Identification of Selection Criteria for Improving Potato Yield Using Genotypic Path Coefficient Analysis under Multi-Location Field Conditions in Iraq

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Abstract

A field experiment was conducted in the spring season of 2023 by planting eight potato genotypes (3P29, 3P30, 3P31, 3P32, 3P35, 3P33, 3P34, and 3P36) in a Randomized Complete Block Design (RCBD) with three blocks in three locations: Bazian in Sulaymaniyah, Bardarash in Erbil, and Al-Qubba in Mosul. The aim was to determine the genotypic path coefficient of traits on total yield to determine the best criterion for selection. A set of growth and yield traits were studied. The path coefficient analysis results indicate that the number of marketable tubers showed the highest and most significant genetic correlation with total yield. It also exhibited a very high positive indirect effect on total yield through the number of main stems. Moreover, the number of main stems was highly and significantly correlated with total yield and showed a very high positive direct effect. These traits therefore represent key selection criteria that can be adopted in breeding programs to improve the productivity of the potato genotypes under study in Sulaymaniyah Governorate. The traits of tuber dry weight and number of main stems were among the most important traits at the Erbil location, as they recorded the highest genetic correlation and the highest positive indirect effect through tuber weight. Therefore, emphasis should be placed on these traits in selection, as they represent effective selection indicators for improving total yield. The traits of tuber dry weight and number of main stems were among the most important traits at the Mosul location, as they recorded the highest genetic correlation and the highest positive indirect effect through tuber weight. Therefore, they can be considered key selection criteria in breeding and improvement programs at this location.

Keywords: Potato; genotypic correlations; path coefficient; Selection criteria; Locations

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Introduction

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The potato (*Solanum tuberosum* L.) is one of Solanaceae family, is a very important vegetable crops worldwide, coming in fourth after wheat, rice, and maize, and topping the tuber crops [6]. The food provided by potato tubers is of high quality and constitutes an important source of many nutrients [14]. Additionally, potato is recognized as a concentrated source of dietary fiber, resistant starch, vitamin C, and potassium, further contributing to its nutritional significance in human diets worldwide [8] .

The environment is a crucial factor affecting the growth and productivity of potato genotypes, since potato yield is determined not only by the genetic potential of the cultivar but also by environmental conditions such as climate and soil characteristics [5].

Varieties are generally governed by genetic and environmental interference, so the genetic nature of the cultivated variety greatly affects the quantity and quality of the yield [9]. The increasing demand for food requires careful evaluation of genotypes, identification of the best ones, and improving them by developing the available genotypes to produce more suitable generations that are better able to adapt to the environment and achieve higher yield; improving yield through selection for its components and other economic traits has been limited due to the interaction between genetic and environmental factors and the compensation mechanism among yield components and their relationship with other traits; therefore, obtaining accurate estimates of the relative importance of these traits is an effective means of identifying the causes of yield reduction [3].Assessing genotype × environment (G×E) interaction is essential because potato cultivars often show inconsistent performance across locations and seasons, which challenges breeders seeking stable, high-yielding genotypes [4]. Despite the crop's importance in northern Iraq, limited studies have analyzed how key agronomic traits collectively influence yield under different environments. This creates a gap in identifying which traits should be prioritized in selection programs. Path coefficient analysis is better than correlation because it can determine the direct and indirect causes of associations and can quantify the relative importance of each because correlation alone sometimes does not provide an accurate picture of the direct and indirect effects of characters upon one another [15]. The path analysis is the partitioning of the total correlation into direct and indirect effects of independent variable(s) on dependent variable. If the variable has positive correlation and the direct effect of the variable or trait is negative or negligible, the positive correlation of the trait is because of the indirect effects through other traits. In such a situation, the indirect casual factors or traits are to be considered simultaneously for selection. The residual effect determines how much best the causal factors or independent variables account for the variability of the dependent variable [17]. In potato previous reports by [10] indicated that simple correlation coefficients were useful to study the interrelationships other characters. Found [16] most of the vegetative and yield traits had positive correlations and direct effects with total tuber yield and dry matter content at phenotypic and genotypic between tuber yield and levels. Therefore, those traits had practical importance in selection of potato genotypes for high total tuber yield and processing purpose. The present research aimed to analyze path coefficient among various traits of eight genotypes of potato in order to estimate direct and indirect effects on total yield, and to determine the best criterion for selection.

Materials and Methods

The trial was implemented in the spring growing season of 2023 at three agricultural locations: Sulaymaniyah, Erbil, and Mosul. Each location was planted with eight potato genotypes (Sound(3P29), Lady Jane (3P30), Hermes (3P31), SHC 1010 (3P32), Acoustic (3P35), Paradiso (3P33), Lady Alicia (3P34), and Argana (3P36). Planting dates at the three locations were approximately the same: Mosul on February 15, 2023; Sulaymaniyah on February 21, 2023; and Erbil on February 23, 2023, for comparison and testing purposes. The experimental fields in the three agricultural areas were prepared uniformly by deep, perpendicular plowing and leveling the soil to a high standard. The experimental unit measuring 8 x 3 m consists of 4 rows 0.75 m apart and 0.25 m between tubers in a row. The plant density achieved per hectare was 53333 plants. Nitrogen fertilizers were administrated at a rate of 160 kg of nitrogen per hectare in the form of urea (46%), and Apply 120 kg P_2O_5/ha of monophosphate (19% P_2O_5) as phosphate fertilizers, while Potassium fertilizers were also applied at a rate of 160 kg K_2O ton/ha in the form of potassium sulfate (52% K_2O) [2]. The trial was implemented as a Randomized Complete Block Design (RCBD) with three blocks at three locations. The traits that were analyzed included: X1: plant height (cm), X2: number of primary stems (stems/Plant), X3: Vegetative dry weight (g), X4: total number of tubers, X5: number of marketable tubers (tuber/Plant). X6: Weight of tuber (g), X7: tuber dry matter %, and X8: total yield (ton/ha). The variance and covariance between tuber yield per hectare and the traits under study were estimated for each location, where genotypic variance was calculated. Genotypic covariance is used to calculate the values of genotypic correlations coefficients [17].

$$rGxy = \frac{\operatorname{cov}.Gxy}{\sqrt{(\sigma^2 Gx)(\sigma^2 Gy)}}$$

Where:

x and y = studied traits

σ^2G represent genotypic variance.

cov.G represent genotypic covariance.

rGxy represent genotypic correlations.

After confirming the presence of genotypic correlation between the studied characteristic, genotypic path coefficient analyses continued, with the foundations laid by [19] and described by [18]. The following diagram shows the causal relationship between the variables :(Figure1)

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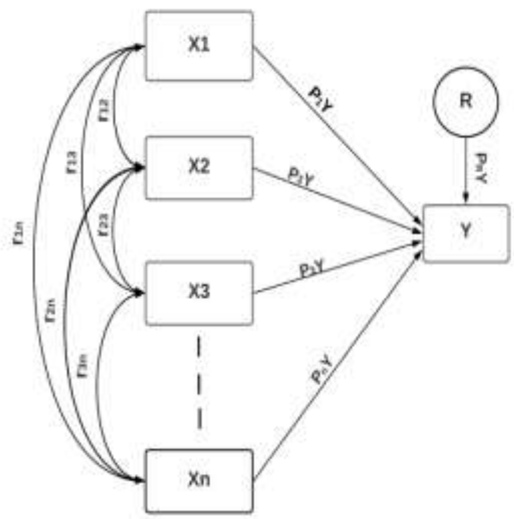

Figure1. Path coefficient diagram depicting interrelationships among traits.

Calculating the matrix first led to calculating the values of the path coefficient:

path coefficient was estimated using matrix method as follows:

$P = R^{-1}. R$

Whereas:

P: direct effects vector.

R^{-1}: Invers of matrix of correlation coefficients between all possible pairs of studied traits.

r: Correlation vector between potato yield and the traits under study.

$$\begin{bmatrix} px1y \\ px2y \\ . \\ . \\ . \\ px10y \end{bmatrix} = \begin{bmatrix} 1 & rx1x2 \ldots\ldots\ldots\ldots rx1x10 \\ rx2x1 & 1 \ldots\ldots\ldots\ldots rx2x10 \\ . & \\ . & \\ . & \\ rx10x1 & rx10x2 \ldots\ldots\ldots\ldots 1 \end{bmatrix} \times \begin{bmatrix} rx1y \\ rx2y \\ . \\ . \\ . \\ rx10y \end{bmatrix}$$

C $\qquad B^{-1} \qquad$ A

By solving the matrix using a computer, the path coefficient estimations followed the method developed by [13]. The study also adopted the scale presented by [12] to determine the importance of direct and indirect effects:

Results and Discussion:

Path coefficient analysis of potato genotypes at the Sulaymaniyah location

Path coefficient analysis is considered one of the most important statistical methods used to partition genotypic correlation coefficients into direct effects and indirect effects, which allows the identification and selection of the traits most efficient in their true influence on total yield.

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It is clear from the table of genotypic path coefficient analysis at each location separately (Table 2), and from arranging the traits of genotypic path analysis according to the values of direct and indirect effects, that the residual value reached (0.0471), which is a low value, indicating that the studied traits explained a high proportion of the genotypic variation in total yield, and this reflects the efficiency of the path analysis model used. The table also showed that plant height had a weak positive direct effect on tuber productivity amounting to (0.1720). It also recorded positive indirect effects with the number of main stems, tuber weight, and tuber dry matter, with the highest being for the trait number of main stems (0.7923). In contrast, plant height was associated with a negative indirect association with vegetative dry weight and the total and marketable number of tubers, which reduced its overall effect.

The trait of number of main stems achieved the highest positive direct effect among all studied traits, with a value of (1.9493). The trait was also associated with a strong negative indirect association with the number of marketable tubers amounting to (-1.4119), and a high positive indirect association through tuber weight amounting to (0.5194). It is noted that the sum of direct and indirect effects affected total yield in a direct positive manner. The vegetative dry weight trait has a high positive direct effect on total yield amounting to (0.9873); likewise, the trait has a high indirect effect through the total number of tubers amounting to (0.5798). The trait also recorded negative indirect effects through the rest of the traits, and the sum of direct and indirect effects was positive on total yield.

The total number of tubers trait had a high positive direct effect on yield amounting to (0.8018). The trait also recorded a high indirect effect on yield through the vegetative dry weight trait amounting to (0.7139). In addition, the trait had negative and positive indirect effects through the other traits on total yield, whose sum had a positive effect.

The result of genotypic path coefficient analysis also shows that the number of marketable tubers had a high negative direct effect estimated at (-1.4250). The trait also achieved high indirect effects through the number of main stems and tuber weight, with the highest being for the number of main stems trait (1.9314). The trait also had negative indirect effects through the rest of the traits on total yield, and it was observed that the sum of direct and indirect effects affected total yield positively.

The tuber weight trait achieved a high positive direct association with total yield amounting to (0.7042). The trait also had a high positive indirect effect through the number of main stems amounting to (1.4376), and a high negative indirect effect through the number of marketable tubers amounting to (-1.0314). It was observed that the sum of the trait's direct and indirect effects influenced yield positively.

The tuber dry weight recorded a high negative direct effect on total yield, reaching (−0.9435). The trait also recorded high positive indirect effects through the number of main stems, the total vegetative dry weight, and the total number of tubers, with the highest reaching (0.9806), and a high negative indirect effect with the number of marketable tubers (−0.6580). The sum of the direct and indirect effects affected total yield in a positive manner. The residual value reached (0.0471), which is a low value, indicating that the studied traits explained a high proportion of the genotypic variation in total yield, and this reflects the efficiency of the path analysis model used.

The results of the path coefficient analysis indicate that the number of marketable tubers achieved the highest genotypic correlation at the level of significance with total yield, and it also achieved a very high positive indirect effect with total yield through the number of main stems. The number of main stems trait also showed a highly significant correlation with yield and a very high positive direct effect, which makes them main selection indicators that can be adopted in breeding programs to improve the productivity of the potato genotypes under study in Sulaymaniyah Governorate. The results agree with [7] and with [11].

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Table 2. Path coefficient analysis and the effect of studied traits on total yield in Baziain in Sulaymaniyah characters

	X1	X2	X3	X4	X5	X6	X7	Total effect (genotypic correlations)
X1	0.1720	0.7923	-0.7852	-0.5536	-0.5948	0.3946	0.4691	- 0.1056
X2	0.0699	1.9493	0.1312	-0.1275	-1.4119	0.5194	-0.4746	0.6558**
X3	-0.1368	0.2591	0.9873	0.5798	-0.1858	-0.1338	-0.8209	0.5489**
X4	-0.1188	-0.3100	0.7139	0.8018	0.2108	-0.3789	-0.4562	0.4625*
X5	0.0718	1.9314	0.1288	-0.1186	-1.4250	0.5097	-0.4357	0.6625**
X6	0.0964	1.4376	-0.1875	-0.4314	-1.0314	0.7042	-0.0930	0.4949*
X7	-0.0855	0.9806	0.8590	0.3877	-0.6580	0.0694	-0.9435	0.6096**

Residual = 0.0471 and indicate significance at 5%* and 1%** level of probability
X1: Plant height (cm) X4: Number of total tubers X7: Tubers dry matter
X2: Number of primary stems X5: Number of marketable tubers X8: Total yield
X3: Vegetative dry weight X6: Weight of tuber (g)

Path coefficient analysis of potato genotypes at the Erbil location:

The path coefficient analysis of the studied traits showed a variable effect on total yield, with a clear variation between direct and indirect effects, which made it possible to identify the traits most effective in improving productivity. Table (3) clearly showed the differences in the strength and direction of the effect among traits, which reflects variation in the physiological and behavioral relationships among them. The

ISSN 2072-3857

residual value reached (0.0192), which is a very low value and close to zero, indicating that the studied input traits explained most of the genotypic variation in total yield, and this reflects the efficiency of path coefficient analysis in explaining the causal relationships among traits.

It is clear from the table of genotypic path coefficient analysis at the Erbil location (Table 3) that plant height had a high negative direct effect on total yield amounting to (−0.7798). In contrast, the trait had high positive indirect effects through vegetative dry weight, the number of marketable tubers, and tuber weight, with the highest being through tuber weight, reaching (0.8424). Plant height also had a negative indirect effect through the total number of tubers, with a value of (−0.6302). The sum of the direct and indirect effects affected total yield positively.

The number of main stems had a low positive direct effect on total yield amounting to (0.1285). The trait also had high positive indirect effects through the number of marketable tubers and tuber weight, with the highest being through tuber weight (0.6132). The trait also had negative indirect effects through plant height and the total number of tubers. It is noted that the sum of the direct and indirect effects positively affected the total yield.

The table also shows that the dry vegetative weight trait had a high direct negative effect on total yield (-0.5321). It also had a high indirect positive effect on total yield through plant height and total number of tubers, with the highest effect being through plant height (0.5605). The characteristic had a negative indirect effect via the tuber weight and number of marketable tubers. The grand total tuber number had the maximum very high positive direct effect on the total yield (1.2101), emphasizing its importance in yield variation explanation. The character also had maximum positive indirect effect through plant height reaching (0.4061). However, the trait showed negative indirect effects through the number of marketable tubers and tuber weight (-0.6939 and -0.3030, respectively), which led to a decrease in the overall correlation value by (0.3381). The trait of the number of

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marketable tubers recorded a high direct positive effect on the total yield, amounting to (0.5259). The trait also had a very high indirect positive correlation with the tuber weight, amounting to (1.0210). In contrast, the trait had high indirect negative effects across the plant length and the total number of tubers, amounting to (-0.6973, -0.6608) respectively. It is noted that the sum of the direct and indirect effects was reflected on the total yield with a relatively high positive correlation of (0.5104). Tuber weight showed a very high direct positive effect on total yield (1.0754). It also had a high indirect positive effect through the number of marketable tubers (0.4993). In contrast, the trait had a negative indirect effect on total yield through plant height and the total number of tubers, reaching (−0.6109 and −0.7808), respectively, and this resulted in a high positive correlation with total yield, reaching (0.4998).

The tuber dry weight trait had a relatively weak positive direct effect on total yield, reaching (0.1463). However, its positive indirect effects were high through the number of marketable tubers and tuber weight, reaching (0.3039 and 0.7682), which contributed to increasing the total correlation with yield to a value of (0.5901).

The two traits, tuber dry weight and number of main stems, are among the most important traits affecting total yield, as they achieved the highest genotypic correlation and the highest positive indirect impact via the tuber weight trait. Therefore, focus should be placed on them in selection, as they represent effective selection indicators for improving total yield. The results agree with [1], as it indicated that the path coefficient results showed that mean tuber dry weight and number of stems yielded the most significant positive impact on productivity. The results also agree with [11].

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Table3. Path coefficient analysis and the effect of studied traits on total yield for Bardarash in Erbil chatacters.

	X1	X2	X3	X4	X5	X6	X7	Total effect (genotypic correlations)
X1	-0.7798	0.0622	0.3824	-0.6302	0.4457	0.8424	0.0266	0.3492
X2	-0.3774	0.1285	-0.0713	-0.1200	0.3157	0.6132	0.0847	0.5733**
X3	0.5605	0.0172	-0.5321	0.5210	-0.1580	-0.2810	0.0647	0.1924
X4	0.4061	-0.0127	-0.2291	1.2101	-0.3030	-0.6939	-0.0394	0.3381
X5	-0.6608	0.0771	0.1599	-0.6973	0.5259	1.0210	0.0846	0.5104*
X6	-0.6109	0.0733	0.1390	-0.7808	0.4993	1.0754	0.1045	0.4998*
X7	-0.1416	0.0743	-0.2354	-0.3258	0.3039	0.7682	0.1463	0.5901**

Residual = 0.0192 and indicate significance at 5%* and 1%** level of probability

X1: Plant height (cm) X4: Number of total tubers X7: Tubers dry matter
X2: Number of primary stems X5: Number of marketable tubers X8: Total yield
X3: Vegetative dry weight X6: Weight of tuber (g)

Path coefficient analysis of potato genotypes at the Mosul location:

Path coefficient analysis aims to decompose the correlation coefficient between the studied traits and total yield into a direct effect of each trait on yield and indirect effects that are transmitted through other traits. Thus, it is possible to distinguish between traits of real importance in improving yield and those whose effect appears only as a result of correlational relationships. It is clear from Table

(4) that the path coefficient analysis for the Mosul location showed that the residual value reached (0.0650), which is a relatively low value, indicating that the studied traits explain most of the genotypic variation in total yield.

Plant height achieved a high positive direct effect on total yield, reaching (0.5366). The trait also had a high positive indirect effect with tuber weight, reaching (0.7326). However, this trait recorded a very high negative indirect effect via the total number of tubers, reaching (−1.0638). The trait also had negative indirect effects through vegetative dry weight and the number of marketable tubers, which led to a decrease in the total correlation coefficient with yield to reach (−0.1766).

The number of main stems had a weak direct negative effect on total yield (-0.0977), but strong indirect positive effects on the total number of tubers and tuber weight (0.3859 and 0.4645, respectively). It also had low negative indirect effects on plant height and the number of marketable tubers. The sum of these direct and indirect effects resulted in a positive correlation with total yield (0.8698).

The dry vegetative mass trait had a low direct positive effect on total yield (0.1272), while it had a high indirect positive effect on total tuber count (0.6026). It also had positive indirect effects on marketable tuber count, tuber weight, and tuber dry weight. Conversely, it had a negative indirect effect on plant height (-0.3527). The sum of these direct and indirect effects resulted in a positive correlation with yield (0.6592). The total number of tubers trait showed the highest direct positive effect on total yield (1.4904), confirming its pivotal role in determining total yield. It also had high negative indirect effects on plant height and tuber weight (-0.3830 and -0.8263, respectively). However, the overall correlation with yield remained positive and strong (0.4904).

The number of marketable tubers trait recorded a high negative direct effect, reaching (−0.3015). In contrast, the trait had a high positive indirect effect through tuber weight, reaching (0.9415), as well as through plant height. The trait also had a high negative indirect effect through the total number of tubers, reaching (−0.8397), which led to a relatively weak overall correlation with yield, reaching (−0.2519).

The tuber weight trait showed the highest very high positive direct effect, reaching (1.1446). In contrast, the trait had a very high negative indirect association through the number of marketable tubers, reaching (−1.0759). This led to a decrease in the total correlation with yield to a value of (0.2373).

Dry matter in tubers had a moderate positive direct effect on total yield, reaching (0.2388). In contrast, the trait had positive indirect effects through vegetative dry weight, the total number of tubers, and tuber weight, with the highest being through tuber weight, reaching (0.5035). The trait also had weak negative indirect effects through plant height, number of main stems, and number of marketable tubers. These contributed to increasing the total correlation coefficient with yield to (0.6914).

The two traits, tuber dry weight and number of main stems, are among the most important traits affecting total yield, as they achieved the highest genotypic correlation and the highest positive indirect effect through the tuber weight trait. Thus, they are considered two selection criteria in breeding and improvement programs. The results agree with [1], which indicated that the path coefficient results show that mean tuber dry weight and number of stems had the highest positive effect on productivity. The results also agree with [11].

Table 4. Path coefficient analysis and the effect of studied traits on total yield in Al-Qubba in Mosul characters

	X1	X2	X3	X4	X5	X6	X7	Total effect (genotypic correlations)
X1	0.5366	0.0195	-0.0836	-1.0638	-0.2676	0.7326	-0.0501	-0.1766
X2	-0.1069	-0.0977	0.1019	0.3859	-0.0672	0.4645	0.1892	0.8698**
X3	-0.3527	-0.0783	0.1272	0.6026	0.0955	0.0697	0.1950	0.6592**

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X4	-0.3830	-0.0253	0.0514	1.4904	0.1698	-0.8263	0.0132	0.4904*
X5	0.4763	-0.0218	-0.0403	-0.8397	-0.3015	0.9415	0.0374	0.2519
X6	0.3434	-0.0397	0.0078	-1.0759	-0.2479	1.1446	0.1050	0.2373
X7	-0.1126	-0.0774	0.1039	0.0824	-0.0472	0.5035	0.2388	0.6914**

Residual = 0.0650 and indicate significance at 5%* and 1%** level of probability

X1: Plant height (cm) X4: Number of total tubers X7: Tubers dry matter
X2: Number of primary stems X5: Number of marketable tubers X8: Total yield
X3: Vegetative dry weight X6: Weight of tuber (g)

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