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Research Article
Evaluation of High Yielding Hybrid Lines of Unhas Corn Based on a Systematic Approach and Genetic Analysis

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Abstract
Background and Objective: The development of hybrid corn lines is crucial in increasing corn production in various countries, including Indonesia. This assembly needs to be evaluated systematically, either through a series of statistical approaches or genetical approaches. Therefore, this research aimed to evaluate and select hybrid lines of Unhas corn with good agronomic characteristics based on statistical and genetical approaches. **Materials and Methods:** This study was carried out in Maros Regency, South Sulawesi Province, Indonesia. A randomized block design was employed in this study using three replications. The main factor in this research was the hybrid corn line which consists of 15 genotypes (13 hybrid lines and 2 check varieties (BISI 18 and P36) and repeated three times. So, there were 45 experimental units. Each experimental unit was observed for its agronomic and morphological potential, consisting of 26 parameters. All parameters were analyzed directionally through analysis of variance, correlation, path analysis and Duncan's Multiple Range Test. **Results:** Systematic analysis approaches are considered effective for use in evaluating hybrid corn lines, such as in this study. The hybrid corn lines HB1, HB2, HB3, HB7 and HP13 have good potential based on the overall evaluation characteristics of stem diameter, number of harvested cobs, harvested ear weight and productivity. The HB1 hybrid line is the best corn hybrid line among the five corn hybrid lines. **Conclusion:** Therefore, these five hybrid lines can still be recommended when considering the release of hybrid corn varieties, especially HB1. However, these hybrid potentials still need to adaptability test in some environments before to proposed in the release variety.

Key words: Correlation analysis, hybrid lines, path analysis, Unhas, *Zea mays*

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Corn (*Zea mays* L.) is an important food commodity after rice. This commodity is often used as raw material for the food processing industry, such as corn flour, bread and cakes and even snacks[1,2]. In addition, corn is also an important part in making poultry feed[3,4]. Nearly 70% of corn use in Indonesia is closely related to this feed[3,5]. Therefore, corn production and development in Indonesia continues to be optimized to support domestic demand.

The increase in corn production cannot be separated from the productivity potential of the varieties being developed. However, the increase in productivity is not significant every year[6]. Based on Statistic Indonesia[7], the average corn productivity in Indonesia is 5.86 ton ha^{-1} in 2022. This productivity has increased from 2020-2022, namely 0.33 ton ha^{-1} (5.53). In addition, corn production until 2023 is projected to experience an average growth of 0.08%. These two data indicate that the development of cultivation technology and the assembly of corn varieties must be carried out to support the sharp linear increase in corn production every year.

Corn development can be induced by assembling hybrid corn varieties[8]. Hybrid corn is the F1 generation resulting from crossing two or more pure lines and has differences in diversity between varieties. Differences in hybrid corn diversity depend on the type of hybridization and the stability of the pure lines used as parents[9]. The hybrid corn has been proven to provide better and more uniform results and is capable of higher production than free-pollinated corn[1,10,11]. This is due to the potential for heterosis possessed by hybrid lines, where these lines have better potential than their two parents[2,12,13]. Therefore, the development of hybrid corn lines is the main goal for almost all corn breeders, including corn breeders at Hasanuddin University.

Hasanuddin University has developed several promising hybrid lines that are worthy of evaluation. Evaluation of these lines should be carried out systematically using a statistical approach and also involving a genetic approach. The effectiveness of systematic evaluation using a statistical approach has been reported by several researchers[6,14-17]. The approach makes the evaluation process more focused and concentrated on the desired goals through estimating the character of the evaluation[6,18]. However, these evaluation characters still require a genetic approach to support the level of confidence in the selection of these characters[19-21]. This indicates that the two approaches are a complementary combination so that both are often included in selection and evaluation. Therefore, statistical and genetic approaches need to be applied in evaluating Unhas hybrid lines to comprehensively estimate the potential of these lines. Hence, this research aimed to evaluate the corn hybrid lines with good agronomic properties based on statistical and genetic approaches.

MATERIALS AND METHODS

Experimental design: This research was carried out in Moncongloe District, Maros Regency, South Sulawesi Province from June, 2023 to September, 2023. The trial was designed using a Randomized Complete Block Design (RCBD) and repeated three times. The main factor in this research was the hybrid corn line which consists of 13 genotypes and 2 comparison varieties (BISI 18 and P36), hence, there are 15 genotypes and 45 experimental units.

Research procedure: Before planting, the land was prepared by conducting soil tillage mechanically and chemically. Seed preparation was carried out by selecting healthy, pithy (filled/dense), shiny and physically and genetically good seeds. The selected seeds were treated with fungicide before planting. Planting was conducted individually with 2-3 seeds per planting hole then covered with soil and given lime. Each genotype was planted in five rows and each row consisted of 25 holes in each experimental block with a planting distance of 70$\times$20 cm. Following planting plant maintenance was conducted consisted of fertilizing, watering, replanting, thinning, hilling, weed control, as well as spraying with leaf fertilizer and controlling pests and diseases. Specifically, fertilization was carried out 3 times with the first fertilization conducted 7 days after planting (DAP) using NPK Phonska and SP36 fertilizer, while the second fertilization was at 35 DAP using urea fertilizer mixed with agricultural lime. Further, the third fertilization was at 50 DAP using urea and SP36 fertilizer, mixed with agricultural lime. Irrigation was carried out by flooding the plot since planting and at intervals of 10 days until harvest if the rain intensity is low or depends on weather conditions. Harvest was carried out when the plant had reached physiological maturity which is marked by the husks drying out and leave no traces when pressed by a fingernail. Harvesting was done by breaking the corn stalks on each plant. Following harvesting, the corn was placed into sample bags according to their respective genotypes or numbers.

Data observation and analysis: Observations were made on plant growth and production parameters i.e., the number of growing plants, plant height, cob height, male flowering age, female flowering age, plant aspect, stem diameter, leaf length, leaf width, leaf angle, leaf curve pattern, husk cover, ear aspect, root fall, stem fall, number of harvested ears, weight of harvested ears, weight of 10 ears, ear diameter, number of rows, number of seeds per row, weight of 1000 seeds, yield, water content and productivity.

Statistical analysis: All data were analyzed using One-way Analysis of Variance (ANOVA). Characters with significant results in the ANOVA at the 5% level will be further analyzed using heritability analysis. Apart from that, these characters will be reduced to obtain evaluation characters through correlation analysis and path analysis. Characters with very high correlations and characters that have a direct effect on the yield will be used as evaluation characters in this research[6,18]. All evaluation characters along with the yield were analyzed using the Duncan's Multiple Range Test significant difference test with a level of 5%.

RESULTS

The results of the ANOVA and heritability analysis were shown in Table 1. Based on this table, differences in hybrid corn genotypes have a significant effect on almost all characters, except for the characters of number of growing plants, male flowering male, female flowering age, stem diameter and water content. Characters that are not significant are attributable to low heritability, hence data were not shown in Table 1. Heritability for significant characters is divided into two categories, namely high and medium. Characters that have moderate heritability are plant aspect (0.28), stem diameter (0.45), leaf curve pattern (0.35), husk cover (0.36), ear aspect (0.42), root fall (0.31), number of harvest ears (0.28), weight of harvested cobs (0.31), weight of 10 cobs (0.45), number of seeds per row (0.50), weight of 1000 seeds (0.34) and yield (0.32). On the other hand, the characters classified as high heritability were plant height (0.82), cob height (0.78), leaf length (0.65), leaf width (0.54), leaf angle (0.83), cob diameter (0.70) and number of rows (0.55).

Table 1: Analysis of variance on growth characteristics of corn hybrid lines

	MS genotype				
Characters	Value	Significant	MS error	CV (%)	Heritability
NPG	16.04	ns	15.92	8.53	-
PH	1160.07	**	77.66	4.55	0.82 (H)
CH	435.58	**	36.99	6.53	0.78 (H)
AMF	0.42	ns	0.44	1.19	-
AFF	0.1	ns	0.3	0.96	-
PA	0.36	*	0.17	14.5	0.28 (M)
SD	3.63	**	1.05	6.61	0.45 (M)
LL	52.66	**	8.09	3.91	0.65 (H)
LW	0.79	**	0.17	5.37	0.54 (H)
LA	164.83	**	10.7	13.69	0.83 (H)
LCP	0.93	*	0.36	27.21	0.35 (M)
HC	0.27	*	0.1	18.46	0.36 (M)
EA	1.09	**	0.34	17.47	0.42 (M)
RF	31	*	13.15	136	0.31 (M)
SF	150.17	ns	98.94	212.14	-
NHE	80.53	*	36.96	17.24	0.28 (M)
WHE	3.12	*	1.34	22.41	0.31 (M)
W10C	196686.4	**	56482	11.5	0.45 (M)
ED	14.35	**	1.78	2.97	0.70 (H)
NR	2.64	**	0.56	5.14	0.55 (H)
NBR	10.49	**	2.62	4.8	0.50 (M)
W1000G	2188.96	*	868.77	10.08	0.34 (M)
YP	0	**	0	2.46	0.69 (H)
WC	7.72	ns	7.22	9.57	-
Yield	2.97	*	1.22	22.62	0.32 (M)

*Significant effect at 5% error level, **Most significant effect at 1% error level, ns: No significant effect, NPG: Number of plants growing, PH: Plant height, CH: Cob height, AMF: Age at male flowering, AFF: Age at female flowering, PA: Plant aspect, SD: Stem diameter, LL: Leaf length, LW: Leaf width, LA: Leaf angle, LCP: Leaf curve pattern, HC: Husk cover, EA: Ear aspect, RF: Root fall, SF: Stem fall, NHE: Number of harvested ears, WHE: Weight of harvested ears, W10E: Weight of 10 ears, W10C: Weight of 10 cobs, ED: Ear diameter, NR: Number of rows, NBR: Number of beans per row, W1000G: Weight of 1000 grains, YP: Yield percentage and WC: Water content

Table 2: Correlation analysis of various growth characteristics of hybrid corn lines

Characters	PH	CH	PA	SD	LL	LW	LA	LCP	HC	EA	RF	NHE	WHE	W10C	ED	NR	NSR	W1000G	YP
CH	0.82**																		
PA	-0.29	-0.50**																	
SD	0.44**	0.61**	-0.33*																
LL	0.12	-0.06	-0.12	0.04															
LW	0.12	0.24	-0.31*	0.41**	0.1														
LA	0.09	-0.01	0.1	0.19	0.22	0.2													
LCP	0.02	-0.16	0.22	0.1	0.43**	0.11	0.61**												
HC	0.26	0.30*	-0.13	0.22	-0.27	0.07	-0.05	-0.30*											
EA	-0.25	-0.21	0.24	-0.2	0.2	-0.36*	0.24	0.15	-0.1										
RF	0.26	0.26	-0.19	0	-0.11	0.01	-0.28	-0.12	-0.11	-0.32*									
NHE	0.27	0.45**	-0.41**	0.38*	-0.25	0.17	-0.43	-0.39**	0.23	-0.47**	0.11								
WHE	0.32	0.51**	-0.41**	0.52**	-0.13	0.35*	-0.30*	-0.27	0.22	-0.51**	-0.04	0.91**							
W10C	0.32	0.40**	-0.27	0.31*	0.19	0.29*	0.17	0.06	0.03	0.03	-0.15	0.27	0.41**						
ED	0.39**	0.52**	-0.45**	0.44**	0.08	0.46**	-0.08	-0.14	0.22	-0.12	-0.08	0.37*	0.55**	0.77**					
NR	0.16	0.32*	-0.30*	0.2	0	0.2	-0.12	-0.26	-0.01	0	-0.22	0.31*	0.41**	0.63**	0.71**				
NSR	0.48**	0.52**	-0.16	0.17	0.26	-0.05	-0.19	-0.06	0.01	-0.13	0.12	0.29	0.36*	0.46**	0.41**	0.43**			
W1000G	0.17	0.16	-0.1	0.42**	0.30*	0.1	0.17	0.15	0.22	0.18	-0.21	0.11	0.22	0.48**	0.40**	0.06	0.12		
YP	-0.23	-0.11	0.19	-0.18	0.01	-0.37*	0.12	0.07	0.02	0.23	-0.26	0.06	0.01	-0.02	-0.38**	-0.12	0.09	0.07	
Yield	0.26	0.47**	-0.34*	0.51**	-0.12	0.30*	-0.27	-0.25	0.25	-0.43**	-0.11	0.89**	0.98**	0.37*	0.46**	0.33**	0.35*	0.26	0.18

*Significant correlated at 5% error level, **Most significant correlated at 1% error level, TT: Plant height, TKTkl: Cob Height, PA: Plant aspect, DB: Stem diameter, PD: Leaf length, LD: Leaf width, SdDn: Leaf angle, PLD: Leaf curve pattern, HC: Husk cover, EA: Ear aspect, RF: Root fall, NHE: Number of harvested ears, WHE: Weight of harvested ears, W10C: Weight of 10 ears, ED: Ear diameter, NR: Number of rows, NSR: Number of seeds per row, W1000G: Weight of 1000 grains and YP: Yield percentage

Table 3: Path analysis of traits that are significantly correlated with the yield

		Indirect effect									
Characters	Direct effect	EH	PA	SD	LW	EA	W10C	ED	NR	NSR	Correlation
EH	0.02		0.03	0.20	-0.02	0.08	0.04	0.04	0.03	0.05	0.47
PA	-0.05	-0.01		-0.11	0.02	-0.09	-0.03	-0.04	-0.03	-0.02	-0.34
SD	0.33	0.01	0.02		-0.03	0.07	0.03	0.04	0.02	0.02	0.51
LW	-0.07	0.00	0.02	0.13		0.13	0.03	0.04	0.02	-0.01	0.30
EA	-0.36	0.00	-0.01	-0.07	0.03		0.00	-0.01	0.00	-0.01	-0.43
W10C	0.11	0.01	0.01	0.10	-0.02	-0.01		0.06	0.05	0.05	0.37
ED	0.08	0.01	0.02	0.15	-0.03	0.04	0.08		0.06	0.04	0.46
NR	0.09	0.01	0.01	0.07	-0.01	0.00	0.07	0.06		0.05	0.33
NSR	0.10	0.01	0.01	0.06	0.00	0.05	0.05	0.03	0.04		0.35
Residual effect	0.53										
R^2	27.41										

EH: Ear height, PA: Plant aspect, SD: Stem diameter, LW: Leaf width, EA: Ear aspect, W10C: Weight of 10 ears, ED: Ear diameter, NR: Number of rows, NSR: Number of seeds per row and R^2 = Determination value

The results of the correlation analysis focused on the character of the yield (Table 2). Characteristics of ear height (0.47), stem diameter (0.51), leaf area (0.30), number of harvested ears (0.89), weight of harvested ears (0.98), weight of 10 ears (0.37), ear diameter (0.46), number of rows (0.33) and the number of seeds per row (0.35) are characters that have a significant positive correlation with the yield. On the other hand, the plant aspect (-0.34) and ear aspect (-0.43) are two characters that have a negative correlation with the yield. Specifically the characteristics of the number of harvested cobs and the weight of harvested cobs per plot, both characters have a very high correlation with the yield. Characters show significant correlation with the yield was analysed further using path analysis.

The path analysis was carried out without including the number of harvested ears and the weight of harvested ears per plot. The path analysis collected a diversity of up to 27.41%. Based on the analysis results, stem diameter was the character with the highest direct influence value, namely 0.33 (Table 3). The characteristics of the weight of 10 cobs (0.11), cob diameter (0.08), number of rows (0.09) and number of seeds per row (0.10) were characters that have a direct positive influence. However, this value did not have a significant direct effect. On the other hand, the ear aspect character was a character with a high direct influence, namely -0.36.

The results of further test analysis of the middle values were carried out on four characters, namely weight of harvested cobs, number of harvested cobs, stem diameter and the yield (Table 4). Based on the stem diameter character, HB5 was a hybrid corn with the best stem diameter. However, this hybrid was not significantly different from almost all other

Table 4: Duncan means value test of evaluation criteria based on systematic analysis

Genotype	SD	NHE	WHE	Yield
HB1	16.72^{a}	46.67^{a}	7.02^{a}	6.45^{a}
HB2	16.54^{a}	39.00^{ab}	6.01^{ab}	5.86^{ab}
HB3	15.87^{ab}	36.67^{abcd}	6.09^{ab}	5.34^{abc}
HB4	15.81^{ab}	34.33^{bcd}	5.28^{abc}	5.17^{abcd}
HB5	17.10^{a}	28.67^{cd}	4.51^{bc}	4.06^{bcd}
HB6	14.23^{ab}	35.33^{bcd}	5.02^{bc}	5.19^{abcd}
HB7	15.77^{ab}	36.67^{abcd}	6.11^{ab}	5.74^{ab}
HB8	14.12^{ab}	39.00^{ab}	5.16^{abc}	4.74^{abcd}
HB9	16.38^{ab}	28.33^{d}	3.38^{c}	3.34^{d}
HB10	14.88^{ab}	28.33^{d}	4.26^{bc}	3.77^{cd}
HB11	14.74^{ab}	34.00^{bcd}	4.73^{bc}	4.39^{bcd}
HB12	14.65^{ab}	31.67^{bcd}	3.65^{c}	3.37^{d}
HB13	16.03^{ab}	38.67^{abc}	5.64^{ab}	5.13^{abcd}
BISI 18	16.46^{ab}	40.67^{ab}	6.17^{ab}	6.38^{a}
P36	13.41^{b}	31.00^{bcd}	4.45^{bc}	4.47^{bcd}

Numbers followed by the same letter in a column indicate no significant difference from DMRT tests level of 5%, SD: Stem diameter, NHE: Number of harvested ears and WHE: Weight of harvested ears

genotypes, except P36. Based on the character of the number of harvested cobs, hybrid HB1 was also the hybrid with the highest JTP potential compared to other hybrids and control varieties. However, this hybrid was not significantly different from HB2, HB3, HB7, HB8, HB13 and BISI 18. On the other hand, the HB9 and HB10 hybrids were the two hybrids with the lowest JTP with a value of 28.33. Based on the characteristics of harvested cob weight per plot, HB1 was the hybrid with the highest BTP value, namely 7.02. However, the BTP of this hybrid was not significantly different from HB2, HB3, HB4, HB7, HB8, HP13 and BISI 18. On the other hand, the HB 9 hybrid was the hybrid with the lowest harvested ear weight (3.38). Meanwhile, the yield character has a potential pattern that is relatively exactly the same as the harvested ear weight character per plot, where the HB1 hybrid was the hybrid with the best yield, namely 6.45 ton ha^{-1}. However, this potential is not significantly different from HB2, HB3, HB4, HB6, HB7, HB8, HP13 and BISI 18. On the other hand, the hybrid with the lowest yield potential was HB9 (3.34 ton ha^{-1}).

DISCUSSION

The results of the ANOVA analysis show that characters that are not significantly influenced by genotype diversity have low heritability, while characters that are significantly influenced have moderate to high heritability. In general, the use of ANOVA and heritability is an initial approach in evaluating the potential of a hybrid line. Both are complementary analyzes[1,2]. Heritability has a strong connection to ANOVA, especially in assessing potential environmental variability[3,4]. Detected environmental diversity will make it easier to assess potential genetic and phenotypic diversity in a population, so ANOVA is often used as a basis for estimating heritability values[1]. However, using ANOVA without the heritability detail consideration will result in a rough assessment. This can be seen from the heritability of characters that are significant in ANOVA, which is not always indicated as high heritability. Therefore, the use of both analyzes in this research is appropriate as an initial selection of evaluation characteristics.

Based on the heritability results, the yield character has moderate heritability. This indicates that there is still quite a large potential for environmental diversity to influence the general diversity of potential productivity of hybrid lines. This phenomenon will have implications for the assessment process, so that the use of several important characteristics supporting production needs to be included as a basis for selection[5,6]. Estimation of production supporting characteristics can be done using a combination of correlation analysis and path analysis. Correlation and cross-tracing are a combination of analytical approaches that are often used in determining secondary characteristics that support production[7-9]. This combination is considered quite effective in determining secondary characters systematically, especially with a large number of observations[2,8,10]. Correlation plays a role in roughly reducing characters that are thought to have a strong relationship with the main character[1,11], while cross-talk plays a role in determining the greatest direct influence of the characters that have been selected in the correlation analysis[2,12,13]. Independent analysis of both can produces quite high bias. Correlation analysis cannot explain cause and effect, while path analysis on very large and unrelated dimensions will reduce the strength of the model and its determination value[11,12]. Therefore, both must be combined to assess important secondary characters in supporting yield potential, including in studies evaluating the potential of corn hybrid lines in this research.

The results of the path analysis in this study did not include the number of harvested ears and the weight of harvested ears per plot. This is because both characters are indicated as characters with a high level of multicollinearity towards productivity[12,14,15]. This is characterized by a very high correlation value with the main character, where the number of harvested ears and the weight of harvested ears per plot correlate 0.89 and 0.98, respectively. These two characters can be directly used as evaluation criteria without going through path analysis. Meanwhile, based on the results of the correlation and path analysis, the stem diameter character is the character with the highest direct influence compared to other characters. This indicates that the stem diameter character can be included along with the number of harvested ears, the weight of harvested ears per plot and the yield as evaluation criteria for the potential of corn hybrid lines. Although the heritability between all these characters is still considered moderate, systematic evaluation can increase the overall heritability potential[6]. Therefore, the entire character can be analyzed further by analyzing the Duncan mean value.

The stem diameter character is one of the vegetative characteristics in this research has quite a good influence in determining the yield of a hybrid line. In general, stem diameter is related to production and lodging[16]. Several reports also explain the correlation between stem diameter and productivity[17-20]. A good stem diameter will support the nutrition and germination resistance of hybrid corn[21,22]. This indicates that hybrid corn should have a stem diameter that is large enough to support production and resistance to corn rot. Based on this, all corn hybrid lines evaluated had good diameter performance, especially the HB1 line. This indicates that all hybrid lines can be optimized as superior hybrid corn lines, especially the HB1 corn hybrid line.

The character of the number of harvested cobs is another important harvest character. This character is also related to the prolific potential of corn hybrid lines. Several studies explain the prolific potential that influences increasing the yield[7,23,24]. In general, prolific potential is closely related to genetics and the environment. However, in this study, the environment was considered relatively the same, so differences in the potential number of harvested cobs were very similar to genetics. This indicates that this evaluation character is important in assessing the potential of a corn hybrid line[7,25]. Based on these evaluation characteristics, the HB1 hybrid line has a higher number of cobs than other genotypes, so this hybrid line has the potential to have high productivity.

The characteristics of the harvested cobs weight per plot and the yield showed strong relationship. The harvested ear weight characteristic is a representative sample of productivity projected in tons per hectare. The relationship between the two is also very well explained by the very high correlation value. Based on these two characters, the corn hybrid lines HB1, HB2, HB3, HB4, HB7, HB8 and HP13 are potential lines with productivity and plot harvest weight that are not significantly different from BISI 18, as the best comparison variety. However, if these lines are combined with other potential characters and considering the deficits with BISI 18, lines HB1, HB2, HB3, HB7 and HP13 are hybrid corn lines that have the potential to be superior hybrid corn lines. Therefore, based on overall considerations, hybrid corn lines HB1, HB2, HB3, HB7 and HP13 can be recommended when considering the release of hybrid corn varieties.

CONCLUSION

This research shows that the use of correlation and path analysis is important in identifying important characters in evaluating the potential of hybrid corn. The characteristics of stem diameter, number of harvested ears, weight of harvested ears per plot and productivity are important evaluation characters for hybrid corn lines. The hybrid corn lines HB1, HB2, HB3, HB7 and HP13 have good potential based on the overall evaluation characteristics, especially HB1. Therefore, these five hybrid lines can be recommended when considering the release of hybrid corn varieties.

SIGNIFICANCE STATEMENT

Based on this study, the characteristics of stem diameter, number of harvested ears, weight of harvested ears per plot and productivity are important evaluation characters for hybrid corn lines. The Unhas hybrid corn lines HB1, HB2, HB3, HB7 and HP13 have good potential based on the overall evaluation characteristics, especially HB1. Therefore, these five Unhas hybrid lines can be recommended when considering the release of hybrid corn varieties.

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