JAPSI (Journal of Agriprecision and Social Impact)
Volume 2 Issue 1 March 2025
e-ISSN: 3032-7849; p-ISSN: 3046-5397, Page 140-152
DOI: https://doi.org/10.62793/japsi.v2i1.51
Available online at: https://journal.kdp.co.id/index.php/japsi

Determining the Relationship Between Yield and Yield Components in Sunflower (*Helianthus annuus* L.)

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Abstract. *Sunflower (Helianthus annuus L.) is an essential commodity with various benefits in food, health, and industry and has a high economic value. The national sunflower plants' productivity is low, so to fulfill the market demands, creating sunflower varieties with high yields has been challenge for plant breeders. This study analyzed the relationship between yield components and sunflower yield, identifying characteristics affecting productivity. Plant selection was carried out by understanding the relationship between yield components and seed yield using statistical methods: correlation, multiple regression, and path analysis. The research was conducted in Ampeldento Village, Karangploso District, Malang Regency, East Java, from March to August 2024, using 13 genotypes of F5 open pollinated generation sunflower. Plant traits observed were plant height, number, leaf length and width of leaves, stem diameter, flowering time, harvesting time, disc flower diameter, number of seeds per plant, 100 seed weight, and seed yield. The results showed that seven yield component characters closely related to seed yield, with positive and negative correlation patterns. The number of seeds per plant had the highest direct effect, while the highest indirect effect occurred in the number of seeds per plant, which was influenced by plant height, number of leaves, stem diameter, flowering time, harvest time, and 100 seed weight. These findings provided important insights for breeding strategies in selecting superior sunflower genotypes.*

Keywords: *Correlation, Path analysis, Regression, Sunflower yield*

Received: January 7, 2025; Accepted: February 27, 2025; Published: March 1, 2025
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INTRODUCTION

Sunflowers are plants with high economic value and are widely used in the food, health supplements, and beauty industries. The demand for sunflower seeds cannot be fulfilled from domestic production, mainly due to the low productivity of the plant, so imports from other countries were the solution. The tropical climate conditions in Indonesia are suitable for the growth and development of sunflower plants. Therefore, sunflowers have the potential to be planted and developed in Indonesia (Santika et al., 2021). High productivity is a major goal for plant breeders to create new superior sunflower varieties through plant selection. One of the ways to accelerate and increase accuracy in the selection of plants is to provide information about the plant characteristics that support the high production of sunflower plants. The information about the relationship between yield components and yield is needed here (Ali et al., 2023). The relationship between these characters could be gained through various statistical analysis methods that are applied to obtain the right characters to be used as selection criteria in the plant breeding program. Some of these statistical methods include correlation, regression, and path analysis. The simultaneous use of these methods can be used to identify factors that influence yield and make breeders design more effective strategies to develop superior plant varieties in terms of quality and productivity (Gopi et al., 2023; Susanti et al., 2019; Radic et al., 2016). This study aimed to determine and analyze the relationship and pattern of relationships and the direct and indirect effects between yield component characters on sunflower yields.

LITERATURE REVIEW

Sunflowers with full light intensity can grow optimally at 200-1200 meters above sea level. Sunflowers are suitable for cultivation in all weather, but this plant is most productive in areas with sufficient humidity and direct sunlight (Jaenudin et al., 2016). The morphology of sunflower plants is around 1-3 meters in height with an upright and sturdy shape, a strong taproot system, and flowers that always follow the direction of sunlight from morning to evening (heliotropic). Sunflowers are cross-pollinated plants. Sunflowers are also among the plants whose selection must be done after flowering (Jocic et al., 2010).

The relationship between yield components and sunflower yield must be studied to help the breeder select the superior genotypes which has high productivity. Information about the characteristics of yield components significantly related to yield characteristics is important to help breeders select traits that can increase crop yields (Hapsari & Herlina, 2019). The resulting component characters and the resulting characters have a mutually supportive relationship or vice versa. Therefore, the reciprocal relationship was analyzed using statistical methods, namely correlation, multiple regression, and path analysis. Correlation is a statistical method for determining the closeness of the relationship between two or more variables (independent variable and dependent variable), which can be a positive or negative relationship (Purba, 2022). Correlation coefficients show relationships among independent characteristics and the degree of linear relation between these characteristics in general. However, describing this relationship is insufficient when the causal relationship among characteristics is needed (Güler et al., 2001). Multiple regression is an analysis of relationship patterns or equations in which changes in one variable are influenced by more than one other variable so that the intensity of the relationship is known and the prediction of the Y value over the X value (Prasetyo et al., 2018). Path analysis is used to obtain further information about the causes and determine the direct and indirect effects of the causal components on the effect component (Yudiatmaja, 2021).

RESEARCH METHODS

This research was carried out from March to August 2024 in Ampeldento Village, Karangploso District, Malang Regency, East Java. The material used was sunflower seeds from 13 genotypes of open pollination F5 generations. This experiment used a single-plant observation method: planting all plants without replication and observing each plant. The variables observed included plant height, number of leaves, leaf length, leaf width, stem diameter, flowering time, harvest time, disk flower diameter, number of seeds per plant, weight of 100 seeds, and seed yield. The data were analyzed using correlation analysis, multiple regression, and path-analysis analysis using OPSTAT (Online Statistical Analysis Tools) software (Sheoran, 1998)**.**

RESULTS AND DISCUSSION

Correlation between Yield Components and Yield

The results of the correlation coefficient between the components of yield and seed yield are shown in Table 1. It showed characters with very significant and not absolute positive correlation values with the yield. Some characters were very significant positive correlation values, which were plant height and seed yield (0.76), number of leaves and seed yield (0.91), stem diameter and seed yield (0.71), flowering time and seed yield (0.91), harvest time and seed yield (0.784), number of seeds per plant and seed yield (0.96), weight of 100 seeds and seed yield (0.76).

The yield component characteristics with a very significant positive correlation with the seed yield character were plant height, number of leaves, stem diameter, flowering time, harvest time, number of seeds per plant, and weight of 100 seeds. This result was agreed upon by Sincik and Goksoy (2014), who concluded that plant height was positively correlated with yield. Apart from that, according to Baraiya et al. (2018), the characteristics of the number of leaves, stem diameter, flowering and harvesting time, the weight of 100 seeds, and the number of seeds per plant were positively correlated with yield character. These results meant that an increase in those characters would follow an increase in seed yield.

Table 1. Correlation between yield component characters and sunflower seed yield

	PH	NL	LL	LA	SD	FT	DD	HT	NS	W100	SY
PH	1										
NL	0.91**	1									
LL	0.27^{NS}	-0.05^{NS}	1								
LA	0.81**	0.70**	0.55^{NS}	1							
SD	0.91**	0.85**	0.30^{NS}	0.77**	1						
FT	0.87**	0.97**	-0.01^{NS}	0.69**	0.84**	1					
DD	0.43^{NS}	0.17^{NS}	0.71**	0.54^{NS}	0.43^{NS}	0.20^{NS}	1				
HT	0.68*	0.82**	-0.20^{NS}	0.41^{NS}	0.67*	0.90**	-0.03^{NS}	1			
NS	0.77**	0.89**	-0.001^{NS}	0.64*	0.77**	0.90**	0.12^{NS}	0.72**	1		
W100	0.76**	0.72**	-0.06^{NS}	0.33^{NS}	0.66*	0.73**	0.34^{NS}	0.68*	0.65*	1	
SY	**0.76****	**0.91****	-0.17^{NS}	0.50^{NS}	**0.71****	**0.90****	0.05^{NS}	**0.78****	**0.96****	**0.76****	1

Description: PH:plant height; NL:number of leaves; SD:stem diameter; FT:flowering time; HT harvest time; NS:number of seeds per plant; W100:weight of 100 seeds; Y:seed yield; *:significant; **:very significant; $^{NS:}$not significant

Stem diameter shows the strength and capacity of the plant to support optimal growth. Stem is related to the nutrient-carrying capacity because, in the stem, there is transport tissue (xylem and phloem), which carries water, nutrients, and the results of photosynthesis (Cartono, 2024). The larger the stem diameter, the greater the carrying capacity of the tissue, thereby supporting optimal growth of the plant as a whole. A larger stem diameter indicates a more muscular (vigor) and healthier plant. In plants that produce fruit or seeds, a prominent stem diameter is needed to support the additional load produced by the fruit or seeds. Stem diameter is important because the fruit and seeds often weigh significantly and must be supported by a robust stem. In addition, strong stems can survive extreme weather conditions such as strong winds, thus protecting other parts of the plant (Nurwardani, 2008). Flowering and harvest time are often important indicators of plant reproduction time. Plants that flower and harvest faster are more efficient in their production cycle by producing better harvests (Gopi, 2023).

Variations in flowering and harvest time would influence plant yield potential because the timing of reproduction is critical for photosynthetic efficiency and energy distribution within plants (Gjorgjieva et al., 2014). The number of seeds per plant indicated that the more seeds produced, the higher the potential yield. The number of seeds per plant is one of the parameters that directly correlates with final production and crop yield is often measured in total seed production (Alipatra et al., 2018). The weight of 100 seeds reflected the size and quality of the seeds. Larger and heavier seeds usually indicated better quality and a more significant contribution to total yield. Characters such as plant height, number of leaves, stem diameter, flowering time, harvest time, number of seeds per plant, and weight of 100 seeds are correlated with yield because these characters are important indicators of plant growth efficiency, reproduction, and the quality and quantity of yield seed.

Regression between Yield and Yield Components

Based on the analysis results, a multiple linear regression equation was obtained (Table 2). The regression coefficient for the variables plant height, number of leaves, flowering time, disk flower diameter, and number of seeds was positive, meaning that when some of these variables increased, the yield of sunflower seeds would also increase. The regression coefficient for stem diameter, harvest time, and weight of 100 seeds was negative, meaning that when some of these variables increased, the yield of sunflower seeds would be decreased. The equation obtained from the regression analysis in the table was Seed Yield (Y) = $36{,}143 + 0{,}28_{PH} + 0{,}069_{NL} - 2{,}437_{SD} + 0{,}604_{FT} - 0{,}222_{HT} + 0{,}091_{NS} - 0{,}448_{W100}$.

Table 2. Multiple Regression Test Results for Yield Component Characteristics and Sunflower Seed Yield

Variable	Regression coefficient	F Value	Sig	Intercept	R^2	Equity
PH = X1	0.28	71.175	0.014	36.143	0.997	$Y = 36{,}143 + 0{,}28X_1 + 0{,}069X_2 - 2{,}437X_5 + 0{,}604X_6 - 0{,}222X_8 + 0{,}091X_9 - 0{,}448X_{10}$
NL =X2	0.069					
SD = X5	-2.437					
FT = X6	0.604					
HT = X8	-0.222					
NS = X9	0.091					
W100 = X10	-0.448					

Description: PH:plant height; NL:number of leaves; SD:stem diameter; FT:flowering time; HT harvest time; NS:number of seeds per plant; W100:weight of 100 seeds; Y:seed yield; R^2 :coefficient of determination; Sig:significance

The yield and yield components had positive and negative relationship patterns. The positive relationship pattern is that if the yield component character increases by 1 unit, the seed yield will also increase. Meanwhile, the negative relationship pattern occurs if the component value increases by 1 unit and the seed yield decreases by the value of that character. This result aligned with the statement of Iqbal (2015) that the independent variable had a unidirectional influence on the dependent variable, while a negative relationship showed an influence in the opposite direction on the dependent variable. Based on the multiple regression equation obtained from the overall data, the variables stem diameter, harvest time, and weight of 100 seeds had negative values. In theory, this indicated that every increase of 1 unit will reduce the results by the value of each variable. Theoretically, the larger the stem diameter, the more linear the contribution to seed yield. However, some factors influence this value negatively.

The results of the observation values for the stem diameter of the 13 genotypes varied quite widely from one to another. Some studies showed that larger stem diameters could increase the number of seeds and seed weight per head, ultimately increasing total yield, but others showed that larger stem diameters were not always directly related to increased seed yields (Ahmad et al., 1991; Kholghi et al., 2011). Stem diameter has an important role in determining sunflower yield. Although larger stem diameter was often associated with increased grain yield, the effect can be varied depending on genetic factors, environment, plant density, and other agronomic treatments such as fertilization

(Mahar et al., 2007). Sunflower plants with larger stem diameters might appear to have a balance that leans more toward vegetative growth than reproduction. The regression equation for harvest time and seed yield had a negative regression coefficient of 0.222, which meant that an increase in harvest time could be associated with a decrease in seed yield or that earlier harvesting could increase seed yield by 0.222 g. Several particular problems in plant growth can explain the negative regression coefficient on sunflower seed yield.

Data obtained from 13 genotypes had different harvest times. The longer the plant had the harvest time, the quality of sunflower seeds tended to decrease. This is caused by plants' natural aging process, which reduces seed components such as oil and protein. This reduction in quality directly impacted grain yield, which was measured in terms of weight or volume (Khilola et al., 2023). Several studies have shown that longer harvest times often conflicted with seed yields. This is because plants that take longer to mature might experience more environmental stress and lose efficiency in resource allocation (Ahmad et al., 1991) (Pandya et al., 2016) (Riaz et al., 2019). This result also agreed with the research result by Smith et al. (2020), which found that harvesting sunflower seeds in the early maturity phase produced better quality and higher yields than harvesting after the seeds fully matured. The weight of 100 sunflower seeds in this equation also had a negative regression coefficient of 0.448, where every 1 g of the weight of 100 seeds increased would reduce the seed yield by 0.448. The negative coefficient value is due to the different variations in seed morphology (length, width, and thickness of seeds) produced by each genotype. The length, width, and thickness of sunflower seeds are some morphological factors that influence seed production and weight. The results obtained through observations showed variations in the seed morphology of the 13 genotypes. The longer, wider, and thicker seed size indicated the potential for higher seed production because the morphology of these seeds tends to have a larger volume and contain more food reserves (Ovuka et al., 2016). Each variety has different genetic advantages, so each variety has different production, depending on the nature of the plant variety itself (Soegito & Arifin, 2004).

The analysis data showed that the characteristics of the yield components significantly influenced seed yield. Sujarweni (2015) stated that if the sig value is < 0.05, then it can be concluded that the independent variable (X) has a significant effect on the dependent variable (Y), and if the sig value is > 0.05. It can be concluded that the independent variable (X) has no significant effect on the dependent variable (Y).

Path Analysis between Yield Components and Yields

The direct and indirect effects of yield components on seed weight yield are presented in Table 3.

Table 3. Direct and Indirect Effects between yield components and sunflower seed yield

	DE	PH	NL	LL	LA	SD	FT	DD	HT	SN	W100	Total
PH	0.43		0.04	-0.01	-0.28	-0.25	0.27	0.02	-0.06	**0.63**	-0.02	0.76
NL	0.05	0.39		0.00	-0.24	-0.23	0.31	0.01	-0.08	**0.73**	-0.02	0.91
LL	-0.05	0.11	0.00		-0.19	-0.08	0.00	0.03	0.02	0.00	0.00	-0.17
LA	-0.35	0.35	0.03	-0.03		-0.21	0.22	0.02	-0.04	0.52	-0.01	0.50
SD	-0.27	0.39	0.04	-0.02	-0.27		0.27	0.02	-0.06	**0.64**	-0.02	0.71
FT	0.32	0.37	0.05	0.00	-0.24	-0.23		0.01	-0.08	**0.74**	-0.02	0.91
DD	0.04	0.19	0.01	-0.04	-0.19	-0.12	0.06		0.00	0.10	-0.01	0.05
HT	-0.09	0.29	0.04	0.01	-0.14	-0.18	0.28	0.00		**0.60**	-0.02	0.78
NS	**0.82**	0.33	0.04	0.00	-0.22	-0.21	0.28	0.01	-0.07		-0.02	0.96
W100	-0.03	0.32	0.03	0.00	-0.11	-0.18	0.23	0.01	-0.06	**0.54**		0.76
	Residual 0.00280											

Note: PH=plant height, NL=number of leaves, SD=stem diameter, FT=flowering time, HT harvest time, NS=number of seeds per plant, W100=weight of 100 seeds, DE=direct effect Y=seed yield

Table 3 shows that the most significant direct effect on seed weight came from the number of seeds (0.824). Significant indirect effects were found on the number of seeds through flowering time (0.738) and the number of seeds through the number of leaves (0.732).

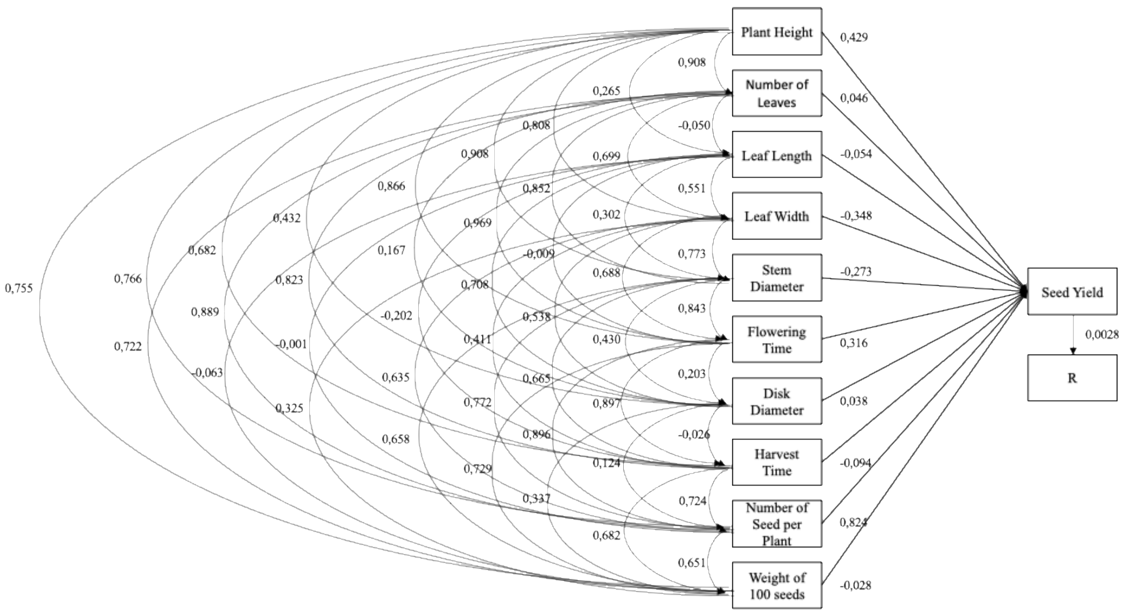

Figure 1. Path diagram of the direct and indirect influence of yield components on sunflower seed yield

Diagram (Figure 1) provides an overview of the direct and indirect effect of independent variables on the weight of sunflower seeds. The independent variables consisted of plant height, number of leaves, leaf length, leaf area, stem diameter, flowering time, disk flower diameter, harvest time, number of seeds per plant, weight of 100 seeds, and seed yield. Arrows pointing directly to the seed yield box indicated the direct effect of each variable on seed weight. Curved lines connecting independent variables indicated indirect effect through other variables. The R-value or residual value of 0.0028 influenced different variables not included in the research.

Based on the results of path analysis, the yield component character with the highest positive direct effect value was the character of the seed number per plant. Research by Kartika and Ardiarini (2019) showed that the most significant positive direct effect was the number of seeds per plant through genotypic and phenotypic correlations. A positive direct effect on a character was a positive and actual correlation to the yield (Gjorgjieva et al., 2014). This research showed that increasing the number of seeds per plant would increase seed yield. Therefore, selecting genotypes with high seed yields would be more efficient if it was carried out by choosing the number of seeds per plant. The direct effect of other yield component characteristics that were very small or negative can be considered a selection criterion if the total effect is considerable (Sadiyah et al., 2015). The most significant indirect effect value was the number of seeds through the characters, number of leaves, stem diameter, harvest time, and weight of 100 seeds. If the indirect effect value is more significant, then the relationship between the independent and dependent variables is more complex because many interactions through other variables must be considered. Direct and indirect effects through intermediary variables must be considered when making a decision because strong indirect effects can significantly impact the results (Streiner, 2005).

CONCLUSION

The number of seeds per plant, number of leaves, flowering and harvest time, plant height, weight of 100 seeds, and stem diameter were closely related to sunflower seed yield. A positive relationship pattern was found in the plant height, number of leaves, flowering time, and number of seeds. In contrast, a negative relationship pattern was identified in the stem diameter, harvest time, and weight of 100 seeds. The most significant direct positive effect was the number of seeds per plant, followed by plant height and flowering time on increasing sunflower seed yield. The most significant indirect impacts on yield were plant height, number of leaves, stem diameter, flowering and harvest time, and weight of 100 seeds.

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