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GENETIC AND PATH COEFFICIENT ANALYSES OF QUALITY-RELATED TRAITS OF OAT (*AVENA SATIVA* L.) WITH POTASSIUM APPLICATION

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SUMMARY

The experiment on oats transpired during the crop season 2021–2022 according to the split-plot design system of the full randomized complete block design (RCBD) with three replicates. The potassium element was in the chief ingredients in three concentrations (0, 10, and 20 g L^{-1}). The genetic structures, secondary pieces, and results showed that the genetic appearance and environmental conditions under the three concentrations were positive and significant in all qualities. The natural and ecological manifestation analyses in laboratories showed complete, high, medium, and indirect effects in all features under study, with a varying percentage between spraying concentrations. With potassium, the qualities indicated a positive and valuable association with the raw protein of the grain summary of the plant at all levels and had notable indirect effects through some other characteristics.

Keywords: Oat (*Avena sativa* L.), genetic features, correlation, path analysis

Key findings: In the phenotypic and genetic correlations, the percentage (%) of ash had a desirable, positive, and significant association at the level of probability of 1% with the characteristics of crude fiber (%), soluble carbohydrates, and moisture percentage of all concentrations under study, yet was excessive in phenotypic associations (0.6403, 0.4874, 0.6171, 0.7781, 0.8885, 0.6613, 0.7362, 0.6193, and 0.7439); but the genetic associations, it reached 0.7399, 0.545, 0.6226, 0.8432, 1.0789, 0.6418, 0.7877, 0.9797, and 0.8561. However, the environmental correlation coefficients did not have a significant effect.

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INTRODUCTION

The oat (*Avena sativa* L.) belongs to the family Poaceae and is considerably important as an annual and herbaceous plant (Ahmad *et al.*, 2014). Many studies indicate that it was widely cultivated in different parts of the world in the past (Atar *et al*., 2018). The cultivated area worldwide (2018) amounted to about 9.50 million ha, producing 23.50 million t. Germany ranks first based on yield per hectare, followed by Denmark and France (USDA, 2018). Meanwhile, in Iraq, the 2018 cultivated area was about 1066.8 kg ha^{-1}, with a production of one ton (Central Organization for Statistics, Information Technology and Agricultural Reports, 2018).

The estimated associations between traits and the outcome and its components in breeding programs are vital because correlation coefficients are critical indicators that give an idea of the extent of traits' response to selection. The associations between traits emerge through the correlation of genetic factors and the influence of environmental factors, since dormant genes in some genotypes sometimes make them non-expressive in a particular condition but expressive in others. The main reason for the correlation is the multiple effects of the gene affecting two or more characteristics; therefore, the isolation of this gene causes changes in the traits (Al-Dulaimi, 2020). Hence, plant breeders resort to elections for qualities from among the components of the yield since the grain yield trait is a complex one affected by numerous genes and environmental factors, not quickly responding to preference; however, the selection may not be efficient due to the association between the components themselves (Al-Jubouri *et al*., 2009).

Following the path coefficient analysis method is one of the paramount methods applied by plant breeders to analyze and understand the genetic and phenotypic correlations between the various traits for adoption in selection programs (Helsel and Skrdla, 1983; Al-Yasari, 2022). Therefore, determining the prime components affecting the protein of the grain yield for improving traits is the result of a segmentation coefficient. The correlation between the yield and its constituents to direct and indirect effects (Al-Zubaidi and Al-Jubouri, 2016) had the scientist Wright (1921) as the first to use the path coefficient theory by studying the genetic behavior of many quantitative traits and using it to fragment each genetic or environmental correlation. Dividing the yield and one of its components into direct and indirect outcomes enabled determining the component significantly impacting the yield; thus, selecting that component in the desired direction serves as a guide for preferences to improve the final yield. Still, the genetics that control these processes are in continuous research, being considered a complex trait affected by numerous genes. However, it remained the main goal in any breeding program for plants of the Poaceae family (Hassan, 2005). The presented study sought to determine the relationship between the valuable traits related to yield according to path coefficients and the relative relationship of the grain yield correlations.

MATERIALS AND METHODS

The study during the crop season (2021–2022) had the field soil experiment intended for agriculture, with the heat inheritances being tilted two times perpendicular, with the settlement operations conducted. In the softening operations on the soil, adding the dab fee (P_2O_5 46) and N (18%) had the amount of 320 kg ha^{-1} (96 g) for each experimental unit. The addition of urea N (46%) ensued at the beginning of the branches at 200 kg ha^{-1}. The manual listing of seeds of oatmeal varieties' names and sources appears in Table 1. The thin and wide bush removal proceeded manually, watering the experiment according to the plants' requirements (Maulani *et al*., 2023).

Each experimental unit has a fixed number of seeds planted in it based on the weight of 1000 grains of genotypes, sowing 105 grains in each line. The study included two factors: the foliar spraying of potassium on the plant at the plant growth stage (elongation)

Table 1. The proportions of genotypes of oats.

Symbol	Genotype	Extraction	Source
1	Alguda	-	Obtained from the Department of Field Crops, College of Agriculture,
2	Anatolia	-	University of Baghdad
3	Pimula	Italy	
4	Genzania	-	
5	Hamel	Italy	
6	Icarda short	ICARDA	Obtained from the joint conservation agriculture program between the
7	Kangaroo	Australia	Ministry of Agriculture, the University of Mosul, and the International
8	Icarda tall	ICARDA	Center for Agricultural Research in the Dry Areas (ICARDA)
9	Mitika	Australia	
10	Possum	Australia	
11	UC-132	America	Obtained from the Agricultural Research Department – Sulaymaniyah
12	Monte Zuma	America	
13	Cayuse	America	

with potassium sulfate K_2O (52%) in three concentrations (0, 10, and 20) gm L^{-1}, symbolized by K_0, K_1, and K_2, respectively. The second factor included 13 genetic compositions of oats.

Genetic analysis

Phenotypic, genetic and environmental correlations

After the analysis of covariance between the traits and the analysis of each of the features under study, the correction coefficients were also estimated (Al-Zubaidi and Khaled, 2016; Maulani *et al*., 2023).

$$rG = \frac{\sigma_{Gx.Gy}}{\sqrt{\sigma_{Gx.}{}^2 \sigma_{Gy}{}^2}}$$

$$rE = \frac{\sigma_{Ex.Ey}}{\sqrt{\sigma_{Ex.}{}^2 \sigma_{Ey.}{}^2}}$$

$$rP = \frac{\sigma_{Px.Py}}{\sqrt{\sigma_{Px}{}^2 . \sigma_{Py}{}^2}}$$

Path coefficient analysis

Using the course of the path of the path of its foundation (WRIGHT, 1921) divided the corridor (R) between two variables for direct effects and indirect effects, according to Dewey and Narrator (1987) (Table 2). The model, which included four independent variables, tested the raw protein (%) with other studied traits and the approved variable, which is the result of the grains as shown in Figure 1, and according to the path coefficient using the correlation matrices as follows:

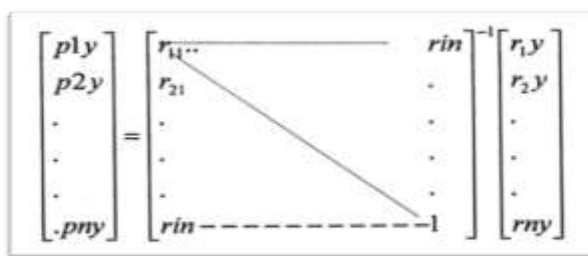

Figure 1. Tested the raw protein (%) with other studied traits. (correlation matrices).

$$[P] = [R]^{-1}[r]$$

Table 2. Values of direct and indirect effects.

Value	Range
1 - and more	Complete
0.8 – 0.99	very high
0.6 - 0.79	High
0.4 - 0.59	Medium
0.2 - 0.39	Weak
0.01 - 0.19	Very weak
0	No linear relationship

RESULTS AND DISCUSSION

Phenotypic, genetic, and environmental correlations

Estimating the correlations between traits in breeding programs is essential because the correlation coefficients are critical indicators of the extent to which traits respond to selection. The correlations between traits happen through the association of genetic factors and the influence of environmental factors on them due to static genes in some genotypes. Sometimes, said gene does not express itself in a particular environment but is revealed in others, as the main reason for the correlation is the multiple effects of the gene affecting two characteristics and more; thus, the gene isolation causes changes to attributes it can affect.

Phenotypic correlation

The percentage of crude protein and the characteristics under study with three concentrations of potassium spray (K_0, K_1, and K_2) are available in Table 3. The percentage of ash positively associated and significantly correlated at the probability level of 1% with the characteristics, crude fiber (%), soluble carbohydrates, and the percentage of moisture for all concentrations under study, but not significant at all concentrations with crude protein (%).

The percentage of moisture with raw fiber (%) and soluble carbohydrates (%) was negatively and significantly correlated at the 1% probability level for concentrations (K_0 and K_1), respectively, and with percent soluble carbohydrates, negatively connected at the 5% probability level for K_0 solution, with the rest of the correlations were not. It reached a significant level, and its values ranged between positive and negative.

The soluble carbohydrates (%) trait had associations with two characteristics: crude protein (%) and crude fiber (%), with a positive and significant correlation at the probability level of 1% for all concentrations under study except for the K_2 concentration in the characteristic of crude fiber (%) that did not reach a level of significance.

Crude fiber (%) with crude protein (%) showed an association of a highly significant positive correlation at the 1% probability level for two concentrations (K_0 and K_1), but they were not significant at the concentration K_2. The quality of the crop and its components had environmental and genetic factors affecting them. When a characteristic of the yield components is positively correlated, this means an improvement in the second trait when the first increases. An increase in the yield increased the protein percentage, and the protein components improved, and vice versa. These results are consistent with past findings that indicated a positive relationship between the quality of the yield and the percentage of protein (Al-Hazzaa, 2001; Zacevic *et al*., 2004).

Genetic correlation

The genetic correlation coefficient between the percentage of crude protein and the traits under study and three concentrations of potassium spray (K_0, K_1, and K_2) appear in Table 3. The ash (%) positively associated and significantly correlated at the probability level of 1% with the crude fiber (%) and soluble carbohydrates characteristics. The percentage

Table 3. The phenotypic, genetic, and environmental association of genotypes in the studied traits.

Traits	Correlate	K	Ash	Humidity	Soluble carbohydrates	Fiber	Protein
Protein	Phenotypic correlation	K_0	-0.2252	-0.2572	**0.6467	**0.8824	
		K_1	-0.3499	-0.3433	**0.6276	**0.6064	
		K_2	-0.0884	0.0631	**0.7323	0.2487	
	Genetic correlation	K_0	-0.2441	-0.1256	**0.7577	1.0574	
		K_1	**-0.5565	**-0.5162	**0.8718	**0.81	
		K_2	-0.0411	0.1395	**0.7871	0.1782	
	Environmental correlation	K_0	-0.1756	**-0.5171	*0.4165	0.1504	
		K_1	0.1396	-0.0407	0.0291	0.2722	
		K_2	-0.2268	-0.1869	**0.5762	*0.4165	
Fiber	Phenotypic correlation	K_0	**0.6403	**-0.5386	**0.718		
		K_1	**0.4874	-0.1498	**0.5384		
		K_2	**0.6171	0.2363	0.365		
	Genetic correlation	K_0	**0.7399	**-0.6448	**0.8753		
		K_1	**0.545	-0.1609	**1.0208		
		K_2	**0.6226	0.3073	0.372		
	Environmental correlation	K_0	*0.419	-0.2711	0.3122		
		K_1	*0.4025	-0.1208	-0.0098		
		K_2	**0.6016	0.0482	0.3535		
Soluble carbohydrates	Phenotypic correlation	K_0	**0.7781	*-0.4142			
		K_1	**0.8885	**-0.5706			
		K_2	**0.6613	-0.0666			
	Genetic correlation	K_0	**0.8432	*-0.4371			
		K_1	**1.0789	**-1.1899			
		K_2	**0.6418	-0.1271			
	Environmental correlation	K_0	**0.5545	-0.3822			
		K_1	0.2323	*0.4029			
		K_2	**0.717	0.0865			
Humidity	Phenotypic correlation	K_0	**0.7362				
		K_1	**0.6193				
		K_2	**0.7439				
	Genetic correlation	K_0	**0.7877				
		K_1	**0.9797				
		K_2	**0.8561				
	Environmental correlation	K_0	*0.4278				
		K_1	0.1124				
		K_2	*0.4552				
Ash	Phenotypic correlation	K_0					
		K_1					
		K_2					
	Genetic correlation	K_0					
		K_1					
		K_2					
	Environmental correlation	K_0					
		K_1					
		K_2					

of moisture for all the concentrations under study gave a negative and significant correlation at the probability level of 1% with crude protein (%) feature at the dilution K_1; however, it was nonsignificant at the concentrations K_0 and K_2, with the characteristic of crude protein (%).

Moisture (%) is interrelated with crude protein (%), crude fiber (%), and soluble carbohydrates (%), with a negative and significant correlation at the 1% probability level for concentrations K_1, K_0, and K_1, respectively, and with soluble carbohydrates (%), a significant negative correlation at the 5% probability level for concentration K_0. Meanwhile, the rest of the correlations did not reach a significant level, and their values ranged between positive and negative.

The characteristic, soluble carbohydrates (%)was associated with two characteristics: crude protein (%) and crude fiber (%), with a positive and significant correlation at the level of probability of 1% for all concentrations under study, except for the formulation K_2 in the trait crude fiber (%) that did not reach a level of significance. Crude fiber (%) with crude protein (%) exhibited associations, with a highly significant positive correlation at the 1% probability level for the two concentrations, K_0 and K_1, but was nonsignificant at the concentration K_2.

The importance of genetic correlation comes from selecting between two traits. If the correlation is positive, then an improvement in one of them will result in an improvement in the second trait. If the correlation is negative, then the selection to increase one of them will lead to the deterioration of the other. When there is no correlation between the two elected traits, the preference for one will not affect the other (Falconer, 1981). Similar results came from Al-Fahadi (1982).

Environmental correlation

Table 3 shows the genetic correlation coefficient between the percentage of crude protein and traits under study and three concentrations of potassium spray (K_0, K_1, and K_2). An association of the percentage of ash has a positive and significant correlation at the probability level of 1% with the crude fiber (%) trait at concentration K_2 and with soluble carbohydrates at K_0 and K_2 solutions. Likewise, it has a positive and significant correlation at the level of 5% probability with the raw fiber (%) characteristic at concentrations K_0 and K_1 and with the moisture percentage attribute at concentrations K_0 and K_2. However, the rest of the correlations did not reach a significant level, and their values ranged between positive and negative.

The moisture (%) with crude protein (%) gave a negative and significant correlation at the 1% probability level of concentration K_1, and with soluble carbohydrates (%) negatively substantial at the 5% probability level of K_1 dilution. The rest of the correlations did not reach a level of significance, with values ranging between positive and negative.

The soluble carbohydrates (%) trait was associated with two characteristics of crude protein (%), with a positive and significant correlation at the 1% probability level at concentration K_2 and a positive and significant correlation at the 5% probability level, except for concentration K_0. Other correlations did not reach a significant level, and their values ranged between positive and negative.

Crude fiber (%) has a connection with crude protein (%), with a positive and significant correlation at the 5% probability level of concentration (K_2); however, the rest of the correlations did not reach a significant level, and their values ranged between positive and negative (Khaled *et al*., 2023).

Phenotypic, genetic, and environmental path coefficients

The analysis of the phenotypic, genetic, and environmental correlation coefficients between the crude protein and some of the variables affecting it underwent division into direct and indirect effects to find the most influential traits as a criterion for selection. Genotypes in breeding programs mainly depend on the most effective traits through their direct or indirect correlations. It is an essential and better path to achieve the goal of breeding programs. These variables comprised raw fibers (%), soluble carbohydrates (%), moisture (%), and ash (%) percentage, as independent variables with protein. Previous studies and research confirmed that such variables need not have positive and significant correlations to affect the quality of the grain yield. The following tables show the analysis of the crude protein and the studied characteristics of the genotypes' phenotypic, genetic, and environmental path coefficients in three concentrations of potassium spray (K_0, K_1, and K_2).

Crude fiber (%)

Table 4 shows the phenotypic correlation in the raw fiber (%) trait, indicating indirect effects with the percentage of moisture by having a negative and medium direct impact on the phenotypic correlation value (-0.410)) at concentration K_0. It is consistent with results from Ziya *et al*. (2012). As for the genetic correlation (Table 4), the characteristic of raw fiber (%) showed a direct and undesirable effect at concentration K_1 that amounted to -1.216. It is also consistent with reports by Aydin *et al*. (2010).

As for the environmental correlation data in Table 4, raw fiber (%) attribute provided both a direct and indirect environmental correlation that was negative or positive and weak, or there was no linear relationship between them (Atar *et al*., 2018; Hasan and Abdullah, 2020, 2021; Abdullah and Hasan, 2021; Hasan *et al.*, 2022; Muhammad *et al*., 2021; Younis *et al.*, 2022a, b).

Soluble carbohydrates (%)

The phenotypic correlation of the soluble carbohydrates (%) showed indirect effects through the percentage of moisture having a direct, positive, and moderate outcome in its value of the phenotypic correlation at concentrations K_0 and K_2 that amounted to 0.4920 and 0.4010, respectively (Table 5), which was higher than the concentration K_1 at 0.6360. These results align with findings from Ziya *et al*. (2012).

As for the genetic correlation from the data of the same table, the characteristic of soluble carbohydrates (%) showed a direct, negative, and medium effect at the concentration K_1 with a score of -4.789 and the indirect effects through the percentage of ash being positive and very high at K_0 and K_1 solutions in their values. The genetic correlation amounted to 0.9150 and 0.9620 sequentially, consistent with what Aydin *et al*. (2010) obtained.

The environmental correlation data in Table 5 showed the soluble carbohydrates (%) trait with a direct environmental correlation that was positive and average for the concentration K_1 at 0.4020, consistent with several study reports (Atar *et al*., 2018; Abdullah and Hasan, 2021; Hasan and Abdullah, 2020; Hasan and Abdullah, 2021; Hasan *et al*., 2022; Khaled *et al*., 2023).

Humidity (%)

Table 6 shows the phenotypic correlation in the characteristic of humidity (%), exhibiting that the direct effect was medium and positive at concentration K_2, reaching 0.5480, highly positive at concentration K_0 at 0.761, and entirely positive at K_1 solution, amounting to 0.761 and 1.013, aligning with what was found by Ziya *et al*. (2012).

As for the genetic correlation data in the same table, the trait humidity (%) showed a direct, positive, and medium effect at concentration K_1 at 4.295 and a direct, positive, and high effect at concentration K_2 at 0.7030. The indirect effects occurred through raw fiber (%), which was positive and average at concentration K_1, and its value of genetic correlation amounted to -4.175. For the percentage of ash, it is positive and complete at zero potassium concentration (K_0), with the genetic correlation value at 1.106, and highly positive at concentration K_1, reaching 0.763. These results agree with the findings by Aydin *et al*. (2010).

The environmental correlation data in Table 6 indicated the characteristic of humidity (%). The direct environmental correlation was positive and average at the two concentrations (K_0 and K_2) at 0.4640 and 0.550, respectively, consistent with results from Atar *et al*. (2018).

Ash (%)

Table 7 shows the phenotypic correlation in the ash percentage characteristic, revealing that the direct effect was medium and positive at the concentration K_2, amounted to 0.5910, and

Table 4. Analysis of the coefficient of phenotypic, genetic, and environmental pathways for the genotypes in the characteristic of crude fiber (%).

Effect type	Phenotypic correlation			Genetic correlation			Environmental correlation		
K	K_0	K_1	K_2	K_0	K_1	K_2	K_0	K_1	K_2
Direct effect	0.246	-0.301	-0.179	0.085	-1.216	-0.127	0.202	0.200	-0.236
Indirect effect									
Soluble carbohydrates	-0.048	0.078	0.006	0.002	2.472	-0.028	-0.111	-0.016	-0.032
Humidity	-0.410	-0.151	0.129	0.125	-0.691	0.216	-0.125	-0.030	0.026
Ash	-0.012	0.250	-0.039	-0.457	-1.121	-0.100	-0.140	-0.013	0.015
Total correlation with protein	-0.225	-0.349	-0.088	-0.244	-0.556	-0.041	-0.175	0.139	-0.226

Table 5. Analysis of the coefficient of phenotypic, genetic, and environmental pathways for genotypes in the characteristic of soluble carbohydrates (%).

Effect type	Phenotypic correlation			Genetic correlation			Environmental correlation		
K	K_0	K_1	K_2	K_0	K_1	K_2	K_0	K_1	K_2
Direct effect	0.189	-0.228	0.010	-0.018	-4.789	-0.207	0.215	0.402	0.174
Indirect effect									
Fiber	-0.063	0.103	-0.011	-0.010	0.627	-0.017	-0.104	-0.008	0.044
Humidity	0.492	0.636	0.401	-0.147	3.744	0.553	0.193	0.007	0.317
Ash	0.021	-0.024	0.215	0.915	0.962	0.294	0.114	0.001	0.065
Total correlation with protein	0.640	0.487	0.617	0.739	0.545	0.622	0.419	0.402	0.601

Table 6. Analysis of the coefficient of phenotypic, genetic, and environmental pathways for the genotypes in terms of humidity (%).

Effect type	Phenotypic correlation			Genetic correlation			Environmental correlation		
K	K_0	K_1	K_2	K_0	K_1	K_2	K_0	K_1	K_2
Direct effect	0.761	1.013	0.548	-0.194	4.295	0.703	0.464	0.253	0.550
Indirect effect									
Soluble carbohydrates	-0.132	0.045	-0.042	-0.055	0.195	-0.039	-0.054	-0.024	-0.011
Humidity	0.122	-0.143	0.007	-0.013	-4.175	-0.163	0.089	0.011	0.100
Ash	0.026	-0.027	0.147	1.106	0.763	0.141	0.055	-0.009	0.076
Total correlation with protein	0.778	0.888	0.661	0.843	1.078	0.641	0.554	0.232	0.717

Table 7. Analysis of the coefficient of phenotypic, genetic, and environmental pathways for genotypes in the character of ash percentage.

Effect type	Phenotypic correlation			Genetic correlation			Environmental correlation		
K	K_0	K_1	K_2	K_0	K_1	K_2	K_0	K_1	K_2
Direct effect	0.030	-0.044	0.591	1.046	0.942	0.791	0.368	-0.033	.1840
Indirect effect									
Soluble carbohydrates	-0.101	0.172	0.011	-0.037	1.446	0.016	-0.077	0.080	-0.020
Humidity	0.136	-0.123	0.003	-0.015	-4.889	-0.077	0.067	-0.003	0.061
Ash	0.672	0.614	0.136	-0.205	3.479	0.125	0.069	0.069	0.229
Total correlation with protein	0.736	0.619	0.743	0.787	0.979	0.856	0.427	0.112	0.455

the indirect effect was positive and high for the two concentrations (K_0 and K_1), reaching 0.6720 and 0.614, respectively. These results were consistent with the findings of Ziya *et al*. (2012), Muhammad *et al.* (2021), and Younis *et al.* (2022a, b).

The genetic correlation data in the same table provided the characteristic of the percentage of ash with a direct, positive, and complete effect at the concentration K_0, which amounted to 1.046; a direct, positive, and very high effect at the concentration K_1 at 0.9420; and a direct, positive, and high effect at the solution K_2. It amounted to 0.7910, consistent with what Aydin *et al*. (2010) reported. Meanwhile, in the environmental correlation data (Table 7), the characteristic of the percentage of ash showed that the direct and indirect environmental correlations were negative, positive, and weak, or there was no linear relationship between them, in analogy with the findings of Atar *et al*. (2018).

CONCLUSIONS

The traits showed a positive and significant correlation with the crude protein of the grain yield in the oat plant at all levels of spray concentrations, having valuable direct and indirect effects through some other traits; therefore, they can serve as selective evidence to improve the oat's grain yield under the study conditions.

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