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Research Article

Correlation and Regression Analyses of Disease and Agronomic Traits of Ethiopian Mustard (Brassica Carinata A. Braun.) Genotypes

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Abstract

Ethiopian mustard (*Brassica carinata A. Braun*) is an important oilseed crop with significant potential for food and energy production. The study evaluated 36 genotypes using a 6 x 6 lattice design to analyze correlations and regression among traits, aiming to understand their relationships and identify key traits for developing high-performing varieties. The analysis of variance revealed significant variation ($p < 0.001$) for traits including seed yield, flowering time, maturity date, disease resistance, thousand seed weight, oil content and oil yield; indicating the potential for genetic improvement. However, traits such as downy mildew resistance, leaf spot and branching showed non-significant variation, suggesting these traits may be more influenced by environmental factors than by genetic differences among the genotypes. Pearson correlation coefficients highlighted significant relationships among traits. Days to flowering ($r = 0.687$) and maturity ($r = 0.029$) positively correlated with yield, while disease traits negatively impacted seed yield. Notably, Thousand Seed Weight ($r = 0.985$) strongly correlated with yield, underscoring the importance of seed size. A multiple regression model explained 99.7% of the variation in seed yield, with a highly significant intercept (1863.35, $p < 0.001$). Key associations were found with secondary branches (12.32), oil content (-46.79) and oil yield (2.19). This study confirms the potential for improving Ethiopian mustard yield through genetic selection of key traits. It is recommended that breeding programs focus on enhancing seed size and disease resistance while considering environmental factors to maximize yield potential.

Keywords

Ethiopian Mustard, Multiple Regression, Pearson Correlation

1. Introduction

Ethiopian mustard (Brassica carinata) is an important oilseed crop of Ethiopian origin with significant potential for use as a food crop and a sustainable energy source [1, 2]. The crop's versatility in producing both oilseeds and leafy vegetables, as well as its potential for use in the production of biofuels like biodiesel, make it an important crop [3]. Ethiopian mustard's ability to withstand harsh weather conditions makes it a valuable crop to grow in the face of climate change [2, 3]. Due to its many agronomically useful characteristics, such as its resilience to a variety of abiotic and biotic stresses,

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it could be used as a donor in interspecific hybridization to enhance other Brassica Species [2]. Moreover, the abundant amount of glucosinolet in its leaves, which adds mild flavor and possible health advantages when consumed by humans [4]. However, its indeterminate growth habit, tall and branched plant structure, low seed yield, extended maturity period, and low oil content remain significant challenges in fully realizing its potential as a globally adaptable crop [2, 3]. Thus, it should be a top priority to develop high seed yielding cultivars with farmers' desired features that are resistant to biotic and abiotic stress [1]. In order to exploit the genetic potential of the crop many studies have been conducted to understanding trait relationships and patterns of the genetic diversity in germplasm.

Several studies have reported correlation analysis based on agronomic, physiological, oil and fatty acid related traits [4-10]. Alemayehu and Becker [11] employed a mixed linear model for genetic analysis to estimate and predict genetic parameters and interactions for traits like glucosinolet, oil, and protein content. Mekonnen et al. [12], also assessed the genetic diversity in Ethiopian mustard populations indicates substantial genetic diversity within the studied populations. There is a need to diversify the genetic base of Ethiopian mustard to safeguard from future biotic and abiotic threats.

The productivity of Ethiopian mustard has not been as effectively increased by direct selection for yield alone, since yield is complex and influenced by various factors [1, 12]. Correlation and multivariate studies can be used to leverage the correlations between yield and its associated characters for yield improvement. This strategy would aid in determining the most important traits that advance breeding initiatives to boost yield and disease resistance. Trait association studies are crucial for making informed selections, as they help to identify the key traits that contribute most to achieving progress in any breeding and crop improvement.

Correlation analysis measures the mutual relationship among various plant traits and determines the component traits on which selection can be based for improvement in yield and other important traits. It have been a valuable tools in understanding trait relationships The knowledge of association of several characters with yield and among themselves will be therefore, very essential for planning a successful breeding programme [12, 13]. Multiple linear regression (MLR) is an effective statistical method for examining the relationship between a single dependent variable and multiple independent variables [14]. It is commonly used to predict crop yields by considering various agronomic, disease and environmental factors. MLR models have been utilized to estimate yields in crops such as rice, coffee, and peas [15-17]. Although some reports provide understandings into trait correlations in Ethiopian mustard, there is a notable lack of comprehensive correlation and regression analyses specifically focused on disease resistance and agronomic traits. Further research in this area could offer valuable information for breeding programs aimed at improving both high yielder and disease-resistant varieties. Investigating the magnitude and nature of relationships among morphological, yield and disease related traits, along with the strength of their associations, is essential for a comprehensive understanding of their impact on the crop performance. Therefore, this study was designed to assess correlations and perform regression analysis on morphological, yield and disease traits to understand their relationships, predict outcomes and identify key traits that could contribute to the development of improved high-performing Ethiopian mustard varieties.

2. Material and Method

2.1. Description of the Study Site

The field experiment was carried out at Holetta Agricultural Research Centre. Holetta is located in the Oromiya National Regional State, about 30 kilometers southwest of Addis Ababa, at an altitude of 2400 meters above sea level, with geographic coordinates of 09°04' N latitude and 38°30' E longitude. The area receives an average annual rainfall of 1144 mm, with minimum and maximum temperatures of 6℃ and 22℃, respectively.

2.2. Field Layout

The experiments were laid out in a 6 x 6 simple lattice design where each genotype was planted in a plot consisting of 4 rows with plot sizes 3m length, 30 cm row spacing and 60 cm between block. All agronomic practices were carried out uniformly for each plot.

2.3. Data Collection

Data were collected on various traits as follows: Phonological data, including days to 50% flowering (DF) and days to 50% maturity (DM), were recorded on a plot basis. Disease data, encompassing downy mildew (DoM), aphid infestations (AI), leaf spot (LS) and black leg (BL), were also collected on a plot basis. Plant height (PH), number of primary branches per plant (NPB), number of secondary branches per plant (NSB), and number of capsules per plant (NC) were measured from ten randomly selected plants from the central row of each plot. Additionally, seed yield per hectare (SY), thousand seed weight (TSW), oil content (OC) and oil yield (OY) were recorded from the harvested central rows.

2.4. Data Analysis

Analysis of variance (ANOVA) was performed on individual traits to determine whether there were significant differences among the genotypes, following the standard statistical procedure outlined by Gomez and Gomez. The following model structure is used for ANOVA as explained by Cochran and Cox [18]:

$$Yij=\mu+Gi+Bj+\epsilon ij$$

where:

Yij is the observation for the ith genotype in the jth block

μ is the grand mean

Gi is the effect of the ith genotype

Bj is the effect of the jth block

ϵij is the random error term

Interrelationships between the studied characteristics were determined by calculating Pearson's correlation coefficients and visualized using heat map and correlation matrix [19].

A multiple linear regression analysis was conducted to assess the strength of the relationship between agronomic and disease traits and final seed yield. The following regression model were used for the analysis:

$$SY=\beta 0+\beta 1DF+\beta 2DM+\cdots+\beta 13OY+\epsilon$$

Where:

SY is seed yield (response variable).

DF, DM, PH, DoM, AI, etc., are the predictor variables (independent variables).

β0 is the intercept, and β1, β2,…, β13 are the regression coefficients.

ϵ is the random error term.

After fitting the multiple linear regression model, regression coefficients and their significance (p-values) will be evaluated to determine the effect of predictors on seed yield. The R-squared (R^2) will measure the explained variability in seed yield, while Variance Inflation Factors (VIF) will be used to check for multicollinearity, with values above 10 indicating potential issues [20]. All data analysis were conducted using R software V4.3 [21].

3. Result and Discussion

3.1. Analysis of Variance (ANOVA)

The analysis of variance (ANOVA) revealed significant genotype variation for several important agronomic traits (Table 1). Seed Yield (SY) ($p = 0.01$), Days to Flowering (DF) ($p < 0.0001$), and Days to Maturity (DM) ($p < 0.0001$) exhibited strong genotype effects, suggesting these traits can be effectively improved through genetic selection. Additionally, Thousand Seed Weight (TSW) ($p < 0.0001$), Oil Content (OC) ($p < 0.0001$), and Oil Yield (OY) ($p = 0.0096$) were significantly influenced by genotype, indicating potential for enhancing both yield quality and marketability through targeted breeding in Ethiopian mustard. However, some traits related to disease resistance and plant structure showed no significant genotype effects. Downy Mildew (DoM) ($p = 0.614$) lacked genetic variation, pointing to environmental factors as the dominant influence. Aphid Infestation (AI) ($p = 0.0005$) and Blight (BL) ($p = 0.0002$) showed significant variability, indicating susceptibility differences across genotypes. In contrast, Leaf Spot (LS) ($p = 0.35$) did not exhibit genotype-related differences. Similarly, Number of Primary Branches (NPB) ($p = 0.76$) and Number of Secondary Branches (NSB) ($p = 0.81$) were unaffected by genotype, while Plant Height (PH) ($p = 0.022$) showed a marginal genotype effect, indicating that genetic factors may have a modest influence on this trait. These findings highlight the potential for breeding programs to target significant traits like yield and quality, while non-significant traits suggest areas where further research is needed to better understand environmental influences and improve resistance.

Walle et al. [22] reported significant variability for primary and secondary branches, our study did not find genotype effects for both traits, suggesting that environmental factors or different genetic backgrounds may play a vital role in these traits. The consistent significance of traits like days to flowering, oil content, days to maturity, plant height, and seed yield were observed in previous studies [22-24] underscores the genetic diversity present in Ethiopian mustard germplasm, which remains a valuable resource for crop improvement. These findings collectively emphasize the importance of selecting for traits such as yield potential, oil content, and maturity timing to develop high-performing Ethiopian mustard varieties [6, 22]. Studies indicate substantial genotypic variation exists within Ethiopian mustard germplasm collections for various traits, including potential disease resistance, Zhou et al. [25] identified three Ethiopian mustard accessions with resistance to green peach aphid. Ethiopian mustard has a significant agronomic traits, particularly its stress resistance [2, 24]. The variability in disease susceptibility among Ethiopian mustard genotypes highlights the need to integrate disease resistance into breeding programs for sustainable crop production. Significant genotype effects suggest that genetic differences influence resistance to specific diseases. Some genotypes show inherent pest resistance, providing insights for breeding efforts. This knowledge allows breeders to implement targeted strategies, accelerating the development of robust varieties. Identifying resistant genotypes also improves pest management and enhances understanding of disease dynamics. Additionally, this variation can help researchers uncover the genetic mechanisms behind resistance and susceptibility, guiding future breeding initiatives.

Table 1. Analysis of variance for disease susceptibility and agronomic traits of Ethiopian mustard genotypes.

Trait	Sum of Squares	Mean Square
SY	28505750.17	814450.00**
DF	1675.82	47.88***
DM	970.50	27.73***
DoM	1.14	0.03ns
AI	5.00	0.14***
LS	3.57	0.10ns
BL	91.28	2.61***
PH	15308.15	437.38*
NPB	68.00	1.94ns
NSB	186.62	5.33ns
NC	12855.28	367.29ns
TSW	20.33	0.58***
OC	391.78	11.19***
OY	6002118.66	171489.10**

NB: DF (days to flowering); DM (days to maturity); DoM (Downey mildew); AI (Aphid infestation); LS (leaf spot); BL (Blight); PH (plant height); NPB(number of primary branch); NSB (number of secondary branch); NC (number of capsule or pod per plant) SY (seed yield); TSW (thousand seed weight); OC (oil content) and OY (oil yield)

3.2. Correlation Analysis

Figure 1 shows the Pearson correlation coefficients heatmap of agronomic and disease traits in Ethiopian mustard genotypes between seed yield (SY) and other agronomic traits. The correlation analysis revealed significant relationships between Seed Yield (SY) and various agronomic and disease traits in the evaluated genotypes. Notably, Days to Flowering (DF) showed a strong positive correlation with SY (r = 0.687), suggesting that earlier flowering may contribute to higher seed yields, as indicated by the blue color in the heatmap. Additionally, Days to Maturity (DM) also exhibited a positive correlation with SY (r = 0.029), although this relationship was weaker, indicating that maturity time might play a lesser role in influencing yield. In terms of disease traits, Aphid Infestation (AI) demonstrated a negative correlation with SY (r = -0.244), highlighting that increased aphid pressure is associated with reduced seed yield. Similarly, Leaf Spot (LS) (r = -0.172) and Blight (BL) (r = -0.121) were also negatively correlated with SY, indicating that these diseases can adversely affect yield potential. Moreover, Plant Height (PH) exhibited a negative correlation with SY (r = -0.218), suggesting that excessively tall plants may not necessarily translate to higher yields, possibly due to increased susceptibility to lodging. Conversely, Thousand Seed Weight (TSW) showed a strong positive correlation with SY (r = 0.985), emphasized by a deep blue color, underscoring the critical role of seed size in determining overall yield performance. Additionally, Oil Content (OC) (r = 0.336) and Oil Yield (OY) (r = 0.016) also exhibited positive correlations with SY, further underscoring the interconnectedness of yield and oil production traits.

The correlation matrix and corresponding heatmap underscores the importance of selecting genotypes that not only exhibit desirable flowering and maturity traits but also demonstrate resistance to key diseases. Understanding these relationships will enhance breeding strategies aimed at improving seed yield while managing disease pressure effectively.

The current findings are consistent with Amsalu [24], who reported on key traits such as days to maturity, seed yield, oil content, and plant height. Both analyses emphasize the importance of these traits in breeding programs for Ethiopian mustard, highlighting their interrelatedness and impact on oil production. Similarly, Teklehaymanot et al. [4] reported significant correlations involving plant height and the number of branches in relation to yield traits. Additionally, a strong negative correlation between days to 50% flowering and plant height has been documented [6, 22]. Furthermore, Getinet et al. [5] found a positive correlation between seed weight and oil content, underscoring the complex relationships among these traits.

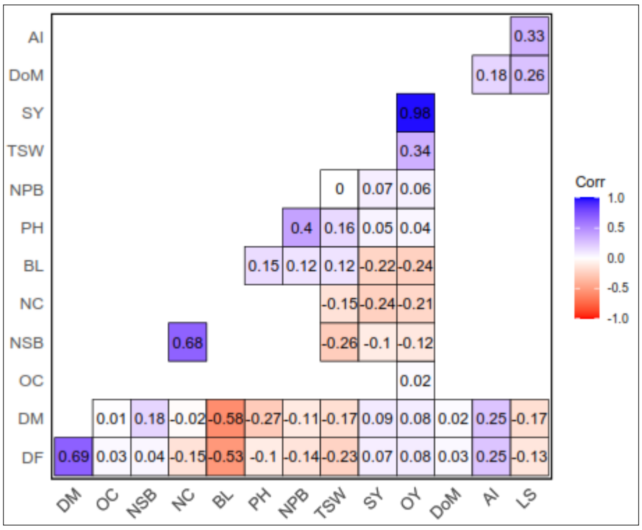

Figure 1. *Correlation Heatmap of Agronomic and disease Traits in Ethiopian Mustard genotypes.*

3.3. Regression Analysis

The multiple regression analysis was performed to evaluate the relationship between various predictor traits and the response variable seed yield (SY). The model explained a significant proportion of the variance in the response variable, as indicated by the high multiple R-squared value of 0.9976 and the adjusted R-squared of 0.9971 (Table 2). This suggests that approximately 99.7% of the variance in the response variable can be explained by the predictors in the model. The extremely small p-value (< 2.2e-16) indicates a strong statistical significance for the overall regression model. This suggests that the likelihood of the model's results occurring by chance is virtually zero. In practical terms, the model is highly reliable, confirming that at least one or more of the predictors (traits) have a significant impact on the response variable, seed yield. This strong significance reinforces the model's validity and its capacity to explain variations in seed yield based on the studied traits. The residual standard error is 43.78, reflecting the average deviation of the observed values from the predicted trait. While this value is relatively high, the exceptional fit indicated by the R-squared values suggests that the model's predictions are generally precise.

Multiple regression analysis is a robust statistical technique that evaluates the relationships between various predictor traits and the response variable like seed yield (SY). This approach enables researchers to examine the cumulative effects of several independent variables on the dependent variable while accounting for the influence of other factors. The high R-squared and Adjusted R-squared values indicate an excellent fit of the model to the data, demonstrating that the predictors included are highly effective in explaining the variance in the dependent variable. The extremely low p-value of the F-statistic reveals the overall significance of the regression model, confirming that the predictors have a meaningful impact on the outcome. A multiple regression model using biological yield, thousand seed weight, and harvest index explained 98.85% of the variation in soybean seed yield [26]. The low p-value of the F-statistic is essential for assessing the overall significance of the regression model. According to Siegel and Wagner [27], the F test evaluates whether the predictor variables collectively significantly impact the response variable. A p-value below 0.05 indicates a statistically significant R-squared value, allowing researchers to interpret individual predictors using t-tests. Multiple regression analysis, along with a low p-value of the F-statistic, effectively evaluates the relationship between predictor traits and seed yield. This method identifies key yield components and quantifies their contributions, making it a valuable tool for crop improvement and management strategies.

The Variance Inflation Factor (VIF) is a widely used diagnostic tool for detecting multicollinearity in regression models, which occurs when independent variables are highly correlated. This can lead to unreliable parameter estimates and inflated variances [28].

Table 2. *Summary of Multiple Regression Analysis Model Performance and Significance Results for Ethiopian mustard Response variable (seed yield) and 13 predictors (traits).*

Metric	Value
Residual standard error	43.78
Degrees of freedom	58
Multiple R-squared	0.9976
Adjusted R-squared	0.9971
F-statistic	1886***
F-statistic numerator degrees of Freedom (df1)	13
F-statistic denominator degrees of Freedom (df2)	18
p-value	< 2.2e-16

VIF measures the extent to which the variance of an estimated regression coefficient is increased due to this collinearity among predictors. The VIF analysis reveals that multicollinearity is not a major concern for most predictors (Table 3), as their VIF values are below the threshold of 5 [20]. However, the predictor TSW has a VIF of 5.40, suggesting a moderate level of multicollinearity. While this does not indicate severe multicollinearity, it may require further investigation to ensure it does not excessively influence the model's results.

The results presented in Table 3 highlight key coefficients and their interpretations. The intercept was 1863.35, which was highly significant ($p < 0.001$), indicating the baseline seed yield when all predictor variables are held constant. The coefficient for the number of secondary branches (NSB) was

12.32 ($p < 0.01$), suggesting that an increase in secondary branches positively influences seed yield. In contrast, the coefficient for oil content (OC) was -46.79 ($p < 0.001$), demonstrating a significant negative association; as oil content increases, seed yield decreases. Oil yield (OY) exhibited the strongest positive relationship with seed yield, with a coefficient of 2.19 ($p < 0.001$), indicating that higher oil yield significantly enhanced by seed yield. Other traits, including did not show statistically significant associations with seed yield.

Table 3. *Regression estimates, significance levels and variance inflation factors (VIF) for Seed Yield of Ethiopian Mustard with 13 Predictor Traits.*

Trait	Estimate	Std. error	t value	p-value	VIF-results
(Intercept)	1863.35***	338.07	5.51	0.001	
DF	-1.42^{ns}	1.53	-0.93	0.358	2.28
DM	2.24^{ns}	2.04	1.10	0.276	2.48
DoM	-18.30^{ns}	30.55	-0.60	0.552	1.22
AI	27.24^{ns}	18.20	1.50	0.14	1.67
LS	-16.97^{ns}	20.63	-0.82	0.414	2.43
BL	2.58^{ns}	5.97	0.43	0.667	2.18
PH	-0.19^{ns}	0.32	-0.59	0.559	1.42
NPB	6.99^{ns}	4.56	1.53	0.131	2.00
NSB	12.32**	3.80	3.25	0.002	3.15
NC	-0.81^{ns}	0.45	-1.79	0.078	5.40
TSW	14.71^{ns}	10.56	1.39	0.169	1.54
OC	-46.79**	2.66	-17.61	0.001	1.82
OY	2.19**	0.02	125.82	0.001	1.50

4. Conclusion

The study highlights significant genotype variations in key agronomic traits of Ethiopian mustard, emphasizing the potential for genetic selection to enhance seed yield, oil content and flowering and maturity times. The analysis of variance (ANOVA) and correlation analyses revealed strong relationships among these traits, indicating that selecting for specific characteristics can lead to improved overall performance. Notably, the strong positive correlations between seed yield and traits such as thousand seed weight and days to flowering suggest that targeted breeding strategies could effectively enhance yield potential. Furthermore, the regression analysis demonstrated a robust relationship between predictor traits and seed yield, with an impressive explanatory power. However, the lack of significant genotype effects for certain traits, particularly in disease resistance, underscores the necessity for further investigation into environmental influences and their impact on these traits. For future research, it is recommended to expand the study to include a broader range of genotypes and environments to gain a more comprehensive understanding of trait interactions. Additionally, integrating molecular techniques could help identify genetic markers associated with disease resistance, ultimately guiding the development of resilient, high-performing Ethiopian mustard varieties. This approach will contribute significantly to sustainable agricultural practices and improve the economic viability of Ethiopian mustard production.

Abbreviations

DF	Days to Flowering
DM	Days to Maturity
DoM	Downey Mildew
AI	Aphid Infestation
LS	Leaf Spot
BL	Blight
PH	Plant Height
NPB	Number of Primary Branch
NSB	Number of Secondary Branch
NC	Number of Capsule or Pod Per Plant

SY	Seed Yield
TSW	Thousand Seed Weight
OC	Oil Content
OY	Oil Yield

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Author Contributions

Birhanu Mengistu Aboye: Conceptualization, Formal Analysis, Methodology, Project administration, Software, Supervision, Writing – original draft

Alemu Doda Gemeda: Data curation, Methodology, Writing – review & editing

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Data Availability Statement

The data is available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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