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RESEARCH ARTICLE

Genetic variability and association studies for yield and its attributes in cultivated potato (*Solanum tuberosum* L.)

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Abstract
Sufficient genetic variability on the basis of various parameters of variability was recorded in 357 tetraploid potato genotypes, including varieties, advanced breeding lines and exotic germplasm. The estimates of heritability and genetic gain were found to be high for the number of stems per hill, plant height, number of leaves per plant, number of leaflets per compound leaf, leaflet length, leaflet width, leaf length, leaf area, number of tubers per plant, tuber length, average tuber weight and average tuber yield per plant indicating the importance of additive gene action for the inheritance of these attributes. Correlation coefficient studies indicated the importance of the number of stems per hill, leaflet length, leaflet width, leaf width, tuber length, number of tubers per plant and average tuber weight, while path coefficient analysis directed to focus selection on the basis of average tuber weight and number of tubers per plant to develop high yielding potato varieties.

Keywords: Correlation coefficient, Genetic variability, Heritability, Path-coefficient, Potato

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Introduction
Potato (*Solanum tuberosum* L.) is an important calorie-dense vegetable crop and has the ability to help feed the world's expanding population. After wheat, rice, and maize, potato is the fourth-most significant food crop worldwide (Muthoni et al., 2011). For this reason, productivity has to be raised in order to produce more potato harvests on a given plot of land. Yield is a complicated trait with several significant aspects. In order to distinguish between heritable and non-heritable components of the observed variation, an assessment of several genetic parameters, such as PCV, GCV, heritability, genetic gain, etc., is required. However, understanding the relationships between quantitative characters, particularly the yield and its associated traits, may help to choose the right characters from a varied population. For a breeding program to be successful, genetic variability is a very crucial factor. Therefore, it would be crucial to evaluate the magnitude and direction of the relationship between various features and tuber yield and to pinpoint the traits that are important for a high yield. Correlation coefficients simply identify the relationship, while path coefficient analysis enables a rigorous assessment of the particular feature that creates the given association (Amadi et al., 2008). The results of a correlation analysis demonstrate the interdependence between yield and its component attributes. When there are more than two

variables involved, the correlation by itself does not give an accurate picture of how they interact. In order to evaluate the cause-effect relationship and effective selection, path coefficient analysis is utilized. Additionally, it facilitates evaluating the degree of relationship between yield and its attributing traits and permits a critical analysis of certain elements for a given correlation (Singh et al., 2023). To clarify the degree of relationship that exists on the dependent characters by its various contributors, path coefficient analysis must be used to split the correlation coefficients into their direct and indirect impacts (Lamboro et al., 2014). Keeping these points in view, the present investigation has been planned to develop a variety with high tuber yield and other attributes through genetic variability as well as correlation and path analysis studies.

Materials and Methods

An experiment was conducted at Litchi and Mango Research Station, Nagrota Bagwan, Dr YS Parmar UHF, Nauni, Solan HP in collaboration with ICAR-CPRI, Shimla HP during the winter season of 2021-22 and 2022-23. The experimental material comprised 357 potato genotypes and was laid out in an augmented block design. Medium-sized and healthy tubers were selected and planted at the spacing of 60 cm and 20 cm between ridges and tubers, respectively. The standard package of practices was followed as recommended by ICAR-CPRI, Shimla, HP to raise the healthy crop. The observations were recorded for average tuber yield per plant (AYP) and its 14 related traits *viz*., number of stems per plant (SPH), plant height (PH), number of compound leaves per plant (LPP), number of leaflets per compound leaf (LLCL), leaflet length (LLL), leaflet width (LLW), leaf length (LL), leaf width (LW), leaf area (LA), number of tubers per plant (TPP), tuber length (TL), tuber width (TW), tuber dry matter content (DW) and average tuber weight (TWt) during both the years. Pooled data was analyzed for GCV (genotypic coefficient variation), PCV (phenotypic coefficient of variation) and h^2 (heritability) in a broad sense as per the formulae given by Burton and De Vane (1953). Genetic advance (GA) was assessed according to Johnson et al. (1955). Following the method of Al-Jibouri et al. (1958) and Dewey and Lu (1959), the phenotypic and genotypic coefficients of correlation were carried out. Using the relevant correlation coefficients of the various component characters, as indicated by Wright (1921) and refined by Dewey and Lu (1959), the direct and indirect impacts of component characters on the average tuber yield per plant were calculated.

Results and Discussion

The optimal breeding program may be created for the genetic enhancement of the target crop based on the knowledge of PCV as well as GCV, which provides an estimation of the magnitude of variations present in the existing genetic material. The estimates of PCV were higher than that of GCV for all traits under study (Table 1), which indicated that apparent variations were not only due to the genotypes but also the environment and its role in influencing the trait of interest. Thus, due to the unexpected nature of environmental variances, caution must be used when selecting target characters solely based on phenotype. Lamboro et al. (2014), Patel et al. (2018) and Pradhan et al. (2016) also reported higher PCV estimates than that of GCV in their respective studies. A critical evaluation of the results revealed that all the attributes showed either a high or medium magnitude of genotypic coefficient of variation except dry weight during the second year, indicating the presence of a broad genetic base. High PCV and GCV were observed for SPH, PH, LPP, TPP, TWt and AYP irrespective of years. This encourages the use of yield parameters for the improvement of genotypes. Earlier research workers have also observed high or medium magnitude of PCV and GCV for LPP, TPP and TWt (Pradhan et al., 2016), TPP, TW and TWt (Tripura et al., 2016), PH and AYP (Patel et al., 2018).

A measure of heritable variation known as heritability may be used to anticipate the degree of improvement that would be expected via selection in conjunction with the GCV, according to Burton and De Vane (1953). The heritability estimates were high for SPH, PH, LPP, LCL, LLL, LL, LA, TPP, TL, DW, TWt and AYP during years 2021-22, 2022-23 and pooled over years (Table 1). LW also showed high heritability estimates in pooled over the years. High estimates of heritability specified the greater role of a genetic component of variation and less influence of the environment. Earlier research workers have also reported high heritability estimates for PH, TPP, TL, TW and AYP (Tripura et al., 2016) and LA, SPH and TPP (Patel et al., 2018) in their respective breeding materials with different environmental conditions. Johannsen (1909) added that heritability alone could not be the only criterion for identifying the actual effects of selection since high heritability does not always imply considerable expected genetic development. Because of this, selection may benefit more from predictions based on both of these estimations (Sharma et al., 2016). The estimates of heritability and genetic gain were found high for SPH, PH, LPP, LCL, LLL, LLW, LL, LA, TPP, TL, TWt and AYP irrespective of years in addition to total soluble solids during 2021-22 and 2022-23, DW during 2021-22 as well as pooled over the years, and LW in pooled years; thus highlighting the significance of additive gene action for the control of these traits, and phenotypic selection may be used to improve these traits. Similar results were found for LPP and TPP (Pradhan et al., 2016), SPH and TPP (Patel et al., 2018), TW and TWt (Tripura et al., 2016).

Traits with a strong and likable connection to one another might be efficiently exploited to increase yield. Correlation helps to base the selection process when two opposing desirable traits influencing the major trait are

Table 1: Estimates of parameters of variability for different traits in potato (Based on pooled data of 2021-22 and 2022-23)

Trait	*GCV*			*PCV*			*h^2*			*GAM (%)*		
	2021-22	*2022-23*	*Pooled*	*2021-22*	*2022-23*	*Pooled*	*2021-22*	*2022-23*	*Pooled*	*2021-22*	*2022-23*	*Pooled*
SPH	46.00	38.20	38.06	48.29	39.70	39.49	90.72	92.60	92.9	90.38	75.83	75.68
PH	31.55	26.84	28.68	32.09	30.01	29.69	96.67	79.99	93.33	64.00	49.51	57.17
LPP	62.30	52.18	56.8	65.40	60.62	61.71	90.76	74.09	84.73	122.44	92.65	107.87
LCL	16.17	16.17	16.17	18.20	18.20	18.2	78.96	78.96	78.96	29.64	29.64	29.64
LLL	19.65	22.18	18.88	22.91	23.93	20.76	73.57	85.87	82.72	34.78	42.40	35.43
LLW	18.43	17.60	16.47	25.42	24.37	22.53	52.55	52.17	53.41	27.56	26.23	24.83
LL	16.98	18.09	18.29	21.51	21.49	19.16	62.30	70.81	91.15	27.65	31.40	36.03
LW	18.89	18.99	28.78	25.69	28.87	29.21	54.05	43.28	97.12	28.65	25.78	58.52
LA	31.18	27.00	19.48	31.68	27.63	24.88	96.86	95.55	61.31	63.31	54.46	31.46
TPP	34.83	22.57	25.35	37.12	26.42	27.13	88.06	72.98	87.27	67.44	39.78	48.85
TL	19.92	16.61	18.21	22.24	20.17	19.71	80.24	67.86	85.38	36.81	28.23	34.72
TW	12.46	12.34	11.48	19.89	16.98	16.84	39.24	52.81	46.49	16.10	18.49	16.15
DW	14.62	9.35	12.31	15.83	11.48	12.86	85.34	66.32	91.64	27.87	15.70	24.31
TWt	50.45	35.40	41.96	51.67	43.84	44.72	95.31	65.18	88.06	101.61	58.96	81.23
AYP	57.51	46.47	47.61	63.16	52.05	50.95	82.91	79.72	87.33	108.02	85.59	91.79

PCV and GCV represent phenotypic and genotypic coefficients of variation, respectively; h^2: heretability in broad sense; GAM (%): Genetic advance over mean (%)
SPH- Number of stems per plant, PH- Plant height, LPP- Number of leaves per plant, LCL- Number of leaflets per compound leaf, LLL- Leaflet length, LLW- Leaflet width, LL- Leaf length, LW- Leaf width, LA- Leaf area, TPP- Number of tubers per plant, TL- Tuber length, Tuber width, DW- Tuber dry matter content, TWt- Tuber weight, AYP- Average tuber yield per plant

Table 2: Estimates of genotypic correlation coefficients for different pairs of horticultural traits in potato (Based on pooled data of 2021-22 and 2022-23)

Traits	*SPH*	*PH*	*LPP*	*LCL*	*LLL*	*LLW*	*LL*	*LW*	*LA*	*TPP*	*TL*	*TW*	*DW*	*TWt*
PH	0.067													
LPP	0.319*	0.556*												
LCL	0.005	0.301*	0.220*											
LLL	0.058	0.067	0.063	0.013										
LLW	0.093	0.011	0.016	-0.035	0.827*									
LL	0.111*	0.203*	0.208*	0.120*	0.367*	0.313*								
LW	0.088	0.180*	0.206*	0.265*	0.570*	0.537*	0.483*							
LA	-0.051	-0.106*	-0.1	-0.029	0.293*	0.231*	0.117*	0.130*						
TPP	0.329*	0.012	0.119*	-0.018	0.201*	0.170*	0.136*	0.125*	0.029					
TL	0.017	-0.112*	-0.036	0.001	0.266*	0.251*	0.063	0.196*	0.164*	-0.064				
TW	0.069	-0.08	0.014	0.042	0.310*	0.262*	0.099	0.176*	0.200*	-0.008	0.716*			
DW	0.028	0.104	0.165*	-0.012	0.042	0.037	0.042	0.107*	-0.073	0.044	-0.057	-0.053		
TWt	0.03	-0.037	0.038	0.046	0.330*	0.287*	0.101	0.272*	0.163*	-0.005	0.751*	0.703*	-0.053	
AYP	0.193*	-0.007	0.093	0.036	0.386*	0.336*	0.164*	0.312*	0.155*	0.498*	0.598*	0.593*	-0.024	0.838*

*Significant at $P \leq 0.05$
SPH- Number of stems per plant, PH- Plant height, LPP- Number of leaves per plant, LCL- Number of leaflets per compound leaf, LLL- Leaflet length, LLW- Leaflet width, LL- Leaf length, LW- Leaf width, LA- Leaf area, TPP- Number of tubers per plant, TL- Tuber length, Tuber width, DW- Tuber dry matter content, TWt- Average tuber weight, AYP- Average tuber yield per plant

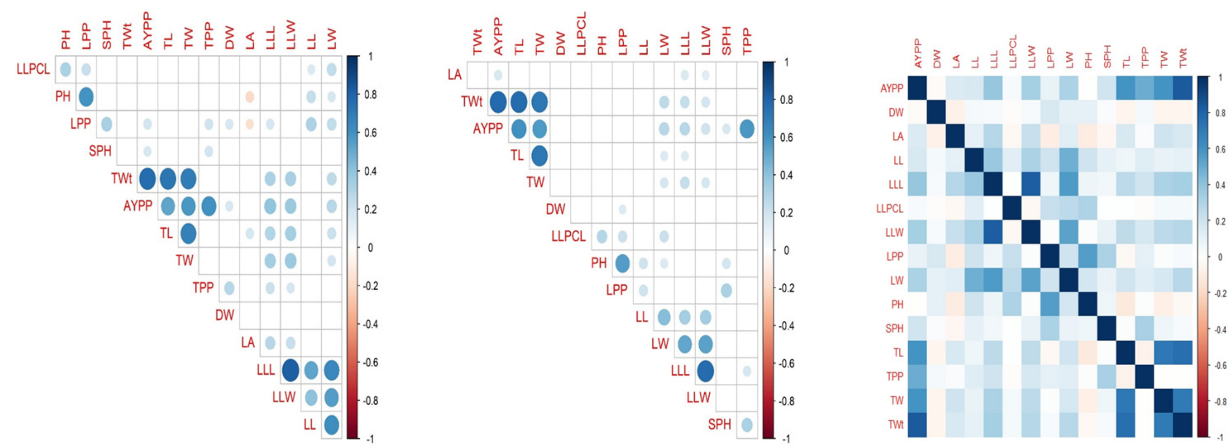
Table 3: Estimates of direct and indirect effects of different traits on average tuber yield/plant at genotypic levels in potato (Pooled data of 2021-22 and 2022-23)

Traits	*SPH*	*PH*	*LPP*	*LCL*	*LLL*	*LLW*	*LL*	*LW*	*LA*	*TPP*	*TL*	*TW*	*DW*	*TWt*	*r*
SPH	0.003	0.002	-0.006	0.000	-0.001	0.001	0.000	0.002	0.000	0.165	0.000	0.001	0.000	0.025	0.193**
PH	0.000	0.027	-0.010	-0.001	-0.001	0.000	0.000	0.005	0.000	0.006	0.001	-0.002	0.000	-0.031	-0.007
LPP	0.001	0.015	-0.018	-0.001	-0.001	0.000	0.000	0.006	0.000	0.060	0.000	0.000	-0.001	0.032	0.093
LCL	0.000	0.008	-0.004	-0.004	0.000	0.000	0.000	0.007	0.000	-0.009	0.000	0.001	0.000	0.038	0.036
LLL	0.000	0.002	-0.001	0.000	-0.015	0.006	0.000	0.016	0.001	0.101	-0.002	0.006	0.000	0.274	0.386**
LLW	0.000	0.000	0.000	0.000	-0.013	0.007	0.000	0.015	0.001	0.085	-0.002	0.005	0.000	0.238	0.336**
LL	0.000	0.005	-0.004	-0.001	-0.006	0.002	-0.001	0.013	0.000	0.068	0.000	0.002	0.000	0.084	0.164**
LW	0.000	0.005	-0.004	-0.001	-0.009	0.004	-0.001	0.028	0.000	0.063	-0.001	0.003	0.000	0.225	0.312**
LA	0.000	-0.003	0.002	0.000	-0.004	0.002	0.000	0.004	0.003	0.015	-0.001	0.004	0.000	0.135	0.155**
TPP	0.001	0.000	-0.002	0.000	-0.003	0.001	0.000	0.003	0.000	0.502	0.000	0.000	0.000	-0.004	0.498**
TL	0.000	-0.003	0.001	0.000	-0.004	0.002	0.000	0.005	0.000	-0.032	-0.008	0.014	0.000	0.623	0.598**
TW	0.000	-0.002	0.000	0.000	-0.005	0.002	0.000	0.005	0.001	-0.004	-0.005	0.019	0.000	0.583	0.593**
DW	0.000	0.003	-0.003	0.000	-0.001	0.000	0.000	0.003	0.000	0.022	0.000	-0.001	-0.004	-0.044	-0.024
TWt	0.000	-0.001	-0.001	0.000	-0.005	0.002	0.000	0.008	0.000	-0.003	-0.006	0.014	0.000	0.830	0.838**

Residual effect = 0.044

*Significant at P ≤ 0.05; bold values indicate direct effects; r: correlation coefficient with average tuber yield per plant

SPH- Number of stems per plant, PH- Plant height, LPP- Number of leaves per plant, LCL- Number of leaflets per compound leaf, LLL- Leaflet length, LLW- Leaflet width, LL- Leaf length, LW- Leaf width, LA- Leaf area, TPP- Number of tubers per plant, TL- Tuber length, Tuber width, DW- Tuber dry matter content, TWt- Tuber weight, AYP- Average tuber yield per plant



2021-22 **2022-23** **Pooled Years**

Figure 1: Genotypic correlation coefficient during 2021-22, 2022-23 and pooled over years

to be selected by showing the degree of association with different traits. Additionally, it promotes the simultaneous growth of different traits (Falconer, 1981). Therefore, it would be crucial to assess the extent and direction of the correlation of various attributes with average tuber yield per plant and to pinpoint the traits that are important for high yield. The correlation studies in the present investigation showed that at genotypic levels, AYP was significantly and positively associated with SPH, LLL, LLW, LL, LW, LA, TPP, TL, TW and TWt. Earlier researchers have also reported that AYP was significantly and positively associated with PH and LPP (Haydar et al., 2009). In general, a significant and positive association of leaflet length, leaflet width, leaf area, leaf length and leaf width was recorded among themselves (Table 2; Fig. 1). Further, a critical insight into the correlation coefficients indicated that TL, TW and TWt showed a significant and positive association with one another and with AYP (Table 2; Fig. 1). Earlier research workers have also reported positive association of AYP with TPP and LLL (Tripura et al., 2016), TPP and TWt (Pradhan et al., 2016). On the basis of correlation studies and their coefficients of determination, it can be concluded that SPH, LLL, LLW, LW, TPP, TL and TWt should be taken into consideration while isolating plants with high tuber yield per plant. The majority of these traits showed a correlation in the same direction over the years, emphasizing their importance for potato improvement programs.

The relationship pattern between yield and its component traits is revealed by correlation analysis, which indicates dependency. It merely shows the overall influence of a few characteristics on yield, not a cause-and-effect relationship. In order to assess the cause-effect relationship and make sound choices, path coefficient analysis is used. A perusal of Table 3 indicated direct and indirect effects at the genotypic level. AYP was taken as the dependent variable, while all the other traits were taken as causal variables. TWt had a maximum positive and direct effect on AYP (0.830), followed by an appreciable contribution of TPP (0.502) at the genotypic level. SPH, PH, LLW, LW, LA and TW also had very little direct contribution toward the total association with AYP. Earlier research workers have also reported positive and direct effects of various traits on AYP viz., PH and LPP (Haydar et al., 2009), TPP (Pradhan et al., 2016), PH, TPP and TWt (Ummyiah et al., 2013), PH, LPP and TPP (Barik et al., 2010). The magnitude of unexplained variation for AYP was very low at the genotypic level (0.064, 0.058 and 0.044) levels during 2021-22, 2022-23 and pooled over the years, indicating that attributes studied in this investigation accounted for a significant portion of the variation in the dependable variation i.e. AYP. In view of the direct and indirect contribution of component traits, selection based on the TWt along with TPP, LW and DW would be a rewarding proposition for evolving high-yielding potato genotypes.

The estimates of heritability and genetic gain were found to be high for SPH, PH, LPP, LCL, LLL, LLW, LL, LA, TPP, TL, TWt and AYP during both years, indicating the importance of additive gene action for the inheritance of these traits. Besides, high heritability along with moderate genetic advance was observed for DW which indicated the manifestation of non-additive gene action for the inheritance of this attribute. Correlation studies indicated that SPH, LLL, LLW, LW, TPP, TL and TWt should be taken into consideration while isolating plants with high tuber yield per plant. Similarly, path coefficient analysis also showed that TWt had a maximum positive and direct effect on AYP followed by an appreciable contribution of TPP.

Conflict of Interest

The authors declare no conflict of interest.

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सारांश

परिवर्तनशीलता के विभिन्न मापदंडों के आधार पर 357 चतुर्गुणित आलू जीन प्ररूपों जैसे कि किस्मों, उन्नत प्रजनन लाइनों और विदेशी जर्मप्लाज्म में पर्याप्त आनुवंशिक परिवर्तनशीलता दर्ज की गई । प्रति हिल तनों की संख्या, पौधे की ऊंचाई, प्रति पौधे पत्तियों की संख्या, प्रति मिश्रित पत्ती में पत्तों की संख्या, पल्लक की लंबाई, पल्लक की चौड़ाई, पत्ती की लंबाई, पत्ती क्षेत्र, प्रति पौधा कंदों की संख्या, कंद की लंबाई, औसत कंद वजन और प्रति पौधा औसत कंद उपज के लिए आनुवंशिकता और आनुवंशिक लाभ का अनुमान उच्च पाया गया जो कि इन विशेषताओं के वंशानुक्रम के लिए योगात्मक जीन क्रिया के महत्व को दर्शाता है। अधिक उपज देने वाले आलू की किस्मों को विकसित करने के लिए सहसंबंध गुणांक अध्ययनों ने प्रति हिल तनों की संख्या, पल्लक की लंबाई, पल्लक की चौड़ाई, पत्ती की चौड़ाई, कंद की लंबाई, प्रति पौधा कंदों की संख्या और औसत कंद वजन के महत्व को दर्शाया, जबकि पथ गुणांक विश्लेषण ने औसत कंद वजन और प्रति पौधा कंदों की संख्या के आधार पर चयन करने का निर्देश दिया है।