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Morphological Differences of Experimental Hybrids and Check Varieties of High-yielding Grain Maize

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ABSTRACT

Malaysia's poultry industry heavily relies on imported grain maize, posing challenges to national food security and economic sustainability. To address this, the development of high-yielding maize varieties is critical. This study evaluated morphological and yield-related traits of ten maize genotypes, which were five experimental hybrids (GH, GJ, HI, HJ, JK) and five check varieties (BTL 1, Pacific 338, Suwan 5, TVDC, GWG888) using a Randomised Complete Block Design (RCBD) with four replications at Universiti Putra Malaysia (UPM), Selangor. Significant differences were observed across all measured parameters. Experimental hybrids, particularly GJ, outperformed check varieties in key yield determinants, including dehusked ear weight, ear diameter, and kernel row count. The most distinctive finding was that hybrid GJ achieved the highest grain yield of 11,794 kg/ha, substantially exceeding that of the check varieties. Strong positive correlations were identified between dehusked ear weight and grain weight ($r = 0.85$, p-value = 0.02, $\alpha = 0.05$), and between plant and ear height ($r = 0.78$, p-value = 0.05, $\alpha = 0.05$), indicating synchronised plant development. Importantly, dehusked ear diameter emerged as a key yield predictor, showing moderate but meaningful correlations with grain yield, kernel rows, and ear weight ($r = 0.61$ - 0.68, p-value = 0.05, $\alpha = 0.05$). These results highlight the pivotal role of ear diameter as a selection criterion in maize breeding programs. The superior performance of hybrid GJ presents a promising solution to Malaysia's maize yield gap. Adoption and further development of such high-performing genotypes could reduce import dependency, strengthen local feed grain supply chains, and enhance national food security.

Keywords: Breeding, genetics, genotype, kernel, plant traits, yield

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INTRODUCTION

Zea mays L., commonly known as maize, exhibits distinct morphology that contributes to poultry nutrition. The morphology of grain maize is characterised by a central cob, surrounded by tightly packed rows of kernels. These kernels serve as a crucial source of calories for poultry, providing the high energy levels required for their growth and development. Grain maize has been extensively used in the formulation of poultry feed, playing a vital role in creating balanced diets that meet its nutritional needs.

The demand for grain maize as poultry feed is substantial both globally and in Malaysia. In the 2021/22 period, worldwide maize production exceeded 1.2 billion metric tons, surpassing other grains, while wheat production amounted to approximately 778.6 million metric tons (Shahbandeh, 2023). However, despite this increasing demand, there is uncertainty regarding whether the future supply of maize will be able to meet the ever-increasing global demand (Nordin et al., 2018). With the increasing demand for grain maize in the poultry feed sector, Malaysia has witnessed substantial growth in the industry. Consequently, there has been a surge in the demand for grain maize within the country. To meet this demand, Malaysia relies heavily on imported grain maize. According to Wahab (2023), approximately 90% of the imported grain maize into Malaysia originates from countries such as Argentina, Brazil, and India. This heavy reliance is driven by a decrease in local grain maize production by 16% in 2021 from 2020 (Wahab, 2023). To address this challenge, it is crucial to focus on enhancing local production and improving crop yields in Malaysia. This effort is essential for ensuring a sustainable supply of grain maize for poultry feeding and reducing dependence on imports.

In the pursuit of improving crop yield, maize with desirable morphology or traits plays a pivotal role in achieving high productivity. Breeders can effectively influence grain yield by targeting specific traits such as plant height, ear height, ear weight, number of kernels per row, ear length, and others (Mohammedali et al., 2021; Mousa et al., 2021; Uba et al., 2018). It has been found that maize genotypes with shorter plant height have been found to outperform in yield compared to the taller plants (Nordin et al., 2018). However, another finding by Greveniotis et al. (2019) and Uba et al. (2018) stated that yield is primarily focused on ear traits. In particular, Haddadi et al. (2012) also observed a significant positive correlation between the number of kernels per row and grain yield. Similarly, Singh et al. (2020) identified multiple traits, including plant height, ear height, ear length, ear diameter, and the number of kernel rows per ear, that exhibited a significant positive correlation with grain yield. Understanding and selecting maize varieties with favourable traits are crucial for researchers to enhance crop performance, leading to higher yields. Consequently, developing maize varieties with improved traits has become a primary objective in most breeding programs, enabling the production of maize varieties that significantly augment yield production.

Research Objectives

The primary objective of this study is to identify characteristics among several genotypes of maize, determine the differences and similarities in traits associated with high yield, and figure out the relationships existing among these traits.

MATERIALS AND METHODS

Study Overview

The study was conducted at Field 15, Universiti Putra Malaysia, Selangor. The experimental site is located in a tropical climate region characterised by warm temperatures and frequent rainfall throughout the year.

Experimental Design

The study evaluated ten maize hybrids, consisting of five experimental hybrids and five established check varieties. The experimental hybrids included CML331 x CML383 (GH), CML331 x CML491 (GJ), CML383 x CML428 (HI), CML383 x CML491 (HJ) and CML491 x CML498 (JK). In addition, five established check varieties were included for comparison, namely Breeder Test Line 1 (BTL 1), Pacific 338, Suwan 5, TVDC and GWG888. This diverse selection of hybrids and varieties forms the basis of this investigation into various morphological traits and yield parameters.

The experiment used a Randomised Complete Block Design (RCBD) with a single factor, which was the maize genotype. The experimental layout consisted of four blocks, with each block containing ten plots corresponding to the ten genotypes, with sizes for each being 19.5 m^2 per block. Thus, the total number of experimental units was 40, giving a sample size of $n = 40$.

Cultural Practices

Every single hole was filled with two seeds, and thinning was done between 7 - 14 days after sowing. On days 7 and 21, the fertiliser was applied at 50 kg/ha of N, 20 kg/ha of P and 20 kg/ha of K. On day 35, the fertiliser was applied at 50 kg/ha of N, 50 kg/ha of P and 70 kg/ha of K.

Statistical Analysis

Initially, the Anderson-Darling normality test was performed to evaluate whether the data followed a normal distribution, allowing for the identification of parametric and non-parametric data. Since these were normally distributed data, the analyses were conducted using Analysis of Variance (ANOVA) and Duncan's Multiple Range Test (DMRT) as mean comparison, which were applied to the parameter with a total of ten samples when the F-value showed a significant difference at 95% confidence level, when compared with F-value references in the F-table. In order to study the correlations between the traits, Pearson's correlation analysis was applied to measure the strength and direction of the linear relationship between two variables. All of these analyses were run using R Studio (Version 3).

Data Collection

The data collection was taken based on yield and yield components. The yield data were collected from a harvested area of 11 m^2, representing the harvested portion. In contrast, the data on yield components were acquired through a random sampling process, where a total of 10 samples were taken from the harvested area. The data were taken at a maturity level of 110 - 120 days.

A total of nine parameters were considered to evaluate the yield and other characteristics for yield components, namely plant height, ear height, dehusked ear weight, dehusked ear diameter, dehusked ear length, number of kernel rows per ear, number of kernels per row, grain weight and grain yield.

Plant Height and Ear Height

In this study, plant height and ear height were measured to assess the morphological characteristics of maize plants. Plant height was measured using a measuring tape from the ground level, specifically from the point where the uppermost brace roots emerge, to the base of the tassel on the plant, where the flag leaf is located. Similarly, ear height was measured from the ground level, starting from the uppermost brace roots' emergence to the base of the first ear on the plant.

The measurements of both plant height and ear height were recorded in centimetres (cm). The data collected was then presented as the average of plant height per plant and ear height per plant. These measurements were taken during the harvesting time, indicating that the plants were assessed at their mature stage when the ears had fully developed.

Dehusked Ear Weight

The samples were weighed using a CAMRY electronic weighing balance (Model EK3211, China). The measurements were recorded in grams (g) and were presented in average dehusked ear weight per ear.

Dehusked Ear Diameter and Length

The diameter measurements were taken using an electronic digital vernier calliper capable of measuring from 0.1 millimetre (mm) up to 150 mm. The measurements were recorded in mm. The diameter measurements were taken on three different sections of the ears, which were the top, middle and bottom of the ear. Subsequently, the data from these sections were averaged to determine the diameter value. The data were presented in average dehusked ear diameter per ear.

On the other hand, the dehusked ear length was determined by measuring the length of the ear where kernels were produced. A ruler with a length of 30 cm was used for measuring the dehusked ear length. The data were recorded in cm and presented in average dehusked ear length per ear.

Number of Kernel Rows per Ear and Kernels per Row

The number of kernel rows per ear was determined by manually counting each dehusked ear. The data was presented in an average number of kernel rows per ear. Similarly, the number of kernels per row was manually counted on each dehusked ear. A total of three rows were randomly selected on the dehusked ear, and the number of kernels in each of those rows was counted. The counts from the three rows were averaged to calculate the average number of kernels per row per ear.

Grain Weight and Yield

In order to measure grain weight and yield, moisture content measurements were taken along during the weighing process and recorded as a percentage (%). The moisture content data collection was conducted using a digital grain moisture meter (AR991, China). The moisture content value recorded was utilised for the calculation of grain weight and yield, ensuring standardisation to a moisture content level of 15%. This standardised moisture content level holds significance as indicated by Nordin et al. (2018), who concluded that maintaining a moisture content of 15% is crucial for optimising both grain yield and quality.

The dehusked ears were manually shelled to separate the grain from the cob. The grain samples were then individually weighed to determine the grain weight per ear. Additionally, the grain from the harvested area was weighed to obtain the grain yield. The samples were weighed using a CAMRY electronic weighing balance (Model EK3211, China).

The grain weight data were presented as the average grain weight per ear and expressed in g unit. The data for grain yield were presented as the average of grain weight per plot and converted to kilograms per hectare (kg/ha).

RESULTS AND DISCUSSION

Plant Height and Ear Height

Plant height is one of the parameters that correlated with lodging resistance and yield production in maize (Wang et al., 2019). Table 1 reveals an intriguing pattern when it comes to plant height in experimental hybrids. It is evident that the experimental hybrids differ significantly from one another, resulting in a distinct plant height for each. GH and HJ hybrids are the most distinctive, having the shortest plant height, 165.2 cm and 184.9 cm, respectively. In another study, a local maize hybrid (Sweet King) planted at Terengganu, Malaysia, recorded a plant height of 151.33 cm ± 3.20 (Nordin et al., 2018).

However, in an unexpected turn, the check variety showed no significant difference in plant height, ranging from 192.2 cm to 212.4 cm, respectively. Comparing the results with other studies, the GWG888 (192.2 cm) check variety in this study exhibits similarities with the findings from other experiments conducted at different locations in the Peninsular Malaysia area in 2019 and 2020, which recorded 197.5 cm for GWG888 (Adham et al., 2022). It is interesting to see how the performance of this revised check variety aligns with previous observations, suggesting a certain level of consistency and reliability in its growth characteristics.

Interestingly, based on the previously mentioned result, Nordin et al. (2018) categorised shorter plants as preferred genotypes because of their possible influence on root attachment to the soil. This evidence supports the notion that shorter plant heights may be advantageous, especially in withstanding strong winds and preventing toppling.

In addition to plant height, ear height also showed significant differences between experimental hybrids and the check varieties (Table 1) (p-value = 0.003). The ear height of Pacific 338, BTL 1, HI, JK, Suwan 5 and GH ranged from 98.8 cm to 110.5 cm, and were significantly different from GH, GWG888, TVDC and HJ (81.2 cm to 91.9 cm). The difference in ear height between these two groups was 16.77%. In other studies, it has been suggested that an ear height of 78.5 cm is considered acceptable and desirable (Nordin et al., 2018). It is because shorter ear heights will lead to issues of a crowded canopy, poor aeration and limited sunlight transmission to lower sections that can lead to a significant decrease in crop output (Nordin et al., 2018).

Moreover, another study recorded that crosses of M 703 x M 733 achieved better yielding with an ear height of 101.7 cm compared to other crosses with higher ear heights (El-Hosary et al., 2018). These findings indicate a general preference for higher ear heights, as they facilitate better crop yield by allowing proper canopy spacing, improved aeration, and optimal sunlight penetration. However, it is important to note that excessively high ear placement can lead to lodging and have a negative impact on the final yield (Nordin et al., 2018).

Dehusked Ear Weight

The dehusked ear weight is a key factor in determining the yield of maize, as a higher weight indicates that the maize plant has produced more kernels. The dehusked ear weight (Table 2) of maize hybrids varied significantly (p-value = 0.000003), with JK, HJ and GJ

Table 1

The effects of genotypes on selected experimental and check varieties on plant height and ear height of grain maize

Genotype	Plant Height/Plant, cm	Ear Height/Plant, cm
GH	165.2±12.6c	81.2±4.8c
GJ	209.9±17.9a	110.5±13.3a
HI	200.1±6.2ab	100.8±1.8ab
HJ	184.9±29.5bc	91.9±22.3bc
JK	200.9±13.5ab	103.7±9.1ab
BTL 1	193.7±24.3ab	99.2±8.4ab
Pacific 338	211.7±14.9a	98.8±7.2ab
Suwan 5	209.6±12.0a	108.4±7.0a
TVDC	212.4±11.9a	88.6±10.1bc
GWG888	192.2±11.4ab	83.1±7.0c
cv	7.460	10.143

Note. Means followed by the same letter are not significantly different among genotypes by the DMRT test at p-value ≤ 0.05. Values are presented as mean ± standard error (SE). CV refers to the coefficient of variation, which indicates the relative variability of the data

Table 2

The effects of genotypes on selected experimental and check varieties on dehusked ear weight, dehusked ear diameter, dehusked ear length, kernel rows per ear and kernels per row of grain maize

Genotype	Dehusked Ear Weight/Ear, g	Dehusked Ear Diameter/Ear, mm	Dehusked Ear Length/Ear, cm	Kernel Rows per Ear	Kernels per Row
GH	246.1±18.9bc	46.24±0.79bc	17.29±0.30cd	12.4±0.3e	36.6±1.0bcde
GJ	298.9±25.7a	50.30±0.63a	16.55±0.89cd	14.8±0.3b	38.1±1.7abc
HI	206.1±24.0d	42.12±2.22d	16.35±0.97cd	12.5±0.2e	35.0±2.1cdef
HJ	289.6±14.5a	46.63±0.49b	18.97±1.75ab	14.0±0.1bcd	40.2±2.7a
JK	273.2±11.6ab	49.76±0.89a	16.26±0.87d	15.6±0.7a	33.7±1.6ef
BTL 1	253.3±23.9bc	47.11±1.07b	17.13±1.03cd	14.3±0.6bc	34.4±2.2def
Pacific 338	256.7±14.0bc	46.81±1.0b	17.08±0.344cd	13.7±0.4cd	37.3±0.9abcd
Suwan 5	226.7±19.0cd	45.40±1.94bc	17.83±1.02bc	13.4±0.5d	34.5±2.6def
TVDC	253.5±23.9bc	44.54±2.10c	17.44±0.29cd	13.6±0.7cd	32.0±2.3f
GWG888	256.7±10.7bc	45.25±0.38bc	19.63±0.38a	14.7±0.4bc	38.3±1.0ab
cv	7.649	2.729	5.376	3.644	5.319

Note. Means followed by the same letter are not significantly different among genotypes by the DMRT test at p-value ≤ 0.05. Values are presented as mean ± standard error (SE). CV refers to the coefficient of variation, which indicates the relative variability of the data exhibiting the highest weights of 272.2 g, 289.6 g and 298.9 g, respectively. In contrast, HI and Suwan 5 had the lowest recorded weights of 206.1 g and 226.7 g, respectively. This represents a 9% lower from the genotype with the highest dehusked ear weight. In a study conducted by El-Hosary et al. (2018), it was shown that the crossbreeding of M 702 x M 722 resulted in an ear weight of 249.2 g, leading to a significant increase in yield. Conversely, the crossbreeding of M 702 with M 704 resulted in a lower ear weight of 161.0 g (El-Hosary et al., 2018).

This variation in dehusked ear weight among the hybrids can be attributed to several factors, including genetic traits, environmental conditions, soil fertility, and agronomic practices employed during cultivation. As the environmental conditions in this study were standard for all hybrids, this parameter might be influenced by the genetic traits. More than 70% of ear attributes have heritability values over 0.5, suggesting that genetic factors continue to have a significant impact on maize ear features (Wang et al., 2023). In another finding, a total of four single-nucleotide polymorphisms (SNPs) were identified, with two SNPs associated with both ear length and weight, and two SNPs associated with ear row number and length (Khatun et al., 2022). These findings collectively emphasise the significant role of genetics in shaping maize ear characteristics, providing valuable insights for future breeding efforts aimed at enhancing ear weight and overall crop yield.

Dehusked Ear Diameter and Length

The dehusked ear diameter is an important trait to consider as it provides insights into the size and potential yield of the maize ear. A larger diameter indicates a larger ear size, which can accommodate a greater number of kernels and potentially result in higher grain yield. From Table 2, the dehusked ear diameter of maize hybrids varied significantly (p-value ≤ 0.0001), with experimental hybrids JK and GJ exhibiting the largest diameters of 49.76 mm and 50.30 mm, respectively. Experimental hybrids JK and GJ were 15.81% bigger in dehusked ear diameter compared to others, ranging from 42.12 mm to 47.11 mm.

Rahouma and Mahmud (2021) reported a significant difference in dehusked ear diameter, with Pioneer 3084 displaying a diameter of 45.2 mm. Additionally, Carvalho et al. (2021) found that cultivars of P1630 had a dehusked ear diameter of 46.8 mm. In comparison, the current study surpasses these previous findings, reporting even larger diameters of 50.30 mm for experimental hybrid GJ. These results highlight the remarkable potential of the experiment hybrids in achieving larger ear diameters, suggesting their superiority in terms of size and yield potential.

The variation in dehusked ear diameter among hybrids is likely influenced by genetic factors, as different genotypes have distinct genetic backgrounds that contribute to their ear size (Karaşahin, 2022). Furthermore, environmental factors such as climatic conditions during grain filling stages can also affect ear diameter (Zuo et al., 2021). The findings of this research emphasise the importance of considering dehusked ear diameter as a key trait in maize breeding programs. It plays a significant role in determining the potential yield of maize (Mottin et al., 2021). Therefore, selecting hybrids with larger dehusked ear diameters can contribute to achieving higher grain yields in maize cultivation.

According to Mosharrof et al. (2021), dehusked ear length in maize serves as a critical parameter for determining the overall yield and productivity. Among the experimental hybrids, HJ exhibited a significantly longest dehusked ear length (p-value ≤ 0.001), which was 18.97 cm (Table 2). In contrast, other experimental hybrids (JK (p-value = 0.008), HI (p-value = 0.01), GJ (p-value = 0.02) and GH (p-value = 0.02)) showed significant differences in ear length compared to the HJ hybrid, ranging between 16.26 cm and 17.29 cm. Meanwhile, among the check varieties, GWG888 displayed a significant difference in ear length with 19.63 cm compared to BTL 1 (p-value = 0.02), Pacific 338 (p-value = 0.01), Suwan 5 (p-value = 0.02) and TVDC (p-value = 0.05). In comparison with the experimental and check varieties, both hybrids GWG888 and HJ stood out with the longest dehusked ear lengths compared to the other genotypes, with differences reaching up to 11.97%, highlighting their distinctiveness in this aspect. Their exceptional length sets them apart from the rest of the genotypes in this study (Figure 1).

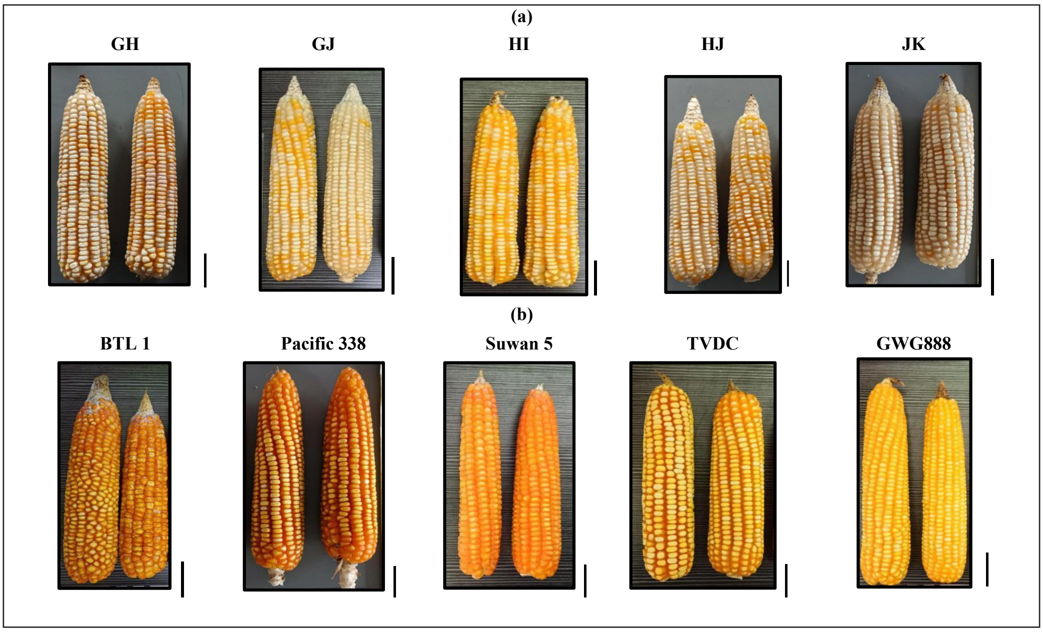

Figure 1. (a) Harvested ears for five experimental hybrids (GH, GJ, HI, HJ and JK); (b) Harvested ears for five check varieties (BTL 1, Pacific 338, Suwan 5, TVDC and GWG888). The line at the bottom right of the picture indicates a rule measuring 3 cm in length

It is important to acknowledge that the ear lengths seen in this study, although remarkable, do not surpass the previously documented record of 21.96 cm in the crossbreeding of M 704 x M 712, as reported in a separate study conducted by El-Hosary et al. (2018). Furthermore, Mousa et al. (2021) found a significant difference of 20.97 cm in length between the cross Gz-8093 x SC131. However, this study aligns with the results obtained by Carvalho et al. (2021), who similarly observed a statistically significant difference in AS 1656 PRO2, measuring 18.10 cm, and the experimental hybrid HJ in this study, measuring 18.97 cm.

The variations in dehusked ear length among the hybrids indicate the distinct genetic composition of these hybrids. Each hybrid carries a unique combination of genetic factors inherited from parental lines contributing to phenotypic variations (Dong et al., 2023). Hence, breeders need to identify the genetic components underlying this trait. However, identifying the genetic components underlying this trait is challenging due to the complexity of the maize genome and the difficulty of cloning ear length quantitative trait loci (Zuo et al., 2021).

Number of Kernel Rows per Ear and Kernels per Row

One of the factors of grain maize production that is of significance includes a high count of kernel rows per ear and kernels per row. Maize is a wind-pollinated plant, and successful pollination and fertilisation of kernels are essential for grain formation. These characteristics significantly impact maize grain yield and can serve as reliable selection indicators for identifying superior maize genotypes (Prakash et al., 2019).

Table 2 reveals that the experimental hybrid JK had the most kernel rows per ear, with 15.6 kernel rows per ear. The difference in the number of kernel rows per ear between JK and other hybrids was 2.2%. Other hybrid results were recorded with a range of 12.4 to 14.8 kernel rows per ear. These results suggest that JK has the potential to produce ears with more kernel rows than other maize hybrids. Furthermore, the number of kernels per row among various genotypes showed significant differences (p-value ≤ 0.0001), as shown in Table 2. Pacific 338, GJ, GWG888 and HJ exhibit significant differences from other hybrids, with the highest value recorded to be 37.3 to 40.2 kernels per row, respectively.

It is interesting to note that the results of this study are consistent with those of other studies. For example, El-Hosary et al. (2018) reported a value of 15.3 for the number of kernel rows per ear in the cross M 712 x M 705; meanwhile, Rahouma and Mahmud (2021) reported a value of 14.3 for the variety Pioneer 3084. In terms of the number of kernels per row, El-Hosary et al. (2018) observed the highest count of 43.0 kernels per row in the cross M 712 x M 705. On the other hand, Rahouma and Mahmud (2021) documented a value of 52.2 kernels per row in the Pioneer 3084 variety.

The recognition that the experimental hybrid JK exhibited the highest number of kernel rows per ear underscores the paramount importance of this trait in enhancing maize productivity. The number of kernel rows per ear directly shapes the formation of grains, underscoring its pivotal role in determining the overall yield. Usually, each ear will form an even number of 12 to 18, where the beginning of the first kernel initiates separation, resulting in the formation of two rows from one (Zhong-zhi et al., 2010). The genetic makeup of a hybrid is the primary determinant of the potential number of rows per ear, with environmental factors playing a comparatively minor role. The establishment of the number of kernel rows per ear occurs rapidly after the initiation of the ear shot, and once determined, no additional rows will develop. This intricate interplay of genetic and environmental factors underscores the swift and decisive nature of kernel row development in maize.

On the other hand, the number of kernels per row trait is also mostly determined by genetic factors, but they can also be modified by environmental conditions. Specifically, a higher number of kernels per row in maize signifies successful pollination and fertilisation processes (Wei et al., 2019). Overall, the results of this study suggest that JK has the potential to produce ears with more kernel rows, while HJ has the potential to produce ears with more kernels per row than other maize hybrids. Further research is needed to determine the factors that contribute to the higher number of kernel rows and kernels per row in JK and HJ.

Grain Weight and Yield

Grain weight and yield are key factors in determining the profitability of maize production. The grain weights exhibited significant variation among the experimental hybrids, as seen by the data presented in Table 3. Although the experimental hybrids had higher grain weight overall, it is worth noting that one of the experimental hybrids, particularly HI, demonstrated the lowest grain weight, measuring at 174.4 g per ear. This observation implies that these genotypes exhibit significant variations (p-value = 0.0003) in grain weight attributes. Surprisingly, there were no statistically significant differences (p-value > 0.1) seen among the experimental hybrid HI, BTL 1 (193.1 g), Suwan 5 (180.4 g), and GWG888 (181.7 g). The observed gap underscores the variability in grain weight and its potential influence on overall crop productivity.

Plants experience elevated levels of photosynthesis when there is an increase in carbon dioxide, resulting in higher production of carbohydrates and biomass (Kellner et al., 2019; Thompson et al., 2017). This will be a directing resource to reproductive structures like ears, resulting in higher ear weights and potential crop yield. However, this process can be interrupted by the environment. Heterogeneous light conditions in maize plants lead to a reduction in carbon allocation to the ear, resulting in lower yield and decreased proportion of carbon in the ear (Chen et al., 2020). In this study, genetic factors may also contribute to the efficiency of carbon conversion to biomass because the planting area and environment were standardised for each hybrid.

For maize, Table 3 also shows that there were significant differences (p-value = 0.05) in grain yield among the various genotypes. Pacific 338, JK, and GJ had significantly higher grain yields ranging from 10,831 kg/ha to 11,794 kg/ha, compared to other varieties. Among the experimental hybrids, GJ and JK led in grain yield, followed by GH, HJ and HI. Among the check varieties, Pacific 338had significantly higher grain yield than BTL 1 (p-value = 0.03), Suwan 5 (p-value = 0.03), TVDC (p-value = 0.05), and GWG888 (p-value = 0.05).

Maize grain yield is influenced by genetic and environmental factors, including water and nutrient uptake. Proper root development and functioning are crucial for absorbing water and nutrients from the soil. He et al. (2019) found that adequate water and fertiliser can improve photosynthesis and overall maize yield. In addition, the anatomical structure of the ear, comprising its dimensions such as length, diameter, as well as the arrangement of rows and kernels within each row, has a direct influence on the overall grain productivity (Chaurasia et al., 2020; Saritha et al., 2022). Maize cultivars exhibiting larger and more fully developed ears have a propensity to generate grain yields as a result of their capacity to accommodate a higher quantity of kernels (Wei et al., 2019). The role of the ear has been recognised as a crucial determinant of grain yield in several study settings (Jia et al., 2020; Yang et al., 2020). According to the findings shown in Table 3 and Table 2, the check variety TVDC had a relatively high grain weight of 200.1 g per ear. However, it is

Table 3
The effects of genotypes on selected experimental and check varieties on grain weight and yield of grain maize

Genotype	Grain weight/ear, g	Grain yield/plot, kg/ha
GH	198.8±13.1abc	10009±3040.1bcd
GJ	222.8±20.5a	11794±1101.4a
HI	174.4±19.0d	9276±1013.4def
HJ	216.9±10.0ab	9452±863.4cde
JK	211.9±9.1ab	11158±570.6ab
BTL 1	193.1±13.0bcd	9186±139.7def
Pacific 338	213.3±14.1ab	10831±700.5abc
Suwan 5	180.4±15.7cd	8487±1145.4ef
TVDC	200.1±15.6abc	7859±1343.8f
GWG888	181.7±11.0cd	9240±517.4def
cv	7.435	9.586

Note. Means followed by the same letter are not significantly different between the genotypes by the DMRT test at p-value ≤ 0.05. Values are presented as mean ± standard error (SE). CV refers to the coefficient of variation, which indicates the relative variability of the data noteworthy that this particular variety also demonstrated the lowest grain yield, measuring 7,859 kg/ha. Besides exhibiting the lowest grain yield, TVDC also showed inferior performance in terms of other ear characteristics, which are often characterised by the lowest values.

Previous studies have shown that the grain yield of AG 9045 RR PRO, a hybrid maize variety, achieved a grain yield of 10,378 kg/ha (Carvalho et al., 2021). Additionally, Pioneer 3084 showcased its potential by yielding up to 7,192 kg/ha (Rahouma & Mahmud, 2021). These outcomes underscore the substantial potential of the experimental hybrids to attain higher grain yields, akin to the benchmark varieties. Consequently, this indicates that these hybrids are well-suited for cultivation and have promising prospects for increasing overall productivity.

Pearson Correlation

Significant relationships among various traits were observed through correlation analysis (Table 4). Firstly, the correlation coefficient at r = 0.85 (p-value = 0.02) was found between dehusked ear weight and grain weight, which suggests a strong positive correlation between these two variables. An increase in dehusked ear weight correspondingly results in an increase in grain weight, indicating that larger dehusked ears generally contain more grains. These findings can be supported by other studies that reported a strong correlation between dehusked ear weight and grain weight in maize (Nordin et al., 2018; Prakash et al., 2019).

Secondly, plant height and ear height also indicate a strong positive correlation with the correlation coefficient value of r = 0.78 (p-value = 0.05). As the overall height of the plant increases, so does ear height. The study by Singh et al. (2020) further supports this positive correlation, reporting phenotypic correlation coefficients of 0.70 in the maize crop. These findings suggest that taller plants are likely to have higher ear placement, impacting factors such as pollination, ear emergence, harvestability, and optimal sunlight exposure. Plants with greater height possess a heightened capacity to efficiently capture sunlight. Increased sunlight exposure enhances photosynthesis, providing more energy for the development and maturation of the ears and kernels (Yang et al., 2022).

In contrast to the strong positive correlations mentioned above, a weak positive correlation at r = 0.36 (p-value = 0.04) was observed between grain yield and the number of kernel rows per ear. While this correlation suggests that an increase in the number of kernel rows per ear will correspondingly result in an increase in grain yield, it is not as strong as the other correlations mentioned. In contrast, Singh et al. (2020) observed a weak phenotypic correlation coefficient (r = 0.14) but a strong genotypic correlation coefficient (r = 0.80) between the number of kernel rows per ear and grain yield for the maize crop. The differences in findings may be attributed to variations in genetic backgrounds, environmental conditions, or experimental setups.

Table 4
Correlation coefficient estimates among nine traits in maize hybrids

	Plant Height	**Ear Height**	**Dehusked Ear Weight**	**Dehusked Ear Diameter**	**Dehusked Ear Length**	**Kernel Rows Per Ear**	**Kernels Per Row**	**Grain Weight**	**Grain Yield**
Plant Height	1.00								
Ear Height	0.78*	1.00							
Dehusked Ear Weight	0.03	0.02	1.00						
Dehusked Ear Diameter	0.06	0.25	0.68*	1.00					
Dehusked Ear Length	- 0.19	- 0.42*	0.25	- 0.14	1.00				
Kernel Rows Per Ear	0.28	0.26	0.54*	0.65*	- 0.07	1.00			
Kernels Per Row	- 0.11	- 0.04	0.46*	0.23	0.61*	- 0.02	1.00		
Grain Weight	0.13	0.14	0.85*	0.66*	0.09	0.39*	0.44*	1.00	
Grain Yield	0.13	0.29	0.49*	0.61*	- 0.19	0.36*	0.42*	0.59*	1.00

*Indicates significant difference by the F test (p-value ≤ 0.05)

Grain yield is considered the main trait of interest for assessing the correlations with other traits. However, there were three traits, namely plant height, ear height, and dehusked ear length, that recorded a non-significant correlation with grain yield. Meanwhile, a moderate correlation was found between grain yield and dehusked ear diameter, with a correlation coefficient of r = 0.61 (p-value = 0.05), which indicates that ear diameter has a significant impact on grain yield, and as the diameter of the ear increases, the grain yield also increases. Similar findings were reported in other studies, where strong correlations were found between ear diameter and yield in maize crop (Greveniotis et al., 2019), as well as other traits (Tandzi & Mutengwa, 2019).

Furthermore, the dehusked ear diameter not only exhibited a positive correlation with grain yield but also demonstrated positive correlations with dehusked ear weight (r = 0.68, p-value = 0.06), number of kernel rows per ear (r = 0.65, p-value = 0.02), and grain weight (r = 0.66, p-value = 0.06). These correlations indicated that as the diameter increases, the dehusked ear weight, number of kernel rows per ear, and grain weight also increase.

CONCLUSION

This study has provided a comprehensive evaluation of the morphological and yield-related traits among a range of experimental and check variety maize hybrids. Significant variability was observed in traits such as plant height, ear height, dehusked ear weight, ear dimensions, kernel arrangement, and ultimately, grain yield, highlighting the influence of genetic diversity among the hybrids. Notably, hybrids such as JK, GJ, and HJ consistently outperformed others across multiple traits, with JK exhibiting the highest number of kernel rows per ear, GJ demonstrating greater dehusked ear diameter and grain yield, and HJ showing the longest ear length and highest grain weight among experimental hybrids. Shorter plant and ear heights observed in hybrids like GH and HJ are aligned with lodging resistance and agronomic preference in high-wind environments, as supported by previous studies. Meanwhile, moderate to high ear heights in high-yielding genotypes suggest that balance, rather than extremes, in morphological traits may be key to optimising yield. The strong positive correlation between dehusked ear weight and grain weight and between ear diameter and grain yield underscores the pivotal role of ear morphology in determining final grain production. Importantly, the genetic basis of many traits evaluated, such as ear length, kernel row number, and grain weight were reaffirmed by correlations and prior findings on heritability and SNP associations. These insights are vital for maize breeding programs aiming to combine high yield potential with desirable agronomic characteristics. While the influence of environmental conditions was controlled in this study, future research should explore genotype-by-environment interactions to validate the performance stability of superior hybrids across diverse agroecological zones.

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DISCLAIMER

There are no artificial intelligence (AI) tools that were used in the preparation of the manuscript.

REFERENCES

Adham, A., Ghaffar, M. B. A., Ikmal, A. M., & Shamsudin, N. A. A. (2022). Genotype × environment interaction and stability analysis of commercial hybrid grain corn genotypes in different environments. *Life*, *12*(11), 1-12, Article 1773. https://doi.org/10.3390/life12111773

Carvalho, I. R., Eickhoff, F. G., Silva, T. S. da, Schulz, A. D., Ourique, R. S., Malheiros, T. F., Foguesatto, F. da R., Sarturi, M. V. R., Loro, M. V., & Hutra, D. J. (2021). Cultivation of maize in different environments and their effects on agronomic traits. *Agronomy Science and Biotechnology*, *7*, 1-11. https://doi.org/10.33158/ASB.r125.v7.2021

Chaurasia, N., Nirala, R., Singh, B., & Mandal, S. (2020). Trait association and path coefficient analysis in maize (*Zea mays* L.) for grain yield and its attributes. *Journal of Pharmacognosy and Phytochemistry*, *9*(1), 527-531. https://doi.org/10.22271/phyto

Chen, G., Chen, H., Shi, K., Raza, M. A., Bawa, G., Sun, X., Pu, T., Yong, T., Liu, W., Liu, J., Du, J., Yang, F., Yang, W., & Wang, X. (2020). Heterogeneous light conditions reduce the assimilate translocation towards maize ears. *Plants*, *9*(8), Article 987. https://doi.org/10.3390/plants9080987

Dong, X., Luo, H., Yao, J., Guo, Q., Yu, S., Zhang, X., Cheng, X., & Meng, D. (2023). Characterisation of genes that exhibit genotype-dependent allele-specific expression and its implications for the development of maize kernel. *International Journal of Molecular Sciences*, *24*(5), Article 4766. https://doi.org/10.3390/ijms24054766

El-Hosary, A. A. A., Motawea, M. H., & Elgammaal, A. A. (2018). Combining ability for yield and some of its attributes in maize across two locations. *Egyptian Journal of Plant Breeding*, *22*(3), 625-640.

Greveniotis, V., Zotis, S., Sioki, E., & Ipsilandis, C. (2019). Field population density effects on field yield and morphological characteristics of maize. *Agriculture*, *9*(7), Article 160. https://doi.org/10.3390/agriculture9070160

Haddadi, M. H., Eesmaeilof, M., Choukan, R., & Rameeh, V. (2012). Combining ability analysis of days to silking, plant height, yield components and kernel yield in maize breeding lines. *African Journal of Agricultural Research*, *7*(36), 5153-5159. https://doi.org/10.5897/AJAR12.878

He, Z., Xu, C., Liu, B., Yao, B., Wang, H., Chen, Z. Y., Li, D. Y., Bai, Z. Y., & Zhang, Z. A. (2019). Relationship between photosynthesis, bleeding-sap mass, and bleeding components in maize hybrids and corresponding parents in northern China. *Photosynthetica*, *57*(2), 698-704. https://doi.org/10.32615/ps.2019.096

Jia, H., Li, M., Li, W., Liu, L., Jian, Y., Yang, Z., Shen, X., Ning, Q., Du, Y., Zhao, R., Jackson, D., Yang, X., & Zhang, Z. (2020). A serine/threonine protein kinase encoding gene kernel number per rows regulates maize grain yield. *Nature Communications*, *11*, 1-11, Article 988. https://doi.org/10.1038/s41467-020-14746-7

Karaşahin, M. (2022). Performance of some different hybrid dent corn (*Zea mays* L. *indentata* S.) varieties under central Anatolian conditions. *Turkish Journal of Field Crops*, *27*(1), 17- 25. https://doi.org/10.17557/tjfc.971995

Kellner, J., Houska, T., Manderscheid, R., Weigel, H.-J., Breuer, L., & Kraft, P. (2019). Response of maize biomass and soil water fluxes on elevated CO2 and drought—From field experiments to process-based simulations. *Global Change Biology*, *25*(9), 2947-2957. https://doi.org/10.1111/gcb.14723

Khatun, M., Monir, M. M., Lou, X., Zhu, J., & Xu, H. (2022). Genome-wide association studies revealed complex genetic architecture and breeding perspective of maize ear traits. *BMC Plant Biology*, *22*, 1-15, Article 537. https://doi.org/10.1186/s12870-022-03913-1

Mohammedali, M. A., Mohamed, O. A., Abdalla, M. G., Ama, K., & Taha, E. M. M. (2021). Genetic variability, heritability and genetic advance estimates in some maize (*Zea mays* L.) varieties in Sudan. *International Journal of Food Science and Agriculture*, *5*(1), 85- 90. https://doi.org/10.26855/ijfsa.2021.03.012

Mosharrof, M., Uddin, M. K., Jusop, S., Sulaiman, M. F., Shamsuzzaman, S. M., & Haque, A. N. A. (2021). Integrated use of biochar and lime as a tool to improve maize yield and mitigate CO2 emission: A review. *Chilean Journal of Agricultural Research*, *81*(1), 109-118. https://doi.org/10.4067/S0718-58392021000100109

Mottin, M. C., Seidel, E. P., Fey, E., Vanelli, J., Alves, A. L., & Sustakowski, M. C. (2021). Corn and soybean productivity in succession to family coverage plants Poaceae and Fabaceae. *Journal of Agricultural Studies*, *9*(3), 111-123. https://doi.org/10.5296/jas.v9i3.18665

Mousa, S., Mohamed, H., Aly, R., & Darwish, H. (2021). Combining ability of white maize inbred lines via line X tester analysis. *Journal of Plant Production*, *12*(2), 109-113. https://doi.org/10.21608/jpp.2021.154325

Nordin, M., Amani, S., & Hassan, M. (2018). Effect of moisture content on grain yield and quality of maize (*Zea mays* L.). *Journal of Agriculture and Environment*, *19*(2), 113-120.

Nordin, M. N., Lah, C., Alias, M. K., Wan Muda, N., Mat, W. M., & Ngah, N. (2018). Evaluation of yield performance and variation on its adaptation-related traits of hybrid maize to local environment in Terengganu, Malaysia. *International Journal of Engineering & Technology*, *7*(4.43), 19-23. https://doi.org/10.14419/ijet.v7i4.43.25811

Prakash, R., Ravikesavan, R., Vinodhana, N. K., & Senthil, A. (2019). Genetic variability, character association and path analysis for yield and yield component traits in maize (*Zea mays* L.). *Electronic Journal of Plant Breeding*, *10*(2), 518-524. https://doi.org/10.5958/0975-928X.2019.00065.6

Rahouma, A., & Mahmud, A. (2021). Maize growth and yield response to different rates of humic acid and zinc. *Alexandria Science Exchange Journal*, *42*(4), 823-829. https://doi.org/10.21608/asejaiqjsae.2021.203532

Saritha, A., Umarani, E., & Ramanjaneyulu, A. V. (2022). Studies on character association and path coefficient analysis for grain yield and its contributing characters in maize (*Zea mays* L.). *International Journal of Environment and Climate Change*, *12*(12), 102-109. https://doi.org/10.9734/ijecc/2022/v12i121444

Shahbandeh, M. (2023). *Grain production worldwide 2022/23, by type*. Statista.

Singh, D., Kumar, A., Kumar, R., Singh, S. K., Kushwaha, N., & Mohanty, T. A. (2020). Correlation and path coefficient analysis for 'yield contributing' traits in quality protein maize (*Zea mays* L.). *Current Journal of Applied Science and Technology*, *39*(25), 91-99. https://doi.org/10.9734/cjast/2020/v39i2530889

Tandzi, L. N., & Mutengwa, C. S. (2019). Estimation of maize (*Zea mays* L.) yield per harvest area: Appropriate methods. *Agronomy*, *10*(1), Article 29. https://doi.org/10.3390/agronomy10010029

Thompson, M., Gamage, D., Hirotsu, N., Martin, A., & Seneweera, S. (2017). Effects of elevated carbon dioxide on photosynthesis and carbon partitioning: A perspective on root sugar sensing and hormonal crosstalk. *Frontiers in Physiology*, *8*, Article 578. https://doi.org/10.3389/fphys.2017.00578

Uba, C. U., Agbo, C. U., Chukwudi, U. P., Efusie, A. A., & Muojiama, S. O. (2018). Field evaluation of yield and yield component traits of breeding lines of maize over two seasons in derived Savannah agro-ecology. *Notulae Scientia Biologicae*, *10*(4), 567-574. https://doi.org/10.15835/nsb10410329

Wahab, A. G. (2023). *Grain and feed annual* (Report No. MY2023-0001). United States Department of Agriculture. https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Grain+and+Feed+Annual_Kuala+Lumpur_Malaysia_MY2023-0001.pdf

Wang, H., Zhang, X., Hu, F., Liu, M., Zhao, Y., Wang, Y., Gu, L., & Ma, Q. (2019). Systematic identification and characterisation of candidate genes for the regulation of plant height in maize. *Euphytica*, *215*(2), Article 34. https://doi.org/10.1007/s10681-019-2345-1

Wang, J., Zhao, S., Zhang, Y., Lu, X., Du, J., Wang, C., Wen, W., Guo, X., & Zhao, C. (2023). Investigating the genetic basis of maize ear characteristics: A comprehensive genome-wide study utilising high-throughput phenotypic measurement method and system. *Frontiers in Plant Science*, *14*, Article 1248446. https://doi.org/10.3389/fpls.2023.1248446

Wei, S., Wang, X., Li, G., Qin, Y., Jiang, D., & Dong, S. (2019). Plant density and nitrogen supply affect the grain-filling parameters of maize kernels located in different ear positions. *Frontiers in Plant Science*, *10*, Article 180. https://doi.org/10.3389/fpls.2019.00180

Yang, L., Li, T., Tian, X., Yang, B., Lao, Y., Wang, Y., Zhang, X., Xue, J., & Xu, S. (2020). Genome-wide association study (GWAS) reveals genetic basis of ear-related traits in maize. *Euphytica*, *216*(11). https://doi.org/10.1007/s10681-020-02707-6

Yang, Y., Liu, G., Guo, X., Liu, W., Xue, J., Ming, B., Xie, R., Wang, K., Li, S., & Hou, P. (2022). Effect mechanism of solar radiation on maize yield formation. *Agriculture*, *12*(12), Article 2170. https://doi.org/10.3390/agriculture12122170

Zhong-zhi, H., Yan-zhao, L., Jia-peng, Z., & You-gang, Z. (2010). Counting ear rows in maize using image process method. In *2010 Third International Conference on Information and Computing* (Vol. 3, pp. 329-332). IEEE. https://doi.org/10.1109/ICIC.2010.269

Zuo, Z., Lu, Y., Zhu, M., Chen, R., Zhang, E., Hao, D., Huang, Q., Wang, H., Su, Y., Wang, Z., Xu, Y., Li, P., Xu, C., & Yang, Z. (2021). Nucleotide diversity of the maize *ZmCNR13* gene and association with ear traits. *Frontiers in Genetics*, *12*, Article 773597. https://doi.org/10.3389/fgene.2021.773597