotypic coefficients. Yield per plant demonstrated a significant and strong positive phenotypic correlation with fruit length, fruit diameter, fruit weight, number of fruits, photosynthetic rate, stomata conductance, and chlorophyll content. Furthermore, fruit length, fruit diameter, fruit weight, number of fruits, photosynthetic rate, and plant height exhibited a strong, positive association with yield per plant. Therefore, selecting plants based on fruit length, fruit diameter, fruit weight, and number of fruits can effectively contribute to increasing yield per plant.

Direct and indirect effects of growth, physiological and yielding traits on yield per plant

Figure 2 and Table 4 illustrate the phenotypic direct and indirect impacts of yield-related characteristics on yield per plant. Various traits, including plant height, photosynthetic rate, transpiration rate, chlorophyll content, fruit length, fruit weight, and number of fruits, exhibited positive direct effects on yield per plant. Notably, physiological and yield traits, such as photosynthetic rate, transpiration rate, chlorophyll content, fruit length, fruit weight, and number of fruits, demonstrated significant positive direct effects on yield per plant. Conversely, the number of branches displayed a significant negative correlation with yield per plant, primarily due to its negative direct effect on yield. Equally, stomata conductance and fruit diameter exhibited negative direct effects on yield per plant, yet their associations with yield remains significant and substantial. The greatest indirect impact on yield per plant was exerted by stomata conductance and fruit diameter via the weight of the fruit.

Two-stage relations

First-order component (growth and physiological traits) on fruit length

The effect of these traits on fruit length is displayed in Table 5. Days to 50% flowering, photosynthetic rate, stomata conductance, transpiration rate, and content of chlorophyll exhibited a positive association with fruit length. This positive relationship primarily resulted from the direct impact of these characteristics on fruit length. However, days to flowering did not demonstrate a significant correlation. Conversely, the number of branches and plant height displayed a negative relationship with fruit length, which was attributed to the indirect negative effect on fruit length through photosynthetic rate, stomata conductance, transpiration rate, and content of chlorophyll. The number of branches exhibited a negative correlation with fruit length.

First-order component (growth and physiological traits) on fruit diameter

The inter-relationships of days to 50% flowering, photosynthetic rate, transpiration rate and chlorophyll content have positive direct effect with fruit diameter (Table 5). The adverse impact of the duration between flowering events on the length of fruits was found to be minimal, potentially due to the significant positive influence of the duration between flowering events on the diameter of fruits. This positive influence is mediated through traits such as plant height, photosynthetic rate, stomata conductance, and content of chlorophyll.

First-order component (growth and physiological traits) on fruit weight

Table 5 presents the results of the path analysis for the first-order component on fruit weight. We found that there was a positive relationship between days to flowering, photosynthetic rate, stomata conductance, and content of chlorophyll with fruit length. This positive relationship was primarily due to the direct effects of these factors on fruit weight. Additionally, we observed a low negative direct effect of days to flowering on fruit length, which may be explained by the strong positive indirect effect of days to flowering on fruit diameter through plant height, photosynthetic rate, stomata conductance, transpiration rate, and chlorophyll content. Furthermore, the number of branches showed a significant negative correlation with fruit weight, mainly because of its direct negative effect on fruit weight

Table 2. Analysis of variance (mean square) for twelve traits for *Solanum melongena*.

Traits	Genotype (df=31)	G × S (df=31)	Error (df=124)
Days to flowering	563.6529**	42.7752**	4.1708
Number of branches	21.1108**	5.8304**	0.2317
Plant height	518.1962**	339.0825**	4.6500
Photosynthetic rate	52.9453**	1.8220**	0.3364
Stomata conductance	0.0595**	0.0024**	0.0001
Transpiration rate	4.5082**	0.3544**	0.0131
Chlorophyll content	3.1750**	0.1514**	0.0047
Fruit length	217.2884**	3.7352**	1.1768
Fruit diameter	1917.1765**	102.8472**	8.8357
Fruit weight	17731.1408**	2304.6441**	28.685
Number of fruits	327.2860**	399.5802**	70.252
Yield per plant	4.8814**	7.3037**	0.0081

** (p≤0.01), df, degree of freedom; G, genotype; S, season

Table 3. Phenotypic (bold) and genotypic correlations among traits of 32 eggplant accessions across seasons.

Variable	DF	NB	PH	PR	SC	TR	CC	FL	FD	FW	NF	Yield
DF		0.649**	0.086NS	0.602**	-0.553**	-0.032NS	0.854**	0.339*	0.659**	0.602**	-0.665**	0.196NS
NB	0.204NS		-0.344*	0.394*	-0.053NS	0.545**	0.828**	0.311*	0.224NS	0.650**	-0.386*	-0.194NS
PH	0.002NS	0.596**		0.542**	0.285NS	-0.575**	-0.248NS	0.680**	0.197NS	0.522**	0.576**	0.929**
PR	0.454**	-0.347*	-0.210NS		0.309*	0.130NS	0.478**	0.924**	0.796**	0.673**	-0.104NS	0.623**
SC	-0.281NS	-0.539**	-0.313*	0.533**		0.406*	-0.356*	0.578**	0.012NS	-0.125NS	0.651**	0.255NS
TR	-0.012NS	-0.288NS	-0.651**	0.395*	0.454**		0.254NS	0.196NS	0.308*	-0.229NS	-0.255NS	-0.331*
CC	0.612**	-0.208NS	-0.565**	0.640**	0.123NS	0.486**		0.258NS	0.524**	0.536**	-0.785**	-0.033NS
FL	0.240NS	-0.323*	-0.145NS	0.889**	0.616**	0.395*	0.472**		0.658**	0.595**	0.238NS	0.783**
FD	0.417*	-0.259NS	-0.237NS	0.712**	0.209NS	0.439**	0.579**	0.573**		0.763**	-0.591**	0.489**
FW	0.338*	-0.455**	-0.281NS	0.742**	0.310*	0.188NS	0.668**	0.653**	0.618**		-0.412*	0.727**
NF	-0.378*	-0.298NS	-0.048NS	0.178NS	0.265NS	0.111NS	-0.104NS	0.311*	-0.097NS	0.052NS		0.397**
Yield	0.077NS	-0.605**	-0.270NS	0.730**	0.431**	0.299*	0.459**	0.715**	0.502**	0.780**	0.550**	

NS = not significant, * = significant at 5%, ** = significant at 1%

Table 4. Path analysis of the direct (bold diagonal) and indirect effects on yield per plant in the eggplant accessions.

	DF	NB	PH	PR	SC	TR	CC	FL	FD	FW	NF
DF	-0.029	-0.006	0.000	-0.013	0.008	0.000	-0.018	-0.007	-0.012	-0.010	0.011
NB	-0.064	-0.312	-0.186	0.108	0.168	0.090	0.065	0.101	0.081	0.142	0.093
PH	0.000	0.117	0.196	-0.041	-0.061	-0.127	-0.111	-0.028	-0.046	-0.055	-0.009
PR	0.103	-0.078	-0.047	0.226	0.120	0.089	0.145	0.201	0.161	0.168	0.040
SC	0.047	0.089	0.052	-0.089	-0.166	-0.075	-0.020	-0.102	-0.035	-0.051	-0.044
TR	-0.002	-0.052	-0.118	0.072	0.082	0.182	0.088	0.072	0.080	0.034	0.020
CC	0.001	0.000	-0.001	0.001	0.000	0.001	0.002	0.001	0.001	0.001	0.000
FL	0.005	-0.007	-0.003	0.020	0.014	0.009	0.010	0.022	0.013	0.015	0.007
FD	-0.013	0.008	0.008	-0.023	-0.007	-0.014	-0.019	-0.018	-0.032	-0.020	0.003
FW	0.181	-0.244	-0.151	0.397	0.166	0.100	0.358	0.350	0.331	0.536	0.028
NF	-0.152	-0.119	-0.019	0.071	0.106	0.045	-0.042	0.125	-0.039	0.021	0.401
Correlated with yield	0.077NS	-0.605**	-0.270NS	0.730**	0.431**	0.299*	0.459**	0.715**	0.502**	0.780**	0.550**

NS = not significant, * = significant at 5%, ** = significant at 1%

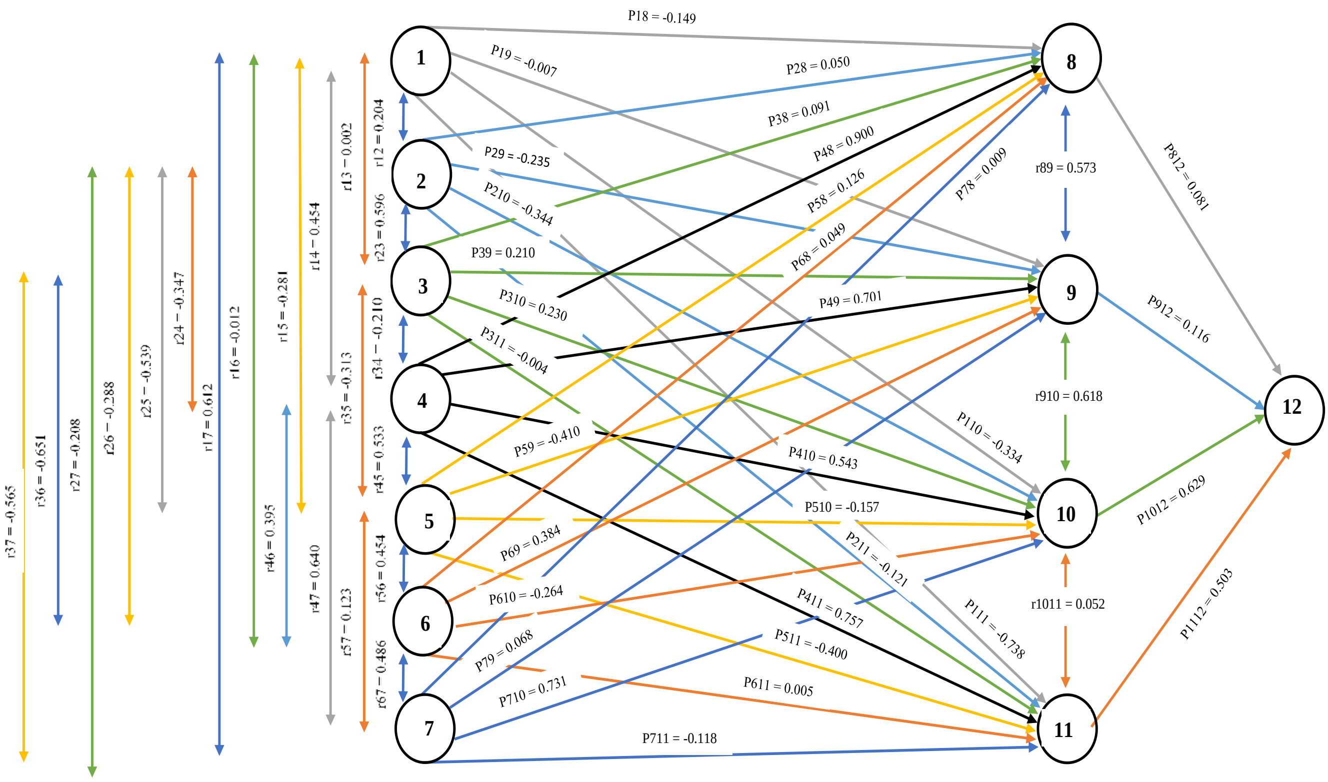

Fig. 2. In the present study, a path diagram was constructed to illustrate the relationships between various factors and their influence on the first-order components, second-order components, and ultimately the yield per plant. The coefficients of these traits were also determined. It is important to note that the *P*ij values represent the direct effects of the traits, while the rij values indicate the correlation coefficients. In the path diagram, the presence of single arrowed lines signifies a direct influence, whereas the presence of doubled-arrowed lines indicates a mutual association between the variables.

Table 5. Relationship between first and second order.

	VAR	DF	NB	PH	PR	SC	TR	CC
FL	DF	**-0.149**	-0.030	-0.001	-0.068	0.042	0.002	-0.091
	NB	0.010	**0.050**	0.030	-0.017	-0.027	-0.014	-0.010
	PH	0.001	0.054	**0.091**	-0.019	-0.029	-0.059	-0.051
	PR	0.409	-0.313	-0.189	**0.900**	0.480	0.356	0.577
	SC	-0.036	-0.068	-0.040	0.067	**0.126**	0.057	0.016
	TR	-0.001	-0.014	-0.032	0.019	0.022	**0.049**	0.024
	CC	0.006	-0.002	-0.005	0.006	0.001	0.005	**0.009**
	FL	0.240ns	-0.323*	-0.145ns	0.889**	0.616**	0.394*	0.472**
FD	DF	**-0.007**	-0.002	0.001	-0.0034	0.002	0.001	-0.005
	NB	-0.048	**-0.235**	-0.140	0.082	0.127	0.068	0.049
	PH	0.001	0.125	**0.210**	-0.044	-0.066	-0.137	-0.119
	PR	0.319	-0.243	-0.147	**0.701**	0.374	0.277	0.449
	SC	0.115	0.221	0.128	-0.219	**-0.410**	-0.186	-0.051
	TR	-0.004	-0.110	-0.250	0.152	0.174	**0.384**	0.187
	CC	0.042	-0.014	-0.039	0.044	0.008	0.033	**0.068**
	FD	0.417*	-0.259**	-0.237**	0.712**	0.209ns	0.439**	0.579**
FW	DF	**-0.334**	-0.068	-0.001	-0.152	0.094	0.004	-0.204
	NB	-0.070	**-0.344**	-0.205	0.120	0.186	0.099	0.072
	PH	0.001	0.137	**0.230**	-0.048	-0.072	-0.150	-0.130
	PR	0.247	-0.188	-0.114	**0.543**	0.289	0.215	0.347
	SC	0.044	0.085	0.049	-0.084	**-0.157**	-0.071	-0.019
	TR	0.003	0.076	0.172	-0.104	-0.120	**-0.264**	-0.128
	CC	0.447	-0.152	-0.413	0.468	0.090	0.355	**0.731**
	FW	0.338*	-0.455**	-0.281ns	0.742**	0.310*	0.187ns	0.668**
NF	DF	**-0.738**	-0.150	-0.002	-0.335	0.207	0.009	-0.452
	NB	-0.025	**-0.121**	-0.072	0.042	0.065	0.035	0.025
	PH	0.001	-0.002	**-0.004**	0.001	0.001	0.002	0.002
	PR	0.344	-0.263	-0.159	**0.757**	0.403	0.299	0.484
	SC	0.112	0.215	0.125	-0.213	**-0.400**	-0.181	-0.049
	TR	-0.001	-0.002	-0.003	0.002	0.002	**0.005**	0.003
	CC	-0.072	0.025	0.067	-0.075	-0.015	-0.057	**-0.118**
	NF	-0.378*	-0.298ns	-0.048ns	0.178ns	0.265ns	0.111ns	-0.104ns

Days to flowering (DF), number of branches (NB), plant height (PH), photosynthetic rate (PR), stomata conductance (SC), transpiration rate (TR), chlorophyll content (CC), fruit length (FL), fruit diameter (FD), fruit weight (FW) and number of fruit (NF)

First-order component (growth and physiological traits) on number of fruits

Table 5 displays the effects of various traits related to yield on the number of fruits, both directly and indirectly. Traits such as days to flowering, chlorophyll content, stomata conductance, number of branches, and plant height were found to have a negative direct impact on yield per plant. However, both photosynthetic rate and transpiration rate exhibited positive and significant direct effects, which were beneficial for yield per plant. Notably, the negative correlation between days to flowering and yield per plant was primarily due to its negative direct effect on yield.

Second order (yielding traits) on yield per plant

Table 6 and Figure 2 display the impact of second-order components on the yield per plant. The highly positive correlation between fruit length, fruit diameter, fruit weight and number of fruits on yield per plant was mainly a result of the high direct effects of fruit length, diameter, weight, and number on yield per plant.

Table 6. Second order component on yield per plant.

	FL	FD	FW	NF
FL	**0.082**	0.047	0.053	0.025
FD	0.066	**0.116**	0.071	-0.011
FW	0.411	0.389	**0.629**	0.033
NF	0.157	-0.049	0.026	**0.503**
YPP	0.715**	0.502**	0.780**	0.550**

Fruit length (FL), fruit diameter (FD), fruit weight (FW) and number of fruit (NF)

DISCUSSION

In order to develop an efficient plant breeding program, it is crucial to have sufficient knowledge about the correlation between yield and its component traits [12, 13]. The study found a significant strong and positive correlation between all physiological and yielding traits with yield, except for days to flowering, number of branches, and plant height, which showed a negative or no correlation at the phenotypic level. This indicates that these particular traits may not be useful for the improvement of yield per plant in eggplant. However, at the genotypic level, plant height, photosynthetic rate, fruit length, fruit diameter, fruit weight, and number of fruits showed a positive correlation with yield, suggesting their potential for enhancing yield in eggplant production. The genetic coefficients were found to be higher in magnitude compared to the consistent phenotypic coefficients. This difference may be attributed to the influence of the environment, which masks the expression of these traits at the phenotypic level. These findings indicate that selection for yield improvement among eggplant genotypes could be effective, as the variation in yield is primarily influenced by genetics rather than the environment. These results are consistent with previous studies conducted by Usman et al. [11] and Oladosu et al. [14]. The study also revealed a significant association between plant height and yield, which can be explained by an increase in the number of fruits, leading to a higher yield per plant. This finding is in line with previous studies conducted by Ajjapplavara et al. [15] and Jabeen et al. [16], which also reported a significant correlation between various yield attributing traits and yield per plant. On the other hand, the number of branches showed a strong negative correlation with yield and yielding traits, which is consistent with the findings of Tripathy et al. [5]. The length, diameter, weight, and number of fruits demonstrated a strong positive association with yield, indicating that an increase in fruit length or diameter could significantly enhance the weight of the fruit and consequently increase the total fruit yield per plant. Previous studies by Thangamani and Jansirani [17], Patel et al. [18], and Ridzuan et al. [19] have also reported significant positive correlations between yield-related traits. Similarly, all physiological traits showed a positive relationship with yield, which can be attributed to their contribution to higher food production. This suggests that as the photosynthetic rate, stomata conductance, transpiration rate, and chlorophyll content increase, the yielding traits also increase, leading to an overall increase in yield per plant. Although the study revealed significant inter-relationships among various yield components, it is important to consider both their direct and indirect effects when determining the limit of yield [20]. Path coefficient analysis allows for the examination of these direct and indirect relationships by partitioning correlation coefficients, as explained by Usman et al. [11]. In the present investigation, the parameter with the most significant direct impact on crop yield was the weight of the fruit, with the number of fruits per plant ranking second in terms of influence. Additionally, photosynthetic rate, content of chlorophyll, fruit length, and fruit diameter exerted the highest indirect effects on fruit yield per plant via fruit weight. These traits can be utilized to develop a reliable selection index for improving fruit yield in eggplant. Similar findings have been reported by Rani et al. [21], Islam et al. [22], and Onyia et al. [23]. The research findings also indicated that there was a significant positive correlation between the weight of fruits and crop yield, with heavy fruits having the most pronounced direct impact on yield. Additionally, the number of fruits per plant was found to have a moderately positive influence on yield. However, wider fruits and high conductance had a lower negative direct effect, which was counterbalanced by their positive direct effects through fruit weight and number of fruits. These findings align with the study conducted by Kumar and Arumugam [24].

Component compensation was observed in the associations between fruit diameter, conductance, fruit weight, and yield per plant in eggplant. Consequently, the adverse direct impact of fruit diameter and conductance on yield can be ascribed to their indirect influence via fruit weight. In instances where a trait demonstrates a positive correlation and a substantial positive indirect effect, but a negative direct effect, as seen in fruit diameter and conductance, greater attention should be given to the indirect effects. Therefore, when making selections, it is imperative to consider indirect causal traits in conjunction with direct effects. Similar observations have been reported by Sabina and Singh [25] and Tulu [6]. Based on the results, it can be concluded that increasing fruit weight while keeping fruit diameter constant can lead to an increase in yield per plant in eggplant. The study also highlights the significant impact of late flowering on yield per plant in eggplant. This finding is consistent with the research conducted by Islam et al. [22], which reported that early genotypes have lower yields. Early fruit set can lead to a redirection of assimilates towards reproductive growth, potentially at the expense of vegetative growth. This phenomenon has been previously documented by Ukkund et al. [26] and Misra et al. [9]. The number of fruits, as well as their length and diameter, have been found to be genetically associated with fruit weight and positively correlated with fruit yield per plant. This suggests that eggplant fruits initially increase in length and subsequently gain diameter and flesh thickness [11]. Additionally, photosynthesis rate, stomata conductance, and chlorophyll content levels have also been found to be genetically associated with fruit weight and positively correlated with fruit yield per plant.

CONCLUSIONS

Our findings demonstrate a significant and robust correlation between physiological and yielding traits and yield per plant. The outcomes of this study suggest that when selecting eggplant crops, it is crucial to consider factors such as photosynthetic rate, fruit weight, and number of fruits. These traits directly contribute to achieving high yields per plant. Therefore, breeders in these regions should focus on developing early maturing genotypes of eggplant with a substantial fruit weight that can produce a large number of fruits under open field cropping conditions. However, breeding programs should also aim to develop genotypes that yield an optimal amount of fruits to achieve the highest possible yield. Further research is necessary to explore husbandry practices that minimize component compensation effects and enable the realization of increased eggplant yields.

AUTHOR CONTRIBUTIONS

Conceptualization, I.M. (Ibrahim Musa); methodology, I.M. (Ibrahim Musa) and U. M. (Usman Magaji; software, I.M. (Ibrahim Musa), S.C.C. (Samuel Chibuike Chukwu); validation, U.M; formal analysis, I.M. (Ibrahim Musa) and S.S (Senesie Swaray); investigation, I.M. (Ibrahim Musa) and U. M.; resources, I.M. (Ibrahim Musa) and; data curation, I.M. (Ibrahim Musa), U. M., S.C.C., S.S., and A. S. K (Audu Sanusi Kiri); writing—original draft preparation, I.M. (Ibrahim Musa); writing—review and editing, U. M., I.M. and S.C.C.; All authors have read and agreed to the published version of the manuscript.

REFERENCES

1. Sulaiman NNM, Rafii MY, Duangjit J, Ramlee SI, Phumichai C, Oladosu Y, et al. Genetic variability of eggplant germplasm evaluated under open field and glasshouse cropping conditions. Agronomy. 2020;10(3).
2. Musa I, Rafii MY, Ahmad K, Ramlee SI, Md Hatta MA, Magaji U, et al. Influence of wild relative rootstocks on eggplant growth, yield and fruit physicochemical properties under open field conditions. Agriculture. 2021;11(10):943. http://dx.doi.org/10.3390/agriculture11100943
3. Simon SY, Gashua IB, Musa I. Genetic variability and trait correlation studies in okra. Agric Biol J North America. 2013;4(5):532–8.
4. Rahman MS, Parveen S, Rashid MH-U-, Akter R, Hossin AY, Robbani MG. Correlation and path coefficient analysis of tomato germplasms. Int J Appl Sci Biotechnol. 2015;3(2):223–6. http://dx.doi.org/10.3126/ijasbt.v3i2.12421
5. Tripathy B, Department of Vegetable Science- 492012, IGKV, Raipur, Chhattisgarh. Correlation and path analysis studies of yield and yield components in brinjal (*Solanum melongena* L.). Int J Pure Appl Biosci. 2018;6(1):1266–70. http://dx.doi.org/10.18782/2320-7051.5677
6. Tulu BN. Correlation and path coefficients analysis studies among yield and yield related traits of quality protein maize (QPM) inbred lines. Int J Plant Breed Crop Sci. 2014;1:6–17.
7. Mondal M, Hakim MA, Juraimi AS, Mak A, Karim MR. Contribution of morpho-physiological attributes in determining the yield of mungbean. African J Biotechnol. 2011;10:12897–904.
8. Malek MA, Rafii MY, Shahida Sharmin Afroz M, Nath UK, Mondal MMA. Morphological characterization and assessment of genetic variability, character association, and divergence in soybean mutants. Sci World J. 2014:968796. http://dx.doi.org/10.1155/2014/968796
9. Misra S, Lai RK, Darokar MP, Khanuja SP. Genetic associations and path-coefficient analysis of the economic traits in the chili (*Capsicum annuum* L.). Electron J Plant Breed. 2010;346–50.
10. Wright BRE, Caspi A, Moffitt TE, Miech RA, Silva PA. Reconsidering the relationship between ses and delinquency: Causation but not correlation. Criminology. 1999;37(1):175–94. http://dx.doi.org/10.1111/j.1745-9125.1999.tb00483.x

11. Usman MG, Rafii MY, Martini MY, Oladosu Y, Kashiani P. Genotypic character relationship and phenotypic path coefficient analysis in chili pepper genotypes grown under tropical condition: Genotypic and phenotypic correlations among characters of chili pepper. J Sci Food Agric. 2017;97(4):1164–71. http://dx.doi.org/10.1002/jsfa.7843
12. Simon SY, Musa I, Nangere MG. Correlation and path coefficient analyses of seed yield and yield components in okra (*Abelmoschus esculentus* (L.) Moench). Int J Adv Res. 2013;1(3):45–51.
13. Musa I, Rafii MY, Ahmad K, Ramlee SI, Md Hatta MA, Oladosu Y, et al. Effects of grafting on morpho-physiological and yield characteristic of eggplant (*Solanum melongena* L.) grafted onto wild relative rootstocks. Plants. 2020;9(11).
14. Oladosu Y, Rafii MY, Magaji U, Abdullah N, Miah G, Chukwu SC, et al. Genotypic and phenotypic relationship among yield components in rice under tropical conditions. Biomed Res Int. 2018:1–10. http://dx.doi.org/10.1155/2018/8936767
15. Ajjapplavara PS, Patil SS, Hosamani RM, Patil AA, Gangaprasad S. Correlation and path coefficient analysis in chilli. Karnataka J Agric Sci. 2005;18:748–51.
16. Jabeen N, Sofi PA, Wani SA. Character association in chilli (*Capsicum annuum* L.) Rev UDO Agric. 2009;9:487–90.
17. Thangamani C, Jansirani P. Correlation and path coefficient analysis studies on yield and attributing characters in brinjal (*Solanum melongena* L.). Electronic J Plant Breed. 2012;3(3):939–44.
18. Patel VK, Singh U, Goswami A, Tiwari SK, Singh M. Genetic variability, interrelationships and path analysis for yield attributes in eggplant. Env Ecol. 2017;35(2A):877–80.
19. Ridzuan R, Rafii MY, Mohammad Yusoff M, Ismail SI, Miah G, Usman M. Genetic diversity analysis of selected Capsicum annuum genotypes based on morphophysiological, yield characteristics and their biochemical properties. J Sci Food Agric. 2019;99(1):269–80. http://dx.doi.org/10.1002/jsfa.9169
20. Chukwu SC, Rafii MY, Oladosu Y, Okporie EO, Akos IS, Musa I, et al. Genotypic and phenotypic selection of newly improved Putra rice and the correlations among quantitative traits. Diversity. 2022;14(10):812. http://dx.doi.org/10.3390/d14100812
21. Rani I, Veeraragavathatham D, Sanjutha D. Studies on correlation and path coefficient analysis on yield attributes in root knot nematodes resistant F1 hybrids of tomato. J App Sci Res. 2008;4:287–95.
22. Islam B, Ivy NA, Rasul MG, Zakaria M. Characters association and path analysis of exotic tomato (*Solanum lycopercicum* L.) genotypes. Bangladesh J Pl Breed Genet. 2010;23:13–8.
23. Onyia VN, Chukwudi UP, Ezea AC, Atugwu AI, Ene CO. Correlation and path coefficient analyses of yield and yield components of eggplant (*Solanum melongena*) in a coarse-textured Ultisol. Inf Process Agric. 2020;7(1):173–81. http://dx.doi.org/10.1016/j.inpa.2019.03.005
24. Kumar SR, Arumugam T, Balakrishnan S, Anandakumar CR. Variability in the segregating generation of eggplant for earliness and yield. Pak J Biol Sci. 2013;16(20):1122–9. http://dx.doi.org/10.3923/pjbs.2013.1122.1129
25. Singh SI. Correlation and path analysis in sweet pepper (*Capsicum annum* L.). J Veg Sci. 2009;36:128–30.
26. Ukkund KC, Patil MP, Madalageri MB, Mulage R, Jagadeesh RC. Character association and path analysis studies in green chilli for yield and yield attributes *Capsicum annuum* L.). Karnataka J Agric Sci. 2007;20:99–101.