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Morpho-Agronomic Characterization and Yield Evaluation of Doubled Haploid Eggplant (*Solanum melongena* L.) Lines Derived from Anther Culture

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Abstract

The improvement of eggplant yield through breeding is crucial. Doubled haploid technology has accelerated the development of varieties. This study utilized doubled haploid anther culture-derived lines (confirmed through flow cytometry and morphology) developed from embryos from a previous study to evaluate the morpho-agronomic performance and yield of doubled haploid eggplant lines. The experiment used a randomized complete block design (RCBD), three replications, and one factor, namely genotype (35 doubled haploid lines, three F_1 varieties). Observation was made on plant height, dichotomous height, stem diameter, days to flowering and harvesting, fruit length, fruit diameter, weight per fruit, number of fruits, and fruit yield per plant. The data were analyzed using ANOVA, t-Dunnett, Tukey-Kramer at a 5% level, Pearson correlation coefficient, and selection index. The results showed significant variability in the population of doubled haploid lines. Fruit yield was positively correlated with plant height, dichotomous height, stem diameter, days to flowering, fruit length, and weight per fruit, but negatively correlated with the number of fruits per plant. These variables can be used as selection criteria because of their high heritability and genotypic coefficients of variation. The selection index revealed that the high-yielding doubled haploid lines with desirable morpho-agronomic traits were RS-P2, RS-P6, RS-P9, RS-P14, RS-P18, RS-H19, RS-H20, RS-H23, RS-H27, RS-H3, RS-M31, RS-M32, RS-M33, RS-M34, and RS-M37. The selected lines with high yield and good quality fruit, similar to the commercial hybrid parent, were Hitavi's derived lines. All selected lines serve as the genetic basis for production improvements and long-term breeding programs for sustainable and productive eggplants that benefit farmers.

Keywords: fruit yield; haploid; heritability; pure lines; variability

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INTRODUCTION

Eggplant (*Solanum melongena* L.) is an important crop, ranked as the world's third most produced crop in the Solanaceae family, closely followed by tomatoes and potatoes (FAOSTAT, 2023). Its significance is evident in its widespread consumption across East Asia, Southeast Asia, the Middle East, India, and the Mediterranean (Gramazio et al., 2023). The adaptability of eggplant plants is remarkable, making them a staple in various agricultural landscapes. Notably, the five largest eggplant-producing countries are China, India, Egypt, Turkey,

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and Indonesia (FAOSTAT, 2022), underscoring their significant global economic impacts. Additionally, eggplant has a nutritional profile that competes with other members of the Solanaceae family, such as tomatoes and potatoes. It is a significant source of calcium, phosphorus, potassium, iron, protein, folic acid, and vitamins A and B, making it a crucial component of a balanced diet. Moreover, eggplant is low in fat, calories, and sodium, but high in fiber, underscoring its significance as a nutritious vegetable (Rosa-Martínez et al., 2023).

Like any other self-pollinated plant, eggplant breeding is directed toward the formation of highly homozygous plants or pure lines. Achieving homozygosity through repeated selfing takes many years (6 to 8 generations), significantly delaying cultivar development (Meng et al., 2021). Doubled haploids (DH) accelerate breeding cycles, reducing the time needed to develop pure lines for hybrid production or cultivar release (Qu et al., 2024). Because of their complete homozygosity, DH lines exhibit fixed genetic traits, enabling more precise and efficient phenotypic selection. This characteristic is particularly advantageous for quantitative trait improvement, as it eliminates heterozygote masking effects and reduces the phenotypic variance attributable to genetic segregation (Chaikam et al., 2019). The homozygous nature of DH populations facilitates a more reliable trait evaluation and enhances the efficiency of selection processes in breeding programs (Chen et al., 2023). Techniques, such as isolated microspores or anther culture, make DH production feasible (Hooghvorst and Nogués, 2021).

DH or pure lines were obtained after chromosome doubling naturally during culture or induction (Ren et al., 2017). The variability generated from gametic cells cultured *in vitro*, that is, microspores, is referred to as gametoclonal variation and may be caused by meiotic recombination, spontaneous mutations, or the process of *in vitro* culture itself (Rivas-Sendra et al., 2017). Thus, each plant regenerated from each microspore within the anthers is genetically unique and differs among individual lines. After several evaluations, the selected DH lines can be immediately released into new inbred varieties or used as parents to develop new hybrid varieties (Hale et al., 2022). DHs have been widely used to produce commercial varieties in many species, such as Brassica, rice, and wheat, as well as in the Solanaceae family, including pepper and tobacco (Hooghvorst and Nogués, 2021; Eliby et al., 2022; Kyum et al., 2022).

Fruit yield is the primary selection criterion in eggplant breeding because it directly determines the market supply. However, the Ministry of Agriculture (2023) data revealed a decline in eggplant production between 2022 and 2023, which could threaten farmers' livelihoods and market stability. Addressing this challenge requires accelerated breeding strategies to boost productivity by systematically selecting and developing high-yielding varieties. It can increase output without expanding farmland, boosting farmers' incomes and reducing pressure on natural resources (Rahman and Connor, 2022). These productivity gains establish a virtuous cycle; accelerated plant breeding and higher yields lead to greater economic stability for farmers, enabling continued investment in sustainable farming practices (Lenaerts et al., 2019).

The development and utilization of DH lines in eggplant breeding programs remain limited compared to that of major crops such as maize (Sadessa et al., 2024), wheat (Al-Ashkar et al., 2019; Pankaj et al., 2022), or rice (Nurhidayah et al., 2024; Yuana et al., 2025). Most studies have focused on protocol development rather than practical breeding applications. Few studies have evaluated the agronomic performance of derived DH eggplant lines (Rivas-Sendra et al., 2017; Mir et al., 2021). Mulyana et al. (2023) obtained DH eggplant lines from various commercial eggplant hybrids (F_1s) using anther cultures. DH eggplant lines in a previous study were confirmed using flow cytometry and further validated by their anatomy and plant morphology. These lines are promising for use as genetic material in eggplant breeding. However, information about the morpho-agronomic traits of DH eggplant lines, including fruit yield, is an initial step in developing new varieties. This study aimed to characterize morpho-agronomics and develop high-yielding inbred lines from DH eggplant lines that can serve as either direct-use varieties for farmers or parental lines for F_1 hybrids. This research provides a crucial first step in this process by identifying high-yielding genotypes that will serve as the genetic basis for immediate production improvements and long-term breeding programs, ultimately creating a more sustainable and productive eggplant that will benefit current and future generations of farmers.

MATERIALS AND METHOD

Plant materials

The study utilized Provita (F_1), Hitavi (F_1), Mustang (F_1), and their derived DH lines from anther culture (Mulyana et al., 2023). The 35 DH lines consisted of 17 from Provita F_1 (RS-P2 to RS-P18), 12 from Hitavi F_1 (RS-H19 to RS-H30), and 6 from Mustang F_1 (RS-M31 to RS-M37). The lines were categorized by fruit type: Provita has small globes with green and white spots, Hitavi has tubular green fruit, and Mustang has tubular purple fruit. The experiment was conducted at the Leuwikopo Experimental Station, Department of Agronomy and Horticulture, Faculty of Agriculture, IPB University, Bogor, Indonesia, at an altitude of 250 m above sea level, with a maximum temperature of 34 °C and a minimum temperature of 20 °C during the wet season in 2024.

Seed sowing was performed in trays with planting media mixed with a fungicide (20:1) to prevent soil-borne diseases. An AB mix solution (10 g l^{-1}) was applied, starting 14 days after sowing and every 3 days until transplanting. Seedlings with 3 to 4 fully open leaves (25 days after sowing) were selected for use.

Experimental design and planting

The experiment was arranged in a randomized complete block design, with one factor: genotype (35 DH eggplant lines and three hybrid varieties). The experiment was repeated thrice, resulting in 114 units, each consisting of a 1.5 m^2 bed containing five plants.

Eggplants were cultivated according to the standard operational procedures of the Ministry of Agriculture (Ministry of Agriculture, 2009). Green manure was applied at 1 kg m^{-2} before tillage, with beds 0.5 m wide, 3 m long, 30 cm high, spaced 50 cm apart, and covered with silver-black plastic mulch. The planting holes had an in-row spacing of 60 cm between rows (Gurung et al., 2018; Rasheed and Shareef, 2019). Replanting occurred 7 days after planting (DAP). Maintenance included regular watering, weekly fertilization with NPK 16-16-16 (10 g l^{-1}, 250 ml $plant^{-1}$), weeding, and pesticide application, as needed according to the recommended dosage.

Bamboo stakes were installed when the plants were 3 weeks old and spaced 5 to 7 cm apart. Harvesting was performed every 7 to 10 days, 8 times, by cutting the fruit stalk at the base. Optimum harvest criteria (IBPGR, 1990) included the distribution of fruit skin color at horticultural maturity and quantitative traits. The fruit length and diameter of the Provita-derived DH lines were approximately 5 and 3 cm, respectively. For the Hitavi and Mustang-derived DH lines, the fruit length ranged from 10 to over 20 cm, with a diameter of approximately 5 cm.

Observations were made on morpho-agronomic characters, including fruit yield. Plant height (cm) was measured from ground level to the highest growing point, dichotomous height (cm) was measured from ground level to the main branching point, and stem diameter (mm) was measured at a point 5 cm above ground level. These parameters were recorded at the beginning of the generative stage. Days of flowering (DAP) were calculated from transplanting to 50% of the flowering population, and days of harvesting (DAP) were calculated from transplanting until 50% of the plants were harvested. Fruit length (cm) was measured from the petal base to the fruit tip, fruit diameter (cm) at its widest point, and weight per fruit (g) as the total fruit weight per plant divided by the number of fruits per plant. The number of fruits and yield per plant (kg) were calculated up to 8 harvests.

Statistical analysis

Analysis of variance (ANOVA) and post hoc tests (t-Dunnett and Tukey-Kramer at 5% level) were conducted using SAS on Demand for Academics. Pearson's correlation was analyzed with R. The environmental, genotypic, and phenotypic variation, genotypic coefficient of variation, and heritability were estimated using Formulas 1 to 5 (Burton and DeVane, 1953).

$$\sigma^2{}_e = MS_e \quad (1)$$

$$\sigma^2{}_g = \frac{MS_g - MS_e}{r} \quad (2)$$

$$\sigma^2{}_p = \sigma^2{}_g + \frac{\sigma^2{}_e}{r} \quad (3)$$

$$CGV = \frac{\sqrt{\sigma^2{}_g}}{\bar{x}} \times 100\% \quad (4)$$

$$h^2{}_{bs} = \frac{\sigma^2{}_g}{\sigma^2{}_p} \quad (5)$$

Where, $\sigma^2{}_e$ = Environmental variance; $\sigma^2{}_g$ = Genotypic variance; $\sigma^2{}_p$ = Phenotypic variance; MS_e = Mean square error; MS_g = Mean square genotype; r = Number of replications; $\bar{x}$ = The mean value across all genotypes; CGV =

Genotypic coefficient of variation; h^2_{bs} = Broad-sense heritability.

Lines were selected based on a weighted selection index (Falconer and Mackay, 1996).

RESULTS AND DISCUSSION

Morpho-agronomic performance of anther culture-derived DH eggplant lines

This study revealed coefficients of variation (CV) for all characters below 30%, ranging from 5.01 to 23.33% (Table 1). The experimental design used in this study effectively minimized the influence of environmental errors, as indicated by an average below 30% CV for all variables. A low CV value ensured high accuracy in the data obtained during the experiment (Gomez and Gomez, 1984).

Table 1 shows the variation in the observed characters in the population and between the average progeny of each hybrid parent. This variation was caused by the segregation of microspores from anther donor plants. Segregation resulted in high phenotypic variation within the DH line population (Starosta et al., 2023). Variation was observed in all measured traits of Provita F_1-derived DH lines, except for fruit length. The Hitavi F_1-derived DH lines demonstrated variation in nearly all traits, including plant height, harvest age, and fruit number. The Mustang F_1-derived DH lines varied in days to flowering and fruit diameter. The variation indicated the presence of genetic variation. These genetic variations suggest that the F_1 commercial hybrids' parents for creating DH lines may have significantly different genetic backgrounds. These results align with previous studies, which reported significant genetic variation in vegetative traits related to leaves, flowers, and fruits and reproductive traits related to fruit and seed setting or germination rate (Rivas-Sendra et al., 2017). Genetic divergence offers significant advantages for breeding programs as it enhances the potential to identify new and beneficial traits (Swarup et al., 2021; Sanchez et al., 2023).

ANOVA indicated significant trait variation among the average DH lines derived from each parental F_1 hybrid. A post hoc test was performed to analyze these differences in more detail. Based on the Tukey-Kramer grouping at a 5% significance level presented in Table 2, the DH lines derived from Provita F_1 exhibited faster days to flowering, smaller fruit yields per plant, and a higher number of fruits than those derived from Hitavi F_1 and Mustang F_1. As indicated by the shortest number of days to attain 50% and 100% flowering, the high flowering rate provides sufficient time for plants to form many fruits (Onyia et al., 2020).

The results of the post hoc Dunnett test presented in Table 3 indicate that the DH lines derived from Provita F_1 exhibited fruit yields per plant that were not significantly different from those of their parent. This suggested that their performance was similar to that of the hybrid, except for RS10, which showed significantly lower yields than its parent. Similarly, lines RS19, RS23, and RS27 demonstrated fruit yields per plant that were not significantly different from those of their parent, Hitavi F_1. The fruit yield per plant showed no significant difference compared to its parents in all DH lines derived from the Mustang F_1. The pure lines that did not differ significantly from their parents demonstrated performance comparable to that of the hybrid. Therefore, these lines were considered potential pure lines with a high yield performance. According to Rajan et al. (2023), pure line

Table 1. ANOVA of anther culture-derived DH eggplant lines from three different parents

Source of variation	df	PH	DH	SD	DF	DHV	FL	FD	WF	NF	FYP
Replication	2	**	ns	**	ns	ns	ns	ns	**	ns	**
Genotype (Lines)	37	**	**	**	**	**	**	**	**	**	**
Average progeny	2	**	**	**	**	ns	**	*	**	**	**
Lines/Parent P	17	*	**	**	**	**	**	**	**	**	**
Lines/Parent H	12	ns	*	**	**	ns	**	**	*	**	**
Lines/Parent M	6	ns	ns	ns	*	ns	ns	*	ns	ns	ns
Coefficient of variation (%)		9.20	9.98	5.90	5.01	5.17	8.97	4.77	13.13	23.33	23.09

Note: **Very significant at 1% levels of F-test, *Significance at 5% levels of F-test, df = Degree of freedom, Average progeny = Average DH lines from each parent, Lines/Parent P = Provita F_1-derived DH lines, Lines/Parent H = Hitavi F_1-derived DH lines, Lines/Parent M = Mustang F_1-derived DH lines. PH = Plant height (cm), DH = Dichotomous height (cm), SD = Stem diameter (mm), DF = Days to flowering (DAP), DHV = Days to harvesting (DAP), FL = Fruit length (cm), FD = Fruit diameter (mm), WF = Weight per fruit (g), NF = Number of fruits, FYP = Fruit yield per plant (kg), DAP = Days after planting

Table 2. Means progeny from each F1-derived DH line

Characters	Lines/Parent P	Lines/Parent H	Lines/Parent M
PH	56.79[c]	86.26[a]	81.82[b]
DH	15.78[c]	23.22[b]	27.48[a]
SD	10.21[b]	14.24[a]	14.21[a]
DF	27.65[c]	35.59[b]	37.85[a]
DHV	53.13	52.24	53.58
FL	4.26[b]	19.67[a]	19.69[a]
FD	42.85[ab]	42.42[b]	43.96[a]
WF	33.88[b]	122.65[a]	123.72[a]
NF	32.41[a]	13.15[b]	12.71[b]
FYP	0.99[b]	1.61[a]	1.51[a]

Note: Tukey-Kramer grouping is at 5% between the average progeny. Rows with the same letters are not significantly different. Lines/Parent P = Provita F_1-derived DH lines, Lines/Parent H = Hitavi F_1-derived DH lines, Lines/Parent M = Mustang F_1-derived DH lines. PH = Plant height (cm), DH = Dichotomous height (cm), SD = Stem diameter (mm), DF = Days to flowering (DAP), DHV = Days to harvesting (DAP), FL = Fruit Length (cm), FD = Fruit diameter (mm), WF = Weight per fruit (g), NF = Number of fruits, FYP = Fruit yield per plant (kg), DAP = Days after planting

selection in the context of forming inbred or hybrid cultivars is necessary because genetic variation from DH lines is a valuable source of variability in developing new cultivars.

Variance component and heritability (h^2) of DH eggplant lines

In plant breeding, desirable traits are selected based on breeding objectives, which are generally determined by evaluating individual plants. The selected plants are expected to have better traits than the existing ones. The phenotypic traits used for selecting individual plants are still influenced by the environment, which makes it difficult to assess the genotype (Sawadogo et al., 2016). The determination of selection criteria is better assisted by h^2, genotypic coefficient variation, and correlation of a character with yield (Alsabah et al., 2019; Tirtana et al., 2021). Fruit yield is the main trait in the selection process of eggplant plants (Saleh et al., 2019).

Table 4 presents the h^2 estimates. The h^2 values according to Stansfield (1983) were grouped as high (50% < h^2 < 100%), medium (20% < h^2 < 50%), and low (h^2 < 20%). In the present study, all the observed characters had high h^2 values. DH plants have high homozygosity for every locus in the genome, eliminating the action of dominant genes and influencing traits (Seymour et al., 2012), resulting in highly heritable traits. High h^2 indicates that genetic factors contribute more to these traits than environmental factors, and vice versa (Singh et al., 2019). In conventional breeding, characters with high h^2 are better selected at the beginning of the generation to increase the efficiency of the selection process. Characters with moderate or low h^2 can be selected for further generations to ensure they are present in the selected lines (Nuraeni et al., 2021; Lestari et al., 2023).

The GCV values were categorized as low (0 to 10%), medium (10 to 20%), and high (> 20%) (Uddin et al., 2021). In the present study, only the days to harvesting and fruit diameter had a low GCV (Table 4). However, a high GCV in other characters indicated that the variation in characters between individuals in the observed population was high and that the frequency of existing genes was higher. Thus, the opportunity to obtain new traits desired for selection is greater (Sudeepthi et al., 2020). Conversely, the days to harvesting and fruit diameter traits had low GCV values, indicating that the observed population tended to be uniform among individuals. According to Faysal et al. (2022), the selection process will not be effective when the variation is low, and traits with low GCV will only have a slight possibility for improvement. As a result of the criteria outlined, the traits of days to harvest and fruit diameter were not included in the weighted selection index for identifying potential DH lines, despite exhibiting high heritability values.

Correlations of fruit yield performance and other characters

The results of the correlation test indicated a significant and positive relationship between fruit yield per plant and various factors, such as plant height, dichotomous height, stem diameter, days to flowering, fruit length, and weight per fruit, while showing a negative relationship with the number of fruits per plant (Figure 1). The principal focus in evaluating yield performance is the traits directly correlated to yield performance.

According to Kumar et al. (2024), fruit yield per plant was positively correlated with days to first fruit harvest, number of primary branches per plant, pedicle length, number of fruits per plant, and fruit weight, but negatively correlated with plant height. According to Damnjanović et al. (2022), fruit yield positively correlates with the number of fruits per plant. Weight per fruit, number of fruits per plant, plant height, flowering age, and number of branches according to Onyia et al. (2020) positively affected the fruit yield

Table 3. Mean of morpho-agronomic characters of anther culture-derived DH eggplant lines

Lines	PH	DH	SD	DF	DHV	FL	FD	WF	NF	FYP
RS-P2	54.69	15.03	10.25	26.6	46.5	4.63	45.68	40.25	34.4	1.25
RS-P3	53.41	13.98	11.09	26.3	52.7	3.82	43.28	31.09	33.8	1.03
RS-P4	48.69	12.61^{p}	9.17^{p}	27.0	53.4	4.43	43.82	36.21	34.6	1.14
RS-P5	49.77	13.69	9.87	26.5	55.3	3.95	40.23	27.96	29.7	0.84
RS-P6	61.43	16.75	10.57	27.6	54.4	4.18	43.29	33.61	34.5	1.09
RS-P7	55.94	14.17	9.47	26.7	52.5	4.40	44.30	38.92	28.8	1.03
RS-P8	56.34	14.79	9.79	27.4	51.1	4.59	45.29	39.67	26.0^{p}	0.97
RS-P9	55.21	14.44	10.01	28.3	55.0	3.88	40.22	27.07	43.4	1.15
RS-P10	72.30	24.93^{p}	14.73^{p}	30.0	48.2	6.03	49.41^{p}	49.81	4.1^{p}	0.27^{p}
RS-P11	51.23	15.04	9.67	30.3	54.4	4.31	42.29	30.13	35.0	1.00
RS-P12	66.16	14.88	9.07^{p}	28.7	55.0	3.81	39.27	26.46	31.6	0.79
RS-P13	53.79	17.70	9.55	29.1	52.9	4.18	42.01	31.81	28.6	0.88
RS-P14	55.99	16.09	9.81	29.3	54.9	4.12	43.65	32.43	41.5	1.25
RS-P15	55.48	13.38	10.38	26.2	55.7	3.70	37.13^{p}	21.87	41.0	0.87
RS-P16	60.95	15.05	9.60	26.0	55.0	3.49	39.79	24.58	35.7	0.86
RS-P17	54.08	16.75	9.67	26.1	55.4	4.08	43.75	49.08	24.8^{p}	0.98
RS-P18	58.37	16.94	10.06	29.0	52.0	4.60	43.89	35.28	36.2	1.09
RS-H19	86.05	21.76	15.36	29.0^{h}	50.2	18.10^{h}	45.83	133.86	14.6	2.08
RS-H20	87.51	21.45	14.58	36.0	52.3	20.58	44.56	142.16	11.1	1.59^{h}
RS-H21	81.04	25.49	13.64	38.7	54.4	18.93	36.90^{h}	104.21	14.2	1.55^{h}
RS-H22	82.17	24.16	13.83	30.6^{h}	48.4	19.05	43.63	123.71	11.1	1.32^{h}
RS-H23	89.04	24.68	14.17	37.0	52.0	19.50	44.95	128.48	14.7	1.80
RS-H24	88.44	25.79	14.49	37.3	52.0	18.08^{h}	41.46	111.00	12.1	1.26^{h}
RS-H25	84.49	23.62	13.54	38.4	55.3	16.99^{h}	43.05	116.86	8.6	0.97^{h}
RS-H26	88.87	24.16	15.49	38.1	54.4	22.54	37.83	116.52	12.5	1.42^{h}
RS-H27	82.51	21.75	12.83^{h}	36.2	53.1	19.80	44.69	131.04	15.0	2.04
RS-H28	85.07	20.41	14.18	36.8	50.7	20.41	44.79	132.18	12.7	1.61^{h}
RS-H29	86.80	24.41	14.72	40.1^{h}	51.3	21.86	36.89^{h}	108.38	11.9	1.36^{h}
RS-H30	85.01	20.17	13.57	29.2^{h}	52.0	18.85	44.96	122.50	12.8	1.54^{h}
RS-M31	74.46	25.13	13.60	38.6	52.8	20.99	43.45	133.42	12.0	1.52
RS-M32	81.41	27.48	13.99	38.3	52.8	20.07	41.37	123.36	12.6	1.49
RS-M33	84.74	28.26	14.07	38.0	51.7	18.81^{m}	41.99	109.51	11.3	1.33
RS-M34	88.17	29.08	14.48	39.2	55.0	21.34	43.33	122.70	14.2	1.71
RS-M36	78.81	27.93	15.07	35.3	57.3	17.82^{m}	46.72	130.77	8.3	1.05
RS-M37	87.53	25.83	14.13	37.8	51.3	17.35^{m}	46.85	122.83	17.5	1.99
P F_1	58.47	17.75	11.04	26.8	52.0	4.44	44.00	33.65	39.5	1.31
H F_1	94.34	24.03	14.76	35.3	53.2	20.96	41.95	123.51	19.3	2.39
M F_1	77.62	28.66	14.12	37.9	54.3	21.45	44.02	123.46	13.0	1.45

Note: Post hoc using t-Dunnett significance at 5%. p = Significantly different from Provita F_1, h = Significantly different from Hitavi F_1, and m = Significantly different from Mustang F_1. PH = Plant height (cm), DH = Dichotomous height (cm), SD = Stem diameter (mm), DF = Days to flowering (DAP), DHV = Days to harvesting (DAP), FL = Fruit length (cm), FD = Fruit diameter (mm), WF = Weight per fruit (g), NF = Number of fruits, FYP = Fruit yield per plant (kg), DAP = Days after planting. RS2 to RS18 were 17 DH lines derived from Provita F_1, RS19 to RS30 were 12 DH lines derived from Hitavi F_1, and RS31 to RS37 were six DH lines derived from Mustang F_1

Table 4. Estimation of variance component, h², and coefficient of genetic variation of anther culture-derived DH eggplant lines

Characters	σ^2_p	σ^2_e	σ^2_g	h^2_{bs} (%)	GCV (%)	$2\sigma_{\sigma^2_g}$
PH	330.499	45.159	315.446	95.445	24.85	102.180
DH	40.672	4.178	39.279	96.576	30.60	12.499
SD	7.541	0.529	7.364	97.660	22.01	2.304
DF	38.079	2.613	37.208	97.713	18.92	11.632
DHV	6.401	7.477	3.909	61.064	3.74	2.447
FL	93.215	1.231	92.805	99.560	77.86	28.208
FD	11.350	4.180	9.956	87.723	7.35	3.665
WF	3,146.380	112.619	3,108.840	98.807	69.01	955.765
NF	198.502	26.797	189.570	95.500	62.06	61.353
FWP	0.248	0.089	0.218	87.991	36.06	0.080

Note: σ^2_p = Phenotypic variation, σ^2_g = Genotype variation, σ^2_e = Environmental variation, h^2_{bs} = Broad-sense heritability, GCV = Genetic coefficient of variation, $2\sigma_{\sigma^2_g}$ = 2 times the standard deviation of genotypic variance. PH = Plant height (cm), DH = Dichotomous height (cm), SD = Stem diameter (mm), DF = Days to flowering (DAP), DHV = Days to harvesting (DAP), FL = Fruit length (cm), FD = Fruit diameter (mm), WF = Weight per fruit (g), NF = Number of fruits, FYP = Fruit yield per plant (kg), DAP = Days after planting

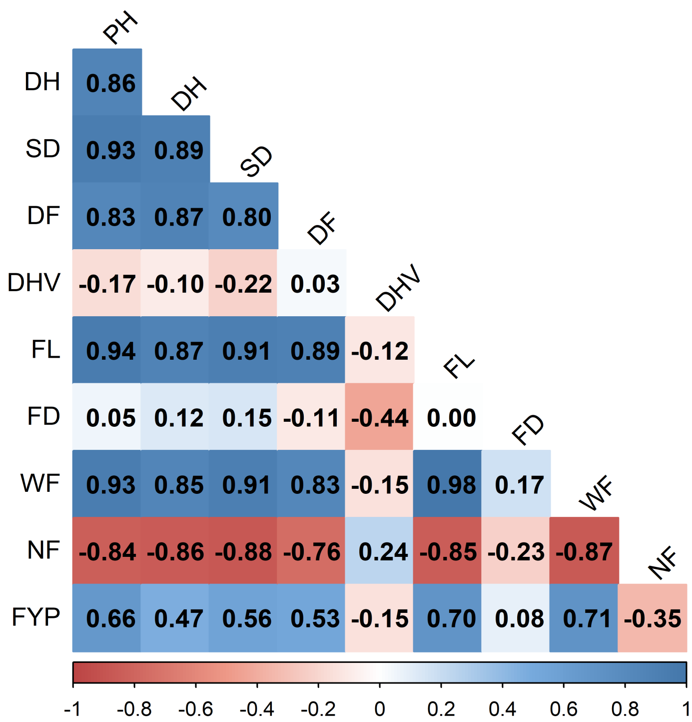

Figure 1. Phenotypic correlation coefficient between morpho-agronomic characters of anther culture-derived DH eggplant lines

Note: PH = Plant height (cm), DH = Dichotomous height (cm), SD = Stem diameter (mm), DF = Days to flowering (DAP), DHV = Days to harvesting (DAP), FL = Fruit length (cm), FD = Fruit diameter (mm), WF = Weight per fruit (g), NF = Number of fruits, FYP = Fruit yield per plant (kg), DAP = Days after planting

per plant. This study showed different results from the previous studies on conventional breeding mentioned above, related to the contrasting correlations between fruit yield per plant and the number of fruits. This may be because of the source-sink trade-offs, where the energy is partitioned toward more fruits, and individual fruit size may decline, and vice versa (Dwivedi et al., 2021; Mathan et al., 2021; Velu et al., 2025).

In contrast, conventional breeding may favor genotypes that optimize both traits over multiple generations and undergo recombination over generations. In DH lines, homozygous alleles can disrupt these interactions, potentially unmasking source-sink trade-offs (Dwivedi et al., 2024).

Correlation provides a measure of the genetic association between characters and reveals characters that may be useful as an index of selection (Kumar et al., 2024). Therefore, selection for increasing plant height, dichotomous height, stem diameter, days of flowering, and weight per fruit will increase the fruit yield per plant.

Selection index

The DH line selection using the weighted selection index model is presented in Table 5. Plant height, dichotomous height, stem diameter,

Table 5. Weighted selection index of 35 anther culture-derived DH eggplant lines and three check varieties

Lines	Z-value of							Weighted index
	PH (1)	DH (1)	SD (1)	DF (-2)	WF (2)	NF (4)	FYP (6)	
RS-H19 H	2.22	0.63	4.16	-2.01	5.00	-1.46	2.62	30.92
RS-M37 M	2.44	2.62	2.48	3.40	3.96	-0.91	2.33	19.01
RS-H27 H	1.68	0.62	0.69	2.43	4.73	-1.38	2.48	16.93
RS-H23 H	2.67	2.05	2.54	2.93	4.49	-1.45	1.70	14.77
RS-H30 H	2.06	-0.15	1.71	-1.87	3.93	-1.81	0.80	12.79
RS-M34 M	2.54	4.21	2.95	4.28	3.95	-1.55	1.37	11.05
RS-H20 H	2.44	0.47	3.10	2.31	5.78	-2.13	0.97	10.23
RS-H22	1.62	1.80	2.06	-1.05	4.04	-2.14	0.08	7.60
RS-H28	2.07	-0.03	2.55	2.82	4.84	-1.83	1.03	7.51
RS-M32 M	1.51	3.42	2.29	3.76	4.01	-1.85	0.66	4.29
RS-H26	2.64	1.80	4.34	3.60	3.37	-1.86	0.40	3.26
RS-M31 M	0.45	2.27	1.75	3.93	4.96	-1.97	0.75	3.20
RS-H21	1.45	2.45	1.80	3.99	2.21	-1.54	0.85	1.08
RS-P14 P	-2.36	-2.15	-3.46	-1.80	-4.56	3.73	-0.16	0.52
RS-P2 P	-2.55	-2.66	-2.86	-3.52	-3.82	2.36	-0.15	-0.14
RS-P9 P	-2.47	-2.96	-3.18	-2.46	-5.06	4.09	-0.50	-0.45
RS-H24	2.58	2.60	2.98	3.15	2.85	-1.94	-0.13	-0.97
RS-M33 M	2.02	3.81	2.39	3.53	2.71	-2.10	0.12	-1.10
RS-M36	1.11	3.65	3.77	1.91	4.71	-2.69	-0.82	-1.57
RS-P6 P	-1.53	-1.83	-2.41	-2.87	-4.45	2.37	-0.68	-3.49
RS-H29	2.33	1.92	3.29	4.88	2.60	-1.99	0.23	-3.64
RS-P18 P	-1.99	-1.73	-3.11	-2.01	-4.29	2.72	-0.69	-4.68
RS-P3	-2.75	-3.18	-1.70	-3.71	-4.68	2.25	-0.89	-5.89
RS-P15	-2.43	-3.47	-2.68	-3.74	-5.55	3.63	-1.42	-6.19
RS-P4	-3.47	-3.85	-4.33	-3.23	-4.20	2.40	-0.52	-7.11
RS-P16	-1.60	-2.66	-3.75	-3.86	-5.30	2.62	-1.47	-9.22
RS-P7	-2.36	-3.09	-3.92	-3.45	-3.95	1.28	-0.89	-10.57
RS-P17	-2.65	-1.82	-3.66	-3.80	-2.99	0.51	-1.07	-10.88
RS-P11	-3.08	-2.66	-3.66	-1.18	-4.77	2.48	-1.00	-12.67
RS-H25	1.98	1.54	1.67	3.81	3.40	-2.62	-1.09	-12.69
RS-P8	-2.30	-2.78	-3.49	-3.03	-3.88	0.74	-1.08	-13.82
RS-P5	-3.30	-3.32	-3.37	-3.57	-4.98	1.45	-1.52	-16.13
RS-P13	-2.69	-1.36	-3.82	-1.97	-4.62	1.24	-1.40	-16.59
RS-P12	-0.81	-2.74	-4.47	-2.21	-5.12	1.82	-1.68	-16.60
RS-P10	0.12	2.18	3.31	-1.39	-2.92	-3.50	-3.43	-32.04
P F_1	-1.98	-1.33	-1.77	-3.37	-4.44	3.35	0.03	6.36
H F_1	3.48	1.73	3.35	1.91	4.02	-0.55	3.65	32.46
M F_1	0.93	4.00	2.46	3.48	4.02	-1.77	0.51	4.49

Note: Selected lines marked by P = Provita F_1-derived lines, H = Hitavi F_1-derived lines, and M = Mustang F_1-derived lines. PH = Plant height, DH = Dichotomous height, SD = Stem diameter, DF = Days of flowering (DAP), WF = Weight per fruit (g), NF = Number of fruits, FYP = Fruit yield per plant (kg), DAP = Days after planting

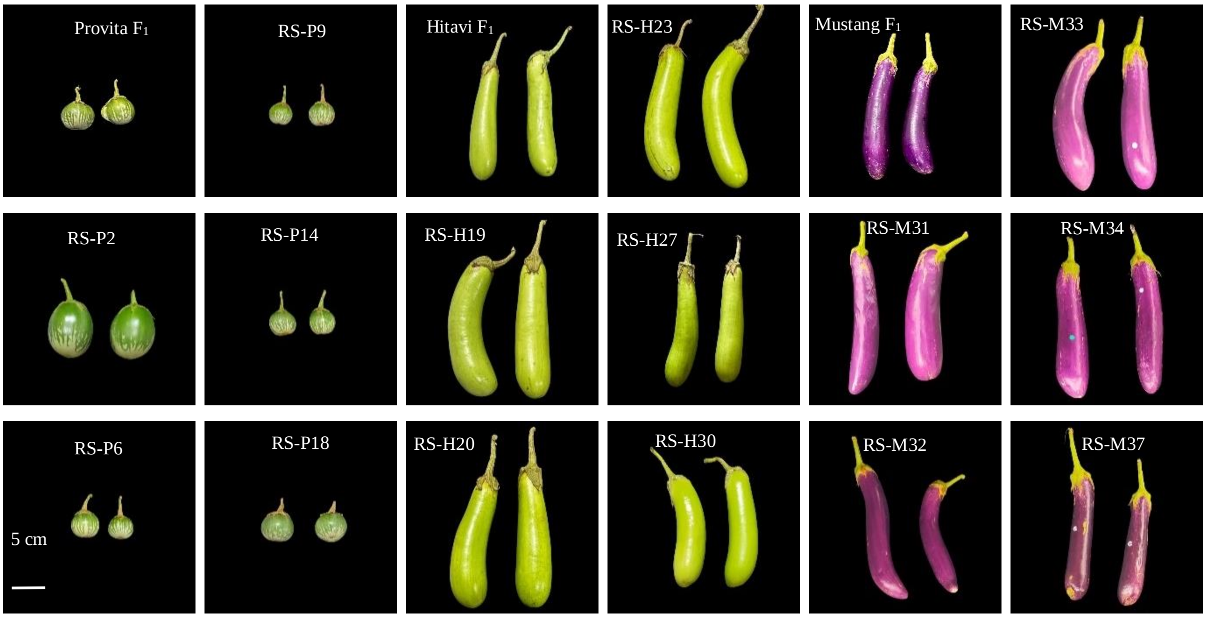

Figure 2. Selected DH lines of eggplant and the parent

Note: RS-P2, RS-P6, RS-P9, RS-P14, and RS-P18 were Provita F_1 derived-lines, RS-H19, RS-H20, RS-H23, RS-H27, and RS-H30 were Hitavi F_1 derived-lines, RS-M31, RS-M32, RS-M33, RS-M34, and RS-M37 were Mustang F_1 derived-lines

days of flowering, and weight per fruit were chosen after considering h^2, GCV, and the results of correlation analysis with the determined breeding direction to increase the fruit yield of eggplant. The number of fruits per plant trait, even though it had a negative correlation with fruit yield, was chosen because potential DH lines were selected based on each type of fruit-derived DH line. Furthermore, DH lines will be selected based on high plant height and dichotomous, large stem diameter, early flowering age, significant weight per fruit, and a large number of fruits, to increase fruit yield per plant. Therefore, all the selected characters were given a positive weight coefficient, except for days to flowering, because the potential DH lines were directed to have early flowering. The values of the weight coefficients 6, 4, and 2 were determined based on fruit yield as the primary trait, followed by yield components (weight and number of fruit) and other additional traits (plant height, dichotomous height, and stem diameter), following the breeding direction. The selection results listed in Table 5 and Figure 2 show the five DH lines from each hybrid parent: RS-P2, RS-P6, RS-P9, RS-P14, RS-P18, RS-H19, RS-H20, RS-H23, RS-H27, RS-H30, RS-M31, RS-M32, RS-M33, RS-M34, and RS-M37. The selected lines had phenotypic traits matching the previously mentioned breeding directions. The selected lines with high yield and good quality fruit (Figure 2), similar to the commercial hybrid parent, were Hitavi's derived lines.

CONCLUSIONS

High variation was observed in the populations of DH eggplant lines. DH lines exhibit a high heritability range of 61.06 to 99.56% and a GCV range of 3.74 to 77.86%, enabling more effective eggplant breeding programs. The selected DH lines with high yield performance and the desired agronomic traits according to the breeding objectives were RS-P2, RS-P6, RS-P9, RS-P14, RS-P18, RS-H19, RS-H20, RS-H23, RS-H27, RS-H30, RS-M31, RS-M32, RS-M33, RS-M34, and RS-M37. The selected Hitavi's derived lines showed a high yield with good-quality fruit, similar to its commercial F_1 hybrid. The selected lines were further evaluated to determine their yield performance and stability.

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