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GENETIC VARIABILITY, CHARACTERS ASSOCIATION, AND PATH ANALYSIS IN SWEET-WAXY CORN

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SUMMARY

Sweet-waxy corn (*Zea mays* ceratina. L.) is one of the most widely consumed foods in Eastern Indonesia. Improving the productivity and quality of waxy corn by developing hybrid sweet-waxy corn with desirable traits directly affecting grain yield is crucial. The presented study aimed to determine the genetic variability and heritability and the traits with direct and indirect effects on the grain yield in sweet-waxy corn, conducted in 2023 at the Pasir Kuda Experimental Farm, IPB University, Bogor, Indonesia. Seventeen sweet-waxy corn hybrids' planting used a randomized complete block design with three replicates. Analysis of variance, genetic parameter estimation, correlation, and path analysis assessed data in this study. The results showed ear diameter (63.85%), ear length (66.31%), and ear weight without husk (76.78%) had a higher heritability. The values for the phenotypic and genotypic coefficient of variation were moderate-high (11.09%–33.08%). The traits, ear diameter, ear length, and kernels per row had a significant positive correlation and positive direct effects on ear weight. In addition, plant height, ear height, and the number of leaves had a strong indirect effect on the ear weight without husk, which could serve as selection criteria.

Keywords: Correlation, genetic variability, heritability, indirect effects, path analysis, and sweet-waxy corn

Key findings: The traits, ear diameter, ear length, and kernels per row have a considerable positive correlation and the highest direct effects on the ear weight without husk in sweet-waxy corn (*Z. mays* ceratina. L.). These traits could benefit as selection criteria to enhance the grain yield in sweet-waxy corn.

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INTRODUCTION

Maize is a widely used alternative staple to rice. Based on its types, corn classification can serve as flour, dent, flint, sweet, pod, waxy, and popcorn (Meena *et al*., 2023). Waxy corn (*Zea mays* ceratina. L) contained 97% amylopectin and 0%–7% amylose, whereas regular corn contained a mixture of 72% amylopectin and 28% amylose (Edy and Ibrahim, 2016). Waxy corn has a homozygous *wx* recessive gene (*wxwx*) affecting its chemical composition, especially the starch, which gives a savory taste (Edy *et al*., 2019).

The waxy corn's first discovery and cultivation happened in China in 1909. Later, the waxy corn's spread, development, and consumption continued in the communities living in Asian countries, including Indonesia (Ozata, 2020). The harvest of waxy corn can be best during the milky stage and fresh stage, with its consumption can be in the form of stew because it has a delicious and nutritious taste (Ketthaisong *et al*., 2013). Processing of the physiologically mature waxy corn can take the form of dry corn kernels ('marning'), flavored corn chips ('emping'), and grits ('bassang') products (Suarni *et al*., 2019). Waxy corn has the potential to support Indonesia's food diversification program.

The waxy corn demand as a food source has not gained significance because of its bland taste and low productivity in Indonesia. Waxy corn plantation is much less than sweet corn in Indonesia, especially in Western Indonesia, such as Java and Sumatra. Waxy corn cultivation and consumption is predominant in Eastern Indonesia, especially in Sulawesi, Maluku, and Nusa Tenggara (Fowo *et al*., 2019). According to Suarni *et al*. (2019), waxy corn production remains relatively low and hardly reaches 2 t ha^{-1} in Indonesia. The cultivation of the local waxy corn genotypes may have caused low productivity. For reducing dependency on rice and for food diversification, improvement in productivity and quality of waxy corn through the assembly of hybrid cultivars is crucial in Indonesia.

The assembly of sweet-waxy corn cultivars can proceed by combining waxy, sweet, and super sweet corns. These three maize types have different single recessive genes controlling them, i.e., the waxy gene (*wx*) for waxy corn, the sugar gene (*su*) for sweet corn, and the shrunken-2 gene (sh_2) for super sweet corn (Simla *et al*., 2016). Therefore, if these three gene traits exist in one genotype, it is possible to produce maize cultivars with a mixture of soft, sticky texture and sweet flavor. This could enhance the consumption of sweet-waxy corn because consumers prefer corn with a balanced flavor, texture, and aroma (Dermail *et al*., 2022). In addition, the hybrid cultivars can significantly increase the productivity of sweet-waxy corn in Indonesia.

The appropriate selection characteristics can further improve the efficiency of plant cultivar assembly. A better selection of characters generally has a broad genetic variability, correlation, and strong direct effects on the yield-related traits. The selection of characters with broad genetic variability proved effective in increasing the genetic potential of the genotypes (Belay, 2018). The higher heritability indicates the estimated genetic variability is quite high. Therefore, heritability plays an important role by providing information about the extent characters have better inheritance by their offspring (Taneva *et al*., 2019).

Correlation analysis helps determine the relationship between the characters and predicts the pattern of relationship between the agronomic and yield-related traits useful for improvement in plant breeding (Tiwari *et al*., 2019). Generally, correlation analysis cannot predict effective selection criteria with precision. Therefore, the path analysis with direct and indirect effects can remove the hindrances through valuable selection. The presented study aimed to obtain information on genetic variability and heritability and determine the traits with direct and indirect effects on ear weight without husk in sweet-waxy corn.

MATERIALS AND METHODS

Experimental site and breeding material

The study on sweet-waxy corn commenced in 2023 at the Pasir Kuda Experimental Farm, IPB University, Bogor, Indonesia (with an altitude of 263 masl 6°36’36.4” S; 106°47’04.1” E). The genetic material for the 14 candidate hybrids of sweet-waxy corn came from the Plant Breeding Laboratory of the IPB University in Bogor, Indonesia. The hybrid parents utilized in this study comprised females originating from the Sulawesi region of Indonesia (JP and JPS codes) and male elders from Thailand (JPM codes). Additionally, the study used three varieties from Indonesian companies included Agri Makmur Pertiwi (Arumba), East West Seed (Kumala), and Cap Kapal Terbang (Srikandi). Details about the genetic material utilized in the study are available in Table 1. The experiment layout had a randomized complete block design (RCBD) with three replications.

Field activities and data collection

The planting distance was 75 cm between rows and 20 cm within rows. Planting each genotype occurred in one row with a length of 4 m, resulting in 20 plants per row. The first fertilization transpired seven days after planting (DAP) using urea fertilizer at 150 kg ha^{-1}, SP-36 at 200 kg ha^{-1}, and KCL at the rate of 200 kg ha^{-1}. The second fertilization at 35 DAP had the rate of 100 kg N ha^{-1}. Crop maintenance activities, including watering, weed control, and pest and disease control, continued as per the recommendations. Sweet-waxy corn harvesting ensued when the corn ears were young.

After the milk stage, 10 plants’ random selection appeared for each genotype. The data recording on traits included plant and ear height, stem diameter**,** leaf width and length, number of leaves, days to anthesis, days to silking, ear weight without husk, kernel rows per ear**,** kernels per row, ear diameter and length, and days to maturity.

Data analysis

Analysis of variance (ANOVA) for all the recorded data proceeded, with the means further compared with a 5% level of probability, using Tukey's test PKBT STAT 3.1 (http://pbstat.com/pkbt-stat/). The genotypic and phenotypic coefficient of variations followed the method by Johnson *et al.* (1955). Calculating broad-sense heritability applied the method of Stansfield (1991). Pearson correlation and path analysis with direct and indirect effects also progressed using RStudio (R version 4.1.2), following the methodology described by Singh and Chaudhary (1979).

Table 1. Breeding material of the sweet-waxy corn used in the study.

Code	Genotypes	Source
G1	JPS-13-6-1P-10 × JPM-1-6P-7	IPB University Hybrid
G2	JPS-13-16-12-7 × JPM-1-6P-7	IPB University Hybrid
G3	JPS-53-10P-15 × JPM-1-2P-3	IPB University Hybrid
G4	JPS-13-16-12-12 × JPM-1-2P-3	IPB University Hybrid
G5	JPS-30-2-15-8 × JPM-1-2P-3	IPB University Hybrid
G6	JPS-13-16-12-12 × JPM-1-6P-3	IPB University Hybrid
G7	JPS-13-6-1P-15 × JPM-1-6P-7	IPB University Hybrid
G8	JPS-13-6-1K-1 × JPM-1-2P-3	IPB University Hybrid
G9	JPS-13-6-1K-1 × JPM-1-2P-6	IPB University Hybrid
G10	JPS-30-21-5-8 × JPM-1-6P-7	IPB University Hybrid
G11	JPS-13-16-12-7 × JPM-1-6P-4	IPB University Hybrid
G12	JPS-13-6-1P-15 × JPM-1-6P-4	IPB University Hybrid
G13	JPS-53-10P-15 × JPM-1-2P-6	IPB University Hybrid
G14	JPS-13-16-12-7 × JPM-1-2P-3	IPB University Hybrid
G15	Arumba	Commercial hybrid
G16	Kumala	Commercial hybrid
G17	Srikandi	Commercial hybrid

Table 2. Analysis of variance for various traits in sweet-waxy corn.

Characters	Mean Squares			CV (%)
	Replications	Genotypes	Error	
Days to anthesis	31.18	21.90^{ns}	16.23	7.55
Days to silking	35.31	17.59^{ns}	16.95	7.64
Plant height (cm)	1,841.39	1796.48**	131.24	5.85
Ear height (cm)	1,923.03	1410.12**	37.82	6.39
Stem diameter (mm)	0.15	0.07**	0.01	5.92
Leaf width (cm)	2.63	0.84**	0.13	4.42
Leaf length (cm)	0.53	69.93**	6.86	2.76
Number of leaves	1.92	3.26**	0.48	6.49
Days to maturity	39.94	8.59**	2.42	2.14
Kernel rows per ear	2.36	2.67**	0.39	5.2
Kernel per row	0.74	22.93**	4.76	6.35
Ear diameter (mm)	8.34	32.25**	5.12	5.42
Ear length (cm)	0.65	4.35**	0.63	4.42
Ear weight without husk (g)	694.95	2459.8**	225.31	9.24

** = significant at $P < 0.01$, * = significant at $P < 0.05$, ns = not significant, CV = coefficient of variability.

RESULTS AND DISCUSSION

Analysis of variance

According to the analysis of variance, the corn genotypes showed significant differences for almost all traits, except days to silking and anthesis (Table 2). The coefficient of variation (CV) revealed a significant diversity in the 15 characteristics, with values ranging from 2.14% to 9.24%. The highly significant genotypic variances for all studied traits indicated the genotypes were genetically different. It also authenticated the differences in the observed traits were due to genotypic variations. This provides an opportunity to select the promising sweet-waxy corn genotypes with improved productivity, quality, and adaptation to environmental conditions by increasing the overall yield. The coefficient of variation for all observed features had values less than 20%, indicating low variability and relatively high accuracy in the data (Ritonga *et al*., 2018).

Morphological and earliness traits

The plant height and ear height in the tested corn genotypes ranged from 152.47 to 229.90 cm and 63.05 to 127.60 cm, respectively (Table 3). The highest plant and ear height was visible in the genotypes G7 and G12. The corn genotypes G1, G2, G4, G6, G10, G11, and G13, and three commercial cultivars showed no significant differences in plant height. Furthermore, the ear height was at par in the corn genotypes G1, G6, and G11 and three commercial cultivars. Past studies also disclosed the higher the plant height, the higher the ear height in maize genotypes (Bastola *et al*., 2021).

The results gave varied values of the sweet-waxy corn hybrids for leaf length and width. The average leaf length and leaf width ranged from 87.17 to 101.47 cm and 7.23 to 9.17 cm, respectively (Table 3). Hybrid G12 showed significantly higher values for both leaf length and width. The genotype G12 provided more leaves than the commercial hybrids G15 and G16; however, it was not significantly different from G17. The number of leaves is an indicator of growth and a parameter that describes the plant's ability for the photosensory process, with the stored products transmitted to other plant parts. Plant height and number of leaves gained notable influences from the level of competition between plants, as further enhanced with narrow spacing. It indicates environmental conditions, such as water, sunlight, and growing space affect the growth and development of hybrid corn (Suwardi and Herawati, 2021).

The flowering age components observed were days to anthesis and silking in corn genotypes (Table 3). For days to anthesis and silking, the corn-tested genotypes had no significant difference with the commercial cultivars Kumala, Arumba, and Srikandi. In all the corn genotypes, the days to anthesis varied from 50.10 to 58.27 DAP, while days to silking varied from 51 to 58.47 DAP. The harvest of sweet-waxy corn happened when the ears were still young and 21 days after pollination (Dermail *et al*., 2018). In addition, the characteristics indicating sweet-waxy corn is ready for harvest are when the ear hairs are dark brown and dry, the kernels are shiny, and the fully filled kernels. Days to maturity of the three commercial sweet-waxy corn had an earlier harvest age; however, these were not substantially different from all the tested hybrids, except G7 (Table 3). It indicates the acceleration of the sweet-waxy corn flowering process considerably affects the efficiency of harvest time, with the same findings reported by studying the genetic traits in waxy corn (Faisal *et al*., 2019).

Yield-related traits

For yield characteristics of sweet-waxy corn, the results revealed in 14 tested hybrids, only two hybrids sequentially showed the shortest ear length (Table 4). The corn hybrids G5 and G14 were visible with the ear diameter of 36.03 and 38.79 mm, correspondingly. Furthermore, in sweet-waxy corn genotypes, the ear length varied from 16.52 to 20.56 cm. Hybrid G7 has a larger ear length and ear diameter and was comparable with the commercial cultivars. Ear diameter and ear length bore influences from environmental variations, in contrast to the characteristics of the kernels per row, as influenced more by genetic variation (Aisah *et al*., 2021).

The kernel rows per ear in sweet-waxy corn genotypes generally ranged from 10 to 16 rows, and the number was always even (Suriani *et al*., 2017). This was following the research showing the kernel rows per ear were in the range of 10 to 14. However, the corn hybrid G3 provided the fewest kernel rows per ear, while the commercial cultivar G17 had the most kernel rows per ear. Meanwhile, the more ear length also indicates the number of kernels per row increased. In addition, the ear weight without husks gave a higher value.

In general, the corn hybrid G7 tested indicated the kernels per row and ear weight without husk were equivalent to the commercial cultivar G17. The ear weight without husk in sweet-waxy corn hybrids ranged from 114.46–214.96 g (Table 4). This signifies these hybrids have considerable production potential. However, by comparing with other types of maize, these genotypes disclosed remarkable differences. In past studies, the local waxy corn showed relatively small grain yield, ranging from 36.24 to 96.63 g (Pangestu *et al*., 2023). For maize, the ear weight without husk emerged with higher values, ranging from 153.44 to 206.33 g (Yuwariah *et al*., 2022). However, the sweet corn hybrid exhibited a much higher ear weight without husk, ranging from 220.80 to 314.10 g (Chozin and Sudjatmiko, 2020).

The selection of sweet-waxy corn ideotypes is crucial for breeders to obtain high-yielding hybrids. The ideotype that can serve as a reference to obtain high yields includes long ear, high number of kernels per row, and heavy ear weight without husk. The G7 hybrid is a concrete example reflecting these ideotypes, with significantly concentrated characteristics. It can be helpful as a reference for farmers to cultivate high-yielding sweet-waxy corn.

Genetic parameters

The traits' heritability is a characteristic transferrable from generation to generation, and can be calculable from the proportion of genetic variance to phenotypic variance (Priyanto *et al*., 2023). In the presented study, the estimated heritability values for all observed traits varied from 3.64% to 97.62%, obtaining the highest heritability for ear height (97.62%) (Table 5). By studying the genetic variability, heritability, correlation, and path coefficient analysis for grain yield and yield component in maize, the study showed same findings (Belay, 2-018). High heritability values can result from the influence of genetic factors being higher than the environmental factors.

Furthermore, the characters with higher heritability values will be more efficient because selection can proceed in early generations. The lowest heritability value (3.64 %) appeared from days to silk. Meanwhile, the days to anthesis had a medium heritability value of 25.89%. Kuswantoro *et al*. (2021) also reported medium heritability for earliness

Table 3. Mean values of the sweet-waxy corn genotypes for agronomic traits.

Genotypes	PH	EH	SD	LW	LL	NL	DA	DS	DM
G1	220.73^{ab}	124.63^{a}	2.38^{a}	8.56^{abc}	99.10^{ab}	11.50^{abc}	58.33	58.27	74.00^{ab}
G2	203.44^{abc}	103.93^{cde}	2.09^{abcd}	8.04^{bcd}	94.31^{abcd}	10.90^{abcd}	55.77	54.8	71.67^{b}
G3	190.20^{bcd}	88.27^{defg}	2.04^{abcd}	8.02^{bcd}	95.98^{abc}	10.00^{bcde}	52.17	52.9	71.67^{b}
G4	219.30^{ab}	104.43^{cde}	1.93^{bcd}	7.33^{d}	95.73^{abc}	10.13^{bcde}	53.3	53.87	73.00^{ab}
G5	152.47^{e}	70.40^{ghi}	1.76^{d}	7.47^{cd}	87.17^{d}	8.73^{e}	52.4	54.53	72.00^{b}
G6	219.45^{ab}	124.24^{ab}	2.08^{abcd}	7.78^{bcd}	97.24^{ab}	11.12^{abcd}	53.27	53.5	72.00^{b}
G7	228.50^{a}	127.60^{a}	2.23^{abc}	8.80^{ab}	101.47^{a}	12.07^{ab}	55.7	56.13	77.00^{a}
G8	179.97^{cde}	73.00^{ghi}	1.98^{bcd}	8.13^{abcd}	88.83^{cd}	9.97^{bcde}	52.37	53.13	71.33^{b}
G9	186.43^{bcde}	81.97^{fghi}	2.01^{abcd}	8.17^{abcd}	94.40^{abcd}	10.47^{bcde}	50.7	51.67	71.33^{b}
G10	202.04^{abc}	105.40^{bcd}	2.00^{abcd}	7.84^{bcd}	98.15^{ab}	10.95^{abcd}	49.9	50.53	74.67^{ab}
G11	214.13^{abc}	110.20^{abc}	2.02^{abcd}	7.98^{bcd}	98.50^{ab}	11.70^{ab}	57.4	57.27	73.00^{ab}
G12	229.90^{a}	126.17^{a}	2.19^{abc}	9.17^{a}	101.17^{a}	12.70^{a}	58	58.47	74.33^{ab}
G13	198.22^{abc}	92.64^{cdef}	2.12^{abcd}	8.31^{abcd}	100.64^{a}	10.42^{bcde}	50.1	51.00	72.33^{ab}
G14	182.97^{cde}	85.60^{efgh}	2.09^{abcd}	7.97^{bcd}	88.30^{cd}	10.73^{abcde}	51.93	52.47	72.67^{ab}
G15	159.38^{de}	67.23^{hi}	1.98^{bcd}	8.27^{abcd}	91.47^{bcd}	9.47^{cde}	51.53	52.63	70.67^{b}
G16	160.98^{de}	63.05^{i}	1.89^{cd}	7.23^{d}	87.40^{d}	9.33^{de}	51.33	52.13	70.67^{b}
G17	180.77^{cde}	86.13^{efgh}	2.30^{ab}	8.88^{ab}	94.30^{abcd}	11.63^{abc}	52.7	52.13	70.67^{b}
HSD 5%	35.69	19.16	0.38	1.12	8.16	2.16	-	-	4.85

PH: plant height (cm), EH: ear height (cm), SD: stem diameter (mm), LW: leaf width (cm), LL: leaf length (cm), NL: number of leaves, DA: days to anthesis (DAP), DS: days to silking (DAP), DM: days to maturity.

Table 4. Mean values of the sweet-waxy corn genotypes for various yield traits.

Genotypes	ED	EL	KNE	NKR	EWHK
G1	44.26^{ab}	19.76^{abc}	11.59^{bcde}	33.19^{abc}	186.67^{abc}
G2	43.66^{ab}	17.77^{bcd}	12.00^{abcde}	34.90^{abc}	176.61^{abc}
G3	33.98^{d}	16.52^{d}	10.20^{e}	35.13^{abc}	114.46^{e}
G4	43.28^{ab}	17.45^{cd}	12.35^{abcd}	33.47^{abc}	166.20^{bcd}
G5	36.03^{cd}	16.90^{d}	11.73^{bcde}	33.40^{abc}	114.53^{e}
G6	42.29^{abc}	17.17^{d}	13.02^{abc}	31.91^{bc}	149.95^{cde}
G7	45.90^{a}	19.98^{ab}	11.78^{bcde}	39.63^{a}	211.11^{ab}
G8	40.00^{abcd}	17.47^{cd}	13.13^{abc}	31.90^{bc}	148.72^{cde}
G9	41.80^{abc}	17.43^{cd}	13.07^{abc}	31.57^{bc}	165.10^{bcd}
G10	44.67^{ab}	18.13^{abcd}	13.32^{ab}	30.49^{c}	172.36^{abcd}
G11	45.14^{ab}	17.10^{d}	11.80^{bcde}	37.40^{ab}	175.00^{abcd}
G12	44.60^{ab}	18.18^{abcd}	11.02^{de}	36.43^{abc}	181.18^{abc}
G13	39.60^{abcd}	17.34^{cd}	11.61^{bcde}	35.43^{abc}	140.78^{cde}
G14	38.79^{bcd}	16.58^{d}	11.52^{bcde}	34.20^{abc}	128.90^{de}
G15	40.95^{abcd}	18.63^{abcd}	11.20^{cde}	33.63^{abc}	156.98^{cde}
G16	41.18^{abc}	16.93^{d}	11.53^{bcde}	31.03^{bc}	159.35^{cde}
G17	43.65^{ab}	20.56^{a}	13.78^{a}	39.79^{a}	214.96^{a}
HSD 5%	7.05	2.46	1.95	6.79	46.77

ED: ear diameter (mm), EL: ear length (cm), KNE: kernels row number per ear, NKR: number of kernels per row, EWHK: ear weight without husk (g).

Table 5. Estimation of genetic parameters for various traits in sweet-waxy corn genotypes.

Characters	$\bar{x}$	σ^2g	σ^2e	σ^2p	H (%)	GCV (%)	PCV (%)
Days to anthesis	54.28	1.37	16.23	18.12	10.43	2.58	7.98
Days to silking	53.85	0.21	16.95	17.16	1.24	0.86	7.69
Plant height (cm)	195.82	555.08	131.24	686.32	80.88	12.03	13.38
Ear height (cm)	96.17	457.43	37.82	495.25	92.36	22.24	23.14
Stem diameter (cm)	2.06	0.02	0.01	0.03	66.67	6.85	8.39
Leaf width (cm)	8.11	3.10	4.11	7.21	42.97	21.69	33.08
Leaf length (cm)	94.95	21.02	6.86	27.88	75.40	4.83	5.56
Number of leaves	10.70	0.93	0.48	1.41	65.88	9.00	11.09
Days to maturity	72.53	10.45	8.59	19.04	54.88	4.46	6.02
Kernel rows per ear	12.04	0.76	0.39	1.15	66.09	7.24	8.91
Kernels per row	34.32	6.06	4.76	10.82	55.99	7.17	9.58
Ear diameter (mm)	41.75	9.04	5.12	14.16	63.85	7.20	9.01
Ear length (cm)	17.88	1.24	0.63	1.87	66.31	6.23	7.65
Ear weight without husk (g)	162.52	744.83	225.31	970.14	76.78	16.79	19.17

$\bar{x}$: mean value, σ^2g: genotypic variance, σ^2e: environmental variance, σ^2p: phenotypic variance, H: broad-sense heritability, GCV: genotypic coefficient of variation, PCV: phenotypic coefficient of variation.

traits. A low heritability value indicates a character has a high environmental influence, whereas the genetic influence is low. Therefore, it should not become a selection criterion in maize (Priyanto *et al*., 2023).

The genotypic coefficient of variation (GCV) is the parameter that functions to measure genetic variability in a population. In addition, GCV can also aid in comparing the characteristic's diversity. Similarly, the phenotypic coefficient of variation (PCV) is the parameter operating to measure the phenotypic variability in a population. Overall, the PCV values were higher than the GCV for all characters, indicating the strong influence of the environment on the attributes (Ram-Reddy and Jabeen, 2016). The highest GCV was evident for ear height (22.24), followed by leaf width (21.69). The highest PCV emerged for leaf width (33.08%), followed by ear height (23.14%) (Table 5). These results were similar to the findings noted for yield and yield-attributing traits in sweet corn (Chavan *et al.,* 2020).

The highest GCV and PCV values indicated genotypic and phenotypic variations had a wide diversity in the observed population. In contrast, low PCV and GCV values were apparent in the characteristics of days to anthesis (5.06% and 2.58%), days to silking (4.50% and 0.86%), and days to maturity (2.33% and 1.98%), respectively. Low PCV and GCV values indicate these features are not effective for selection; therefore, the breeders must choose characters with higher diversity. These results agreed with past findings studying the genetic variation and character association among yield and yield-attributing traits in sweet corn (*Zea mays* L.) (Shankar *et al*., 2023).

Correlation and path analysis

The results revealed 11 characters had significant positive correlations, while three traits showed nonsignificant values with ear weight without husk (Figure 1). Positive correlation with ear weight without husk manifested with plant height (r = 0.434), ear height (r = 0.477), stem diameter (r = 0.535), leaf width (r = 0.522), leaf length (r = 0.411), number of leaves (r = 0.663), kernel rows per ear (r = 0.385), kernels per row (r = 0.405), ear diameter (r = 0.863), and ear length (r = 0.736). These observations were analogous to previous research, stating plant height, ear height, kernel rows per ear, kernels per row, ear length, and ear diameter owned the

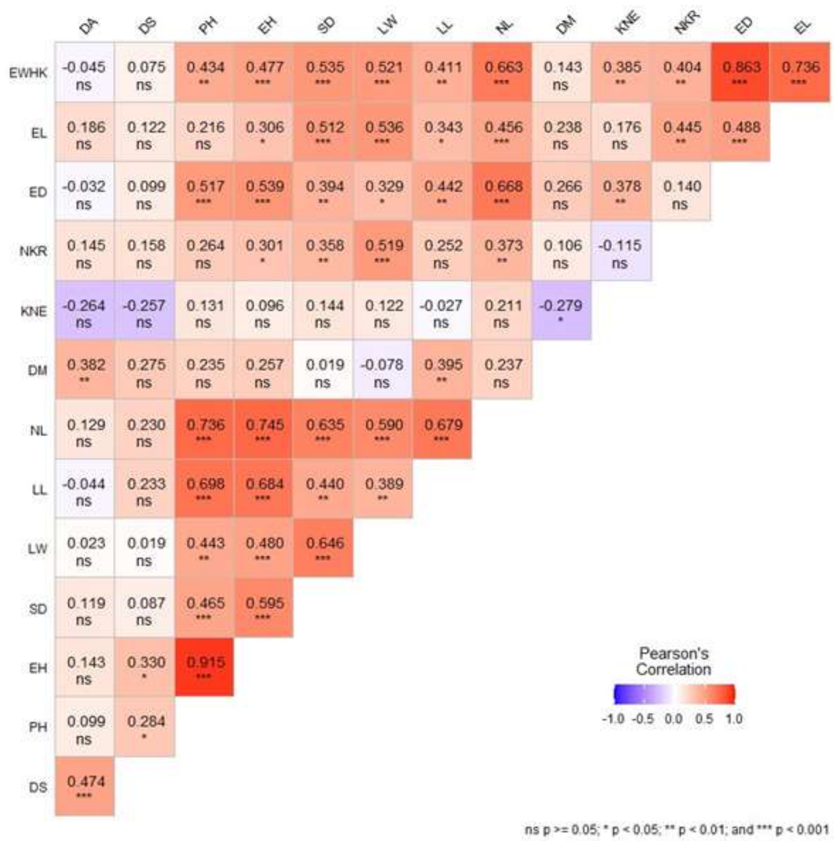

Figure 1. Pearson's correlation among the various traits in sweet-waxy corn.

highest positive correlation with ear weight without husk (Praveena *et al*., 2022). Meanwhile, the characteristics of days to silking and days to maturity displayed a nonsignificant correlation with ear weight without husk. These results were consistent with the research by Nabila *et al*. (2017).

Correlation is a statistical method providing insights into the strength and direction of the relationship in various variables observed in a study. However, correlation values cannot always be applicable to predict effective selection criteria because these observations cannot explain the direct and indirect influences. Path analysis can explain the close relationship among the traits by dividing the association coefficients into direct and indirect effects (Aman *et al.,* 2020). The path analysis results for all characters appear in Table 6. The results enunciated 13 traits of sweet-waxy corn displayed ear diameter had a noticeably direct effect on ear weight without husk (0.661), followed by ear length (0.355) and kernels per row (0.171). This shows these characteristics can benefit as character selection criteria.

These results did not differ from previous studies on several other types of corn. Chavan *et al*. (2020) reported the highest direct effect of the traits of ear diameter and ear length occurred on ear weight without husk in sweet corn. Amin *et al*. (2019) stated the direct effects of the kernels per row on the ear weight without husk in sweet corn. In maize corn, Tadesse and Leta (2019) disclosed a direct effect of the highest number of seeds per row on grain yield. Pavan *et al*. (2011) also found a strong positive direct effect of the traits, ear diameter and ear length on the grain yield in single cross hybrids of maize. The selection of ear length proved less efficient because the observations surfaced at the end of harvest. Therefore, the selection could be more efficient if it can proceed at the beginning of the field observations.

Table 6. Path coefficient analysis on ear weight without husk in sweet-waxy corn.

Characters	Direct effects		Indirect effects													rxy
			DA	DS	PH	EH	SD	LW	LF	NL	DM	NKE	NKR	ED	EL	
DA	-0.099	ns		0.012	0.002	-0.010	0.009	0.000	0.001	0.005	-0.032	-0.011	0.026	-0.020	0.068	-0.050
DS	0.026	ns	-0.047		0.005	-0.023	0.007	0.000	-0.008	0.008	-0.024	-0.011	0.027	0.066	0.043	0.070
PH	0.017	ns	-0.010	0.007		-0.064	0.033	-0.008	-0.024	0.027	-0.020	0.005	0.044	0.344	0.078	0.430
EH	-0.070	ns	-0.014	0.009	0.016		0.044	-0.009	-0.023	0.027	-0.022	0.004	0.051	0.357	0.110	0.480
SD	0.073	ns	-0.012	0.002	0.008	-0.042		-0.012	-0.015	0.023	-0.002	0.006	0.062	0.258	0.181	0.530
LW	-0.019	ns	-0.002	0.001	0.008	-0.033	0.047		-0.013	0.021	0.007	0.005	0.089	0.218	0.192	0.520
LF	-0.034	ns	0.004	0.006	0.012	-0.047	0.032	-0.007		0.025	-0.033	-0.001	0.043	0.291	0.121	0.410
NL	0.036	ns	-0.013	0.006	0.013	-0.052	0.047	-0.011	-0.023		-0.020	0.009	0.063	0.443	0.163	0.660
DM	-0.085	ns	-0.038	0.007	0.004	-0.018	0.001	0.002	-0.013	0.009		-0.011	0.019	0.178	0.085	0.140
KNE	0.041	ns	0.026	-0.007	0.002	-0.007	0.010	-0.002	0.001	0.008	0.024		-0.021	0.251	0.064	0.390
NKR	0.171	**	-0.015	0.004	0.004	-0.021	0.026	-0.010	-0.008	0.013	-0.009	-0.005		0.093	0.156	0.400
ED	0.661	**	0.003	0.003	0.009	-0.038	0.028	-0.006	-0.015	0.024	-0.023	0.015	0.024		0.174	0.860
EL	0.355	**	-0.019	0.003	0.004	-0.022	0.037	-0.010	-0.012	0.017	-0.020	0.007	0.075	0.324		0.740

ns: not significant, **: significant, DA: days to anthesis, DS: days to silking, PH: plant height (cm), EH: ear height (cm), SD: stem of diameter (mm), LW: leaf width (cm), LF: leaf length (cm), NL: number of leaves, DM: days to maturity, KNE: kernels row number per ear, NKR: number of kernels per row, ED: ear diameter (mm), EL: ear length (cm), rxy: correlation coefficient, residual effect 0.2768.

The trait ear length has a remarkable direct effect, apart from it also affecting indirectly through the ear diameter (0.324) (Table 6). It means the ear length is highly effective as a selection character for ear weight without husk. Amin *et al*. (2019) also reported the same findings on the ear length, providing a meaningful positive indirect effect through ear diameter on grain yield in maize. Thus, utilizing the selection criteria for these two characteristics can successfully obtain corn hybrids with the highest productivity.

Corn hybrids with increased plant height will indirectly affect the grain yield through ear diameter. It is due to the taller plants with vigorous performance, increasing the energy obtained from photosynthesis for the formation and filling of cobs. The outcomes showed plant height had a direct influence (0.017) on ear weight without husk and, eventually, the grain yield. Additionally, in corn plants, the ear position can also influence the grain yield. This is because the plant height, which is higher than the ear of corn plants, can hinder the pollination process because the amount of pollen falling on female flowers is less than in the lower position of the ear. This resulted from the greater ability of the female flowers to receive more pollens in maize genotypes (Munawar *et al.,* 2017).

However, the plant height and ear height had the highest indirect effect on ear weight without husk through ear diameter, with coefficient values of 0.344 and 0.357, respectively (Table 6). Amin *et al*. (2019) also described the same findings by studying the genetic variability and character association in maize inbred lines. For the plant height, the sweet-waxy corn genotypes ranged from 170 to 229 cm, while the ear height ranged from 60 to 100 cm. These results indicate both plant and ear height contribute significantly to ear weight without husk, and the effects of both traits can refer to the highest ear diameter. However, breeders still have to pay attention to the plant height values and the location of the corn ear as selection criteria.

Another characteristic beneficial as a selection indicator based on the indirect effect is the number of leaves through the ear diameter (0.443) (Table 6). These observations showed a relationship existed between the number of leaves and the large diameter of the ear, and as a result, a significant improvement in the ear weight without husk occurred. The same also appeared with the highest correlation value (0.663). Therefore, the number of leaves can also help as a selection indicator to select the promising genotypes with the increased ear diameter.

No computations occurred on residual values for residual direct effects for unidentified characters (Karyawati and Puspitaningrum, 2021). However, in this experiment, the residual effect of the path analysis test was 0.2768. It indicates these characteristics can explain 72.31% of the influence of ear weight without husks. Meanwhile, the low residual effect value indicated the traits included in the study explained the highest percentage of the variation in ear weight without husk.

CONCLUSIONS

In sweet-waxy corn genotypes, the traits, ear diameter, ear length, and ear weight without husk had the highest heritability. PCV and GCV values were in the medium-high range. The correlation analysis showed most traits had a positive correlation with ear weight without husk, except days to anthesis, silking, and maturity. The ear diameter, ear length, and kernels per row revealed the highest direct effects on ear weight without husk in sweet-waxy corn. The traits, plant height, ear height, ear length, and number of leaves have an indirect influence on ear weight without husk through ear diameter, and these traits can be beneficial as selection criteria in sweet-waxy corn.

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