Association of traits in potato (*Solanum tuberosum* L.) cultivars evaluated in Central Ethiopia

Lemma Tessema[1,*], Wassu Mohammed[2], Tesfaye Abebe[1]

[1]Ethiopian Institute of Agricultural Research, Holetta Agricultural Research Centre, PO Box 2003, Addis Ababa, Ethiopia
[2]School of Plant Sciences, Haramaya University, PO Box 138, Dire Dawa, Ethiopia

Received: 15 February, 2023 **Accepted:** 15 May, 2023 **Published:** October 30, 2023

ABSTRACT

Knowledge of the magnitude of traits association helps to determine the relative contribution of traits toward yield and other important characteristics in crop breeding programs. The present study was conducted on twenty improved varieties and one local farmers` potato cultivar at two different sites in the Central Highlands of Ethiopia under rain-fed conditions in the *main* cropping season of 2017 to estimate association among traits using a randomized complete block design with three replications. Analysis of variance for each location and over locations revealed the presence of highly significant ($p < 0.01$) differences among varieties for studied traits. Plant height, stem number per hill, average tuber number per hill, average tuber weight, and total starch yield showed positive and significant correlations with total tuber yield at both genotypic and phenotypic levels. Average tuber number per hill, average tuber weight and total starch yield had positive and direct effects on total tuber yield at the genotypic level whereas, plant height, stem number per hill, average tuber number per hill, average tuber weight, total starch yield exerted indirect effects on total tuber yield through other traits. Hence, traits that exerted positive and direct effects on total tuber yield at the genotypic level could be considered as selection criteria in future potato breeding programs considering further comprehensive study by including more potato varieties and local cultivars across wider production environments.

Keywords: Correlation; Path coefficient; Direct effect; Tuber yield; Potato
DOI: https://dx.doi.org/10.4314/ejst.v16i3.3

INTRODUCTION

Potato (*Solanum tuberosum* L.) is the world`s number one non-grain food commodity and is consumed by more than one billion people worldwide (FAO and CFC, 2010; CIP, 2021). A hectare of potato can yield two to four times the food quantity of other grain commodities (CIP, 2021). Potatoes produce more food per unit of water than any other major crops and are up to seven times more efficient in using water than cereals (Bamberg and del Rio, 2005). Potato plays a prominent role in food security for millions of people across South America, Africa, and Asia, including Central Asia (Devaux *et al*. 2020; CIP, 2021). In Ethiopia, potato stands topmost among root and

* Corresponding author: lematessema@gmail.com

tuber crops (RTCs) both in area coverage and total production (CSA, 2021). Hence, the potato became one of the strategic foods and income-generating crops at present with a vast promising prospect in the future considering the ample potential and rapidly growing population leading to rapid land fragmentation and a search for productive crops per unit area (Scott *et al*., 2000; Devaux *et al*., 2020). Although land under cultivation and yield of potatoes increased year after year, the average tuber yield was low (12.1 t ha-1) as compared to the world average (17.6 t ha-1) (FAOSTAT, 2015; CSA, 2021). The low yield was attributed to many factors, of which the most important factors are lack of high yielding and disease-resistant varieties plus inferior seed quality used for planting year after year without any seed renewal by farmers (Endale Gebre *et al*., 2008; Gildemacher *et al.*, 2009; Lemma Tessema *et al*., 2022).

Studies on the association among traits are indeed important to breeding programs (Hajam *et al*., 2019) as they enable to perform an indirect selection for a quantitative trait, usually difficult to select, using another directly correlated trait of higher genetic gain or easy to select phenotypically. Besides, it also helps to determine how a trait can interfere with another trait (Cruz *et al*., 2012). Genotypic and phenotypic correlation coefficients indicate the association among two or more traits (Hajam *et al*., 2019). A significant association suggests that such traits could be improved simultaneously (Lavanya *et al*., 2020). However, such an improvement depends on phenotypic correlation, additive variance and heritability among other aspects to be considered during selection (Ara *et al*., 2009; Harriman *et al*., 2017).

Path coefficient, which is an ordinary partial regression coefficient, specifies the cause-and-effect relationship and measures the relative importance of each variable (Wright, 1921). Path coefficient analysis shows the extent of the direct and indirect effects of the causal components on the response component (Tuncturk and Ciftci, 2005; Faisal *et al*., 2007). Khayatnezhad *et al*. (2011) confirmed stronger, positive, and significant correlations between starch content and dry matter content, tuber yield and main stems per plant, plant tuber weight and plant height. Similarly, Sattar *et al*. (2007) reported a positive and significant correlation between plant vigor, number of tubers per plant, average tuber weight, and dry matter content with tuber yield in potato at the phenotypic and genotypic levels. Tesfaye Abebe *et al*. (2012) reported a strong positive correlation between dry matter and starch content and starch yield in 25 potato genotypes. Sattar *et al.* (2007) reported that plant height and dry matter content showed a negative direct effect on tuber yield whereas tuber number per plant, compound leaves per plant, plant vigor, and average tuber weight showed positive direct effects on tuber yield of potato. Abraham Lamboro *et al*. (2014) also reported positive direct effects on the phenotypic and genotypic path correlation coefficients of plant height, stem number, number of tubers, biological yield, and harvest index on tuber yield. Measurement of the correlation coefficient helps to ascertain the relative contribution of component characters toward yield (Ara *et al*., 2009; Hajam *et al*., 2019). However, the correlation between tuber yield and other traits may sometimes be misleading due to either overestimation or underestimation of tuber yield's association with other component traits and it indicates only the extent and nature of yield and its components. Thus, yield components influence ultimate yield both directly and indirectly (Mohanty, 2014). Moreover, partitioning of total correlation into direct and indirect effects would provide more meaningful interpretation of such association (Lavanya *et al*., 2020). Hence, correlation in combination with path coefficient analysis will be an important tool to find out the association and to quantify the direct and indirect influence of one trait upon another (Dewey and Lu, 1959; Karim *et al*., 2014; Machado *et al*., 2017). Furthermore, the literature on path analysis and applicability as the breeding tool is limited compared to its importance for plant breeders and the addition of information for future breeding work. Therefore, the present study was investigated to estimate the correlation between traits and the direct and indirect effects of traits on potato tuber yield.

MATERIALS AND METHODS

A field experiment was carried out at two locations: Holetta Agricultural Research Centre and Adaberga sub-station under rain-fed conditions in 2017 main cropping season. Holetta Agricultural Research Centre is situated at an altitude of 2,400 m. a. s. l. 09°00`N latitude and 38°29`E longitude. The area is characterized by mean annual rainfall of 1,100 mm and a mean relative humidity of 60.6%. The average annual maximum and minimum temperatures are 22.1 ℃ and 6.2 ℃, respectively. The soil type in the area is predominantly *Nitosols* which was characterized by an average organic matter (AOM) content of 1.8%, nitrogen 0.17%, phosphorous 4.55 ppm and potassium 1.12 Meq 100 g-1 of soil and pH 5.24 (HARC, 2016).

Adea Berga sub-station is situated in the central highlands of Ethiopia at 9° 16' N latitude and 38°23' E longitude. It lies at an altitude of 2,500 m.a.s.l. Adea Berga sub-station is characterized by cool sub-tropical climate with mean annual temperature and rainfall of 18 °C and 1,225 mm, respectively (HARC, 2016).

The planting materials consisted of twenty released varieties and one farmers` potato cultivar (a landrace which is named Nech Abeba named from its white flower color). The experiment was laid out in a randomized complete block design (RCBD) with three replications. The experimental plot size entailed 4 rows each 3 m long and 3.6 m wide, with a spacing of 30 cm between plants and 75 cm between rows. The space between blocks and plots was 1.5 m and 1 m, respectively. Fertilizer was applied at the rate of 108.44 kg N, 92.43 kg P, and 16.59 kg S per hectare in the form of Urea (143 kg/ha) and blended fertilizer (NPS) (237 kg/ha) as per the recommendation for the study area (MALR, 2017). All other agronomic practices and data collection was conducted based on the recommendations of the Holetta Research Centre (Berga Lemaga *et al*., 1992).

Analysis of variance (ANOVA) was computed for individual and over locations using SAS software version 9.3 (SAS Institute, 2010) as per the procedure indicated for the design using a general linear model (GLM) (Gomez and Gomez, 1984). The combined analysis of variance over locations was computed after the homogeneity test of error variances using *F*- test as stated by Gomez and Gomez (1984). Phenotypic (*rp*) and genotypic (*rg)* correlations between two traits were estimated with simple Excel using the formulas suggested by Singh and Chaudhury (1985) based on combined data after homogeneity test.

$$r_g = \frac{G\,cov_{xy}}{\sqrt{(V_g x . V_g y)}} \qquad r_p = \frac{P\,cov_{xy}}{\sqrt{(V_p x . V_p y)}}$$

where, r_p = phenotypic correlation coefficient;
r_g = genotypic correlation coefficient;
$Pcov_{xy}$ = phenotypic covariance between variables x and y;
$Gcov_{xy}$ = genotypic covariance between variables x and y;
$V_p x$ = phenotypic variance of variable x;
$V_g x$ = genotypic variance of variable x;
$V_p y$ = phenotypic variance of variable y; and
$V_g y$ = genotypic variance of variable y.

The calculated phenotypic correlation value was tested for its significance using t-test:
$t = r_{ph}/SE\ (r_p)$
where, r_p = phenotypic correlation; SE (r_p) = standard error of phenotypic correlation obtained using the following formula (Sharma, 1998).

$$SE\ (r_p) = \sqrt{\frac{1 - r^2 ph}{n - 2}}$$

where, n is the number of genotypes tested, r^2_{ph} is phenotypic correlation coefficient. The coefficients of correlations at genotypic levels were tested for their significance by the formula described by Robertson (1959) as indicated below:

$$t = r_{gxy}/SEr_{gxy}$$

The calculated "t" value was compared with the tabulated "t" value at (n-2) degree of freedom at 5% level of significance, where n is the number of genotypes.

$$SErgxy = \sqrt{\frac{1 - r^2 gxy}{h^2 x . h^2 y}}$$

Where, h^2_x = Heritability of trait x, h^2_y = Heritability of trait y

Path coefficient analysis

Based on genotypic and phenotypic correlations, path coefficient analysis was calculated with simple excel as suggested by Dewey and Lu (1959), i.e.,

$$r_{ij} = P_{ij} + \Sigma r_{ik}\, p_{kj}$$

where, r_{ij} = mutual association between the independent trait (i) and dependent trait (j) as measured by the genotypic and phenotypic correlation coefficients.
P_{ij} = direct effects of the independent character (i) on the dependent variable (j) as measured by the genotypic path coefficients, and $\Sigma r_{ik} p_{kj}$ = summation of components of indirect effects of a given independent character (i) on a given dependent character (j) via all other independent characters (k).

The residual effect, which determines how best the causal factors account for the variability of the dependent factor yield, was computed using the formula;

$$1 = p^2R + \Sigma\, p_{ij}\, r_{ij}$$

Where, p^2R is the residual effect.
$p_{ij}\, r_{ij}$ = the product of direct effect of any variable and its correlation coefficient with yield.

RESULTS AND DISCUSSION

Analysis of variance

The results of the analysis of variance revealed that the varieties had highly significant ($p < 0.01$) differences for all traits considered in the experiment (Table 1). The results of combined ANOVA over locations revealed that the mean squares for variety and location were significant for all traits except for days to 50% flowering. The mean squares for genotype x location (G × L) were significant for all traits except for days to 50% flowering, specific gravity, and dry matter content (Table 1) which means, the varieties had consistent performance over the two locations for days to 50% flowering, specific gravity, and dry matter content. This could be because of the past eminent breeding efforts made by the potato breeders to develop varieties that had relative consistency over a wide range of environments. Yield data for twenty improved potato varieties and one farmers' cultivar is also presented in Figure 1. The farmer's cultivar (Nech Abeba) produced the list marketable and total tuber yield than all twenty improved varieties.

Genotypic and phenotypic correlation coefficients with total tuber yield

The genotypic and phenotypic correlation coefficients between all fourteen traits of twenty-one potato cultivars are presented in Table 2. Total tuber yield had a significant positive genotypic correlation coefficient with plant height, average tuber number, stem number, average tuber weight, dry matter content, and total starch yield.

Table 1. Mean squares from combined analysis of variances over locations for 14 traits of twenty one potato cultivars in 2017

Trait	Rep (L) (4)	Variety (V) (20)	Location (L) (1)	L × V (20)	Error (80)	CV (%)
Days to 50% flowering	10.01	61.24**	5.37	0.82	9.7	5.2
Days to physiological maturity	49.25	161.0**	1176.4**	103.8**	10.7	3.3
Number of leaves per plant	8.76	219.2**	3618.2**	117.2**	16.3	9.9
Plant height(cm),	138.97	635.8**	18112.8**	120.1**	16.5	6.84
Stem number per hill	1.15	8.53**	65.3**	2.90**	0.2	11.1
Average tuber number per hill	4.96	25.2**	48.5**	16.7**	2.3	13.4
Average tuber weight (g)	21.24	600.9**	4538.1**	378.8**	21.3	9.0
Total tuber yield (t ha^{-1})	16.99	218.6**	2556.7**	49.4**	4.4	8.3
Marketable tuber yield (t ha^{-1})	15.02	206.0**	1927.9**	44.4**	3.8	9.1
Unmarketable tuber yield (t ha^{-1})	2.63	6.44**	44.3**	1.8**	0.4	16.0
Specific gravity (gcm^{-3})	0.0002	0.0004**	0.01**	0.0001	0.00004	0.6
Dry matter content (%)	2.14	20.5**	321.4**	2.2	1.5	5.6
Starch content % (g 100 g^{-1})	5.62	30.7**	284.8**	4.6*	2.4	10.7
Total starch yield (t ha^{-1})	1.15	8.1**	9.8**	1.0**	0.2	12.4

*, **, significant at P=0.05 and P<0.01, respectively. Rep= replication, CV (%) = coefficient of variation in percent, numbers in the parenthesis are degrees of freedom

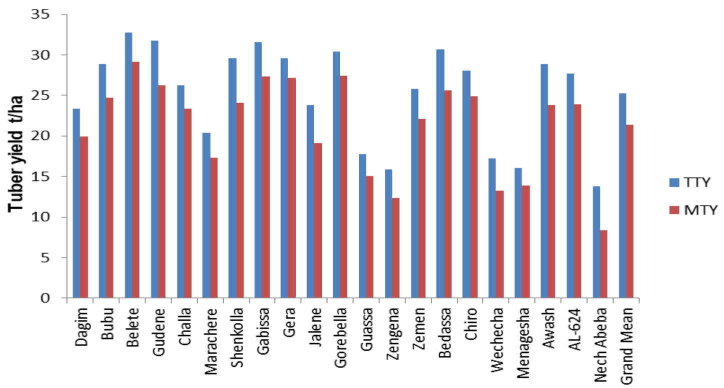

Figure 1. Marketable and total tuber yield (t/ha) for twenty one potato cultivars in Central Ethiopia

A positive and significant relationship of yield per hectare with these mentioned traits suggested that the tuber yield can be increased by a simple selection of these traits. According to Hirut Bitew *et al.* (2017) total tuber yield showed positive and significant correlation coefficient with ground cover (%), stem number, average tuber weight, marketable tuber number and marketable tuber yield, and ground cover (%), plant height, average tuber weight, marketable tuber number and marketable tuber yield under well-watered and water-stressed conditions, respectively. Similarly, marketable tuber yield per plot, number of tubers per plant and stem numbers at 60 days after planting and tuber weight were the most influencing factors to improve the tuber yield (Lavanya *et al.*, 2020). Hajam *et al.* (2019) also pointed out that tuber yield per plant exhibited a significant positive correlation with the number of tubers per plant, average tuber weight, plant height, leaf area, plant spread, and the number of stems per hill. The starch yield was associated strongly with dry matter content, which was supported in the study by Khayatnezhad *et al*. (2011). This result was similar to reports elsewhere (Khayatnezhad *et al*., 2011; Kaur and Aggarwal, 2014; Douches *et al*., 2015; Panja *et al*., 2016; Wassu, 2016; Harriman *et al*., 2017).

At the phenotypic level, the number of leaves per plant, plant height, stem number per hill, average tuber number, average tuber weight, and total starch yield showed a positive significant correlation with total tuber yield (Table 2). Positive and high significant correlations were recorded for plant height, number of stems per hill, and total starch yield indicating that selection for these traits could enable to improve total tuber yield of potato at the phenotypic level. Abraham Lamboro *et al*. (2014) reported positive and significant correlation coefficients in traits *viz*., plant height, stem number, biological yield, and medium tuber percentage, whereas negative and significant correlation coefficient was recorded for small tuber percentage. In contrast, Douches *et al*. (1996) reported that days to maturity had a positive significant phenotypic correlation with total and marketable tuber yield. Similar results were investigated on potato (Sattar *et al*., 2007; Addisu Fekadu *et al*., 2013; Panja *et al*., 2016; Yerima, 2016; Panigrahi *et al*., 2017).

Path Coefficient Analysis

Genotypic path coefficient

The path coefficient analysis based on tuber yield as a dependent variable for genotypic traits revealed that days to 50% flowering, days to maturity, number of leaves per hill, average tuber number, average tuber weight, and total starch yield had positive direct effects (Table 3). The total starch yield had the highest positive direct effect on yield followed by the average tuber number per hill which was supported by Kumar *et al*. (2015). Both total starch yield and average tuber number had a positive significant correlation with yield. These traits had a good response on tuber yield increment if considered at the same time as selection. A direct negative effect on yield was shown by dry matter content, stem number, and plant height in which indirect selection for these traits has contributed to tuber yield. The direct negative effect for dry matter indicated that the effectiveness of indirect selection for these traits. On the other hand, tuber dry matter showed a maximum indirect effect on tuber yield through total starch yield.

Tuber dry matter had a considerable negative direct effect on total tuber yield indicating that the improvement of this trait could be possible with indirect selection through total starch yield (Table 3). This could be due to the fact that 70-80% of potato is water and the dry matter content consists of very low portion of the tuber.

Table 2. Genotypic correlation coefficients (above diagonal) and phenotypic correlation coefficients (below diagonal) of yield related traits with total tuber yield in 21 potato cultivars over two locations

Variable	DF	DM	NLP	PH	SN	ATN	ATW	TTY	DMC	TSY
DF	1	-0.32	0.10	0.206	0.456*	0.360	-0.27	0.07	0.39	0.15
DM	-0.15	1	0.16	0.09	-0.09	-0.47	0.19	-0.08	0.19	0.04
NLP	0.09	-0.14	1	0.73**	0.66**	0.22	0.12	0.39	0.46*	0.46*
PH	0.12	-0.12	0.75**	1	0.68**	0.34	0.34	0.67**	0.56**	0.71**
SN	0.26**	-0.22	0.73**	0.71**	1	0.55**	0.03	0.53*	0.45*	0.56**
ATN	0.18*	-0.24	0.14	0.28**	0.33**	1	-0.31	0.60**	0.15	0.46*
ATW	-0.13	-0.12	0.43**	0.51**	0.34**	-0.33	1	0.48*	0.28	0.49*
TTY	0.04	-0.29	0.50**	0.69**	0.54**	0.49**	0.49**	1	0.54*	0.94**
DMC	0.14	0.27**	-0.17	-0.24	-0.05	-0.05	-0.13	-0.06	1	0.79**
TSY	0.07	-0.11	0.36**	0.51**	0.47**	0.38**	0.41**	0.85**	0.45**	1

* indicates significant at 5% probability, ** indicates significant at 1% probability, DF = days to 50% flowering, DM = days to physiological maturity, NLP = number of leaves per plant, PH = plant height (cm), SN = stem number per hill, ATN = average tuber number per hill, ATW = average tuber weight (g/tuber), TTY = total tuber yield t ha^{-1}, DMC = dry matter content (%), and TSY = total starch yield t ha^{-1}

However, dry matter content, stem number and plant height showed positive significant correlation with yield at genotypic level. Therefore, selection based on these traits would give better response to the improvement of total tuber yield in potato. Similar results were reported by Khayatnezhad *et al*. (2011) for main stem per plant, plant tuber weight and plant height. Results of the path analysis showed that the nine variables together accounted for up to 98.4% of the total observed variability in the tuber yield indicated by the coefficient of determination (R^2) (Table 3). The residual effect of the genotypic path analysis was 0.13 clearly indicated that about 87% of the variability in yield per hectare was contributed by the traits studied. However, there were also some other traits (13%) which were not studied but could influence the tuber yield in potato. It is suggested that maximum emphasis would be given to the studied traits in selecting potato with higher total tuber yield. Similarly, Singh (2008) reported negative direct effect for the traits dry matter content, plant height at maturity, weight of tuber per plant, number of leaves per plant at 45 days after planting on tuber yield. Path coefficient analysis revealed positive and direct effect of marketable yield per plot, unmarketable yield per plot, plant height, number of shoots per plant, fresh weight of shoots per plant, number of compound leaves per plant, and number of tubers per plant. However, high negative direct effects on tuber yield were observed by the number of branches per plant, percent plant emergence, dry weight of shoots per plant, fresh weight of tubers per plant, and tuber dry matter plant (Khayatnezhad *et al*., 2011).

Phenotypic path coefficient

Phenotypic direct and indirect effects of various studied traits on tuber yield are presented in Table 4. Path coefficient analysis based on total tuber yield as a dependent variable for phenotypic characters revealed that days to physiological maturity, plant height, stem number and dry matter content had negative direct effects suggesting that indirect selection for these traits could be effective.

Whereas, total starch yield, average tuber number, average tuber weight, number of leaves per plant and days to 50% flowering had positive direct effect on total tuber yield (Table 4). Total starch yield had highest direct effect indicating that selecting for this trait could be important for total tuber yield improvement. The residual effect of the phenotypic path analysis indicates that about 83% of the variability in tuber yield per hectare was contributed by the traits studied. However, there are other traits that are not included in this study which could account for 17% influencing the potato tuber yield. Similar results were reported by different scholars on their studies (Singh, 2008; Khayatnezhad *et al*., 2011; Wondimu *et al*., 2013). Panigrahi *et al*. (2017) reported negative direct effect for dry matter content, plant height, germination percentage and harvest index while and positive direct effect for marketable tuber yield, unmarketable tuber yield, leaf area index and number of leaves at 50 days after planting on tuber yield of potato.

Table 3. Genotypic direct effect (bold face) and indirect effect (off diagonal) of traits on potato tuber yield

Variable	DF	DM	NLP	PH	SN	ATN	ATW	DMC	TSY	TTY(rg)
DF	**0.083**	-0.009	0.007	-0.007	-0.039	0.049	-0.017	-0.194	0.194	0.066
DM	-0.026	**0.028**	0.011	-0.003	0.008	-0.065	0.012	-0.094	0.051	-0.077
NLP	0.009	0.005	**0.068**	-0.024	-0.057	0.030	0.008	-0.229	0.578	0.387
PH	0.017	0.003	0.050	**-0.033**	-0.050	0.047	0.023	-0.277	0.887	0.657**
SN	0.038	-0.003	0.045	-0.023	**-0.086**	0.074	0.002	-0.224	0.709	0.531**
ATN	0.030	-0.013	0.015	-0.011	-0.047	**0.136**	-0.021	-0.072	0.583	0.599**
ATW	-0.022	0.005	0.008	-0.012	-0.003	-0.043	**0.065**	-0.141	0.616	0.475**
DMC	0.032	0.005	0.031	-0.019	-0.039	0.020	0.019	**-0.495**	0.986	0.541*
TSY	0.013	0.001	0.031	-0.023	-0.049	0.063	0.032	-0.388	**1.257**	0.937**

Residual effect = 0.13

DF = days to 50% flowering, DM = days to physiological maturity, NLP = number of leaves per plant, PH = plant height (cm), SN- stem number per hill, ATN = average tuber number per hill, ATW = average tuber weight (g/tuber), TTY = total tuber yield tha^{-1}, DMC = dry matter content, TSY = total starch yield t ha^{-1}.

Table 4. Phenotypic direct effect (bold face) and indirect effect (off diagonal) of characters on tuber yield.

Variable	DF	DM	NLP	PH	SN	ATN	ATW	DMC	TSY	TTY(rp)
DF	0.050	0.0002	0.0047	-0.003	-0.014	0.012	-0.003	-0.080	0.073	0.041
DM	-0.007	-0.0016	-0.0074	0.004	0.012	-0.015	-0.002	-0.148	-0.123	-0.289
NLP	0.004	0.0002	0.0522	-0.017	-0.039	0.009	0.008	0.095	0.388	0.502**
PH	0.006	0.0003	0.0393	-0.022	-0.038	0.018	0.010	0.131	0.547	0.692**
SN	0.013	0.0004	0.0383	-0.01	-0.0531	0.021	0.006	0.026	0.505	0.541**
ATN	0.009	0.0004	0.0073	-0.006	-0.018	0.064	-0.006	0.028	0.407	0.486**
ATW	-0.007	0.0002	0.0225	-0.011	-0.018	-0.021	0.019	0.070	0.439	0.493**
DMC	0.007	-0.0004	-0.0090	0.005	0.003	-0.003	-0.002	-0.552	0.490	-0.063
TSY	0.003	0.0002	0.0188	-0.011	-0.025	0.024	0.008	-0.251	1.078	0.845**

Residual effect = 0.17

DF = days to 50% flowering, DM = days to physiological maturity, NLP = number of leaves per plant, PH = plant height (cm), SN- stem number per hill, ATN = average tuber number per hill, ATW = average tuber weight (g/tuber), TTY = total tuber yield tha-1, DMC = dry matter content, TSY = total starch yield t ha-1.

CONCLUSIONS

The presence of highly significant differences among potato varieties suggested the existence of genetic background differences which might be related to the wide range of variety development years and seed degeneration of the varieties through long-time production. Plant height, stem number per hill, average tuber number per hill, average tuber weight, and total starch yield had a positive and significant correlation with total tuber yield both at genotypic and phenotypic levels. On the other hand, average tuber number per hill, average tuber weight, and total starch yield had positive and direct effects on total tuber yield at the genotypic level. Whereas, plant height, stem number per hill, average tuber number per hill, average tuber weight, and total starch yield exerted indirect effects on total tuber yield through other traits. Total starch yield, average tuber number per hill, and average tuber weight had major contributions on tuber yield, and hence selection for these traits could lead to improvement in tuber yield of potato for future breeding programs through more comprehensive study including additional potato genotypes and environments would be crucial to be considered in future potato research and development.

ACKNOWLEDGEMENTS

The authors are grateful to Ethiopian Institute of Agricultural Research for financial and other supports required for the field research work.

Author contribution

LT and WM contributed for conception, design, and acquisition and set up the experiment, LT conducted the field work and collected data, LT and WM analyses the data, result interpretation, manuscript draft, TA and WM edited the manuscript and all authors approved the manuscript.

REFERENCES

Abraham Lamboro, Yohannes Petros, Mebeaselassie Andargie. (2014). Correlation and path coefficient analysis between yield and yield components in potato (*Solanum tuberosum* L.). *Plant Science Today* **1**(4): 196–200.

Addisu Fekadu, Yohannes Petros, Habtamu Zelleke. (2013). Genetic variability and association between agronomic characters in some potato (*Solanum tuberosum* L.) genotypes in SNNPRS, Ethiopia. *International Journal of Biodiversity Conservation* **5**(8): 523–528.

Ara, T., Haydar, A., Islam, M.A., Azad, M.A.S and Khokan, E.H. (2009). Path analysis in potato. *Journal of Soil and Nature* **3**(2): 20–23.

Bamberg, J.B and del Rio, A. (2005). Conservation of genetic resources. *In*: Razdan MK, Mattoo A. (eds). Genetic improvement of Solanaceous crops. Science Publishers Inc., Enfield NH. Pp 1–38.

Berga Lemaga, Gebremedhin W/giorgis, Tessera Jaletta, Bereke Tsehai_Tuku. (1992). Horticulture research and development in Ethiopia. Proceedings of the 2nd National Work Shop of Ethiopia. Herath E, and Desalegn L (Eds.). 1–3 December, 1992, EIR/FAO, Addis Ababa, Ethiopia.

CIP. (2021). Potato facts and figures. http://cipotato.org/potato/facts (Accessed on 7 April 2022)

Cruz, C.D., Regazzi, A and Carneiro, P.C.S. (2012). Biometric Models Applied to Genetic Improvement. 4th ed. UFV, Viçosa, MG, Brazil (in Portuguese).

CSA (Central Statistics Agency). (2021). Agricultural sample survey 2020/21 volume V: Report on area, production and farm management practice of *belg* season crops for private peasant holdings. Agricultural samplesurvey volume V, Addis Ababa, Ethiopia. Statistical bulletin 578. pp.147

Devaux, A., Goffa, E-P., Petsakos, A., Kromann, P., Gatto, M., Okello, J., Suarez, V and Hareau, G. (2020) Global food security, contributions from sustainable potato agri-food systems. In: Campos, H., Ortiz, O.(eds) The Potato Crop. Springer, Cham. https://doi.org/10.1007/978-3-030-28683-5-1

Dewey, D.R and Lu, K. (1959). A correlation and path-coefficient analysis of components of crested wheatgrass seed production. *Agronomy Journal* **51**(9): 515–518.

Douches, D.S., Jastrzebski, K., Maas, D and Chase, R.W. (1996). Assessment of potato breeding progress in the United States over the last century. *Crop Science* **36:** 1544–1552.

Douches, D.S., Michael, A.H., Buell, J.B., Robin, C. (2015). Taxonomy and genetic differentiation among wild and cultivated germplasm of *Solanum* sect. *Petota. The plant genome* **8**(1): 1–16.

Endale Gebre, Gebremedhin W/Giorgis, Berga Lemaga. (2008). Potato seed management. In: Gebremedhin W/Giorgis, Endale Gebre, Berga Lemaga (Eds.), Root and Tuber Crops: The Untapped Resources. Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia. Pp. 54–66.

Faisal, M., Malik, N., Ashraf, M., Qureshi, A.S and Ghafoor, A. (2007). Assessment of genetic variability, correlation and path analysis for yield and its components in soybean. *Pakistan Journal of Botany* **39**(2): 405–413.

FAO and CFC. (2010). Strengthening potato value chains: technical and policy options for developing countries. Rome, Italy. ISBN 978-92-5-106627-0.

FAOSTAT. (2015). Data base of agricultural production. Rome, Italy.

Gildemacher, P.R., Demo, P., Barker, I., Kaguongo, W., Gebremedhin, W., Wagiore, W., Wakahiu, M., Leeuwis, C and Struik, P. (2009). A description of seed potato systems in Kenya, Uganda, and Ethiopia. *American Journal of Potato Research* **86**: 373–382.

Hajam, M.A., Bhat, T.A., Rather, A.M., Khan, S.H., Ganie, M.A and Shafi, M. (2019). Correlation and path analysis in potato under temperate conditions. *Journal of Plant Development Sciences* **11**(1): 51–56.

HARC. (2016). Holetta agricultural research center progress report 2015/16.

Harriman, J.C., Okocha, P.I., Nwofia, G.E and Afuape, S.O. (2017). Association between root yield and other traits in orange fleshed sweet potato. *Nigerian Journal of Genetics* **31** (1): 115 –123.

Hirut Bitew, Shimelis Hussein, Fentahun Mengistu, Bonierbale, M., Gastelo, M and Asrat Asfaw. (2017). Combining ability of highland tropic adapted potato for tuber yield and yield components under drought. PLoS ONE **12**(7): 1–22.

Karim, D., Siddique, M.N.A., Sarkar, U., Hasnat, M.Z and Sultana, J. (2014). Phenotypic and genotypic correlation co-efficient of quantitative characters and character association of aromatic rice. *Journal of Bioscience and Agriculture Research* **01**(01): 34–46.

Kaur, S and Aggarwal, P. (2014). Studies on Indian potato genotypes for their processing and nutritional quality attributes. *International Journal of Current Microbiology and Applied Sciences* **3**(8): 172–177.

Khayatnezhad, M., Shahriari, R and Gholamin, R. (2011). Correlation and path analysis between yield and yield components in Potato (*Solanum tubersum* L.). Young Researchers Club, Islamic Azad University, Ardabil Branch. *Middle-East Journal of Science Research* **7**(1): 17–21.

Kumar, P., Vimal, S.C and Kumar, A. (2017). Study of Simple Correlation Coefficients for Yield and its Component Traits in Lentil (*Lens culinaris* Medik.). *International journal of current Microbiology and Applied Sciences* **6**(9): 3260–3265.

Kumar, S., Chauhan, M.P., Tomar, A., Kasana, R.K and Kumar, N. (2018). Correlation and path coefficient analysis in rice (*Oryza sativa* L.). *The Pharma Innovation Journal* **7**(6): 20–26.

Kumar, V., Singh, S.K., Bhati, P.K., Sharma, A., Sharma, S.K and Mahajan, V. (2015). Correlation, path coefficient analysis in maize (*Zea mays* L.). *Environment and Ecology* **33**: 971–975.

Lavanya, K.S., Srinivasa, V., Ali, S., Lakshmana, D and Kadian, M.S. (2020). Correlation and path analysis for yield and yield-related traits of potato (Solanum tuberosum L.) in Karnataka. *National Academy Science Letters* **43**(2): 37–140. https://doi.org/10.1007/s40009-019-00831-z

Lemma Tessema, Ebrahim Seid, Gebremedhin W/Giorgis, Kalpana Sharma, Mulatu Workie, Kasaye Negash, Abebaw Misganaw and Tesfaye Abebe. (2022). Incidence and occurrence of latent *Ralstonia solanacearum* infection in seed potato from Farmer Seed Grower Cooperatives in Southern and Central

Ethiopia. *Potato Research* **65**(3): 649–662. https://link.springer.com/article/10.1007/s11540-022-09541-4

Machado, B.Q.V., Nogueira, A.P.O., Hamawaki, O.T., Rezende, G.F., Jorge, G.L., Silveira, I.C., Medeiros, L.A., Hamawaki, R.L and Hamawaki, C.D.L. (2017). Phenotypic and genotypic correlations between soybean agronomic traits and path analysis. *Genetics and Molecular Research* **16** (2): 1–11.

MALR (Ministry of Agriculture and Livestock Resource) (2017). Plant variety release, protection and seed quality control directorate, crop variety register. Issue number 20, Addis Ababa, Ethiopia.

Mohanty, P. (2014). Studies on genetic variability and correlation analysis in sweet potato (*Ipomoea Batatas* (L.) Lam.) Genotype. MSc. Thesis. Dr. Y.S.R. Horticultural University, Venkataramannagudem.

Panigrahi, K.K., Pradhan, J., Panigrahi, P and Sarkar, K.K. (2017). Genetic variability, character association and path coefficient analysis of yield attributes for medium and late maturing potato cultivars. *International journal of current Microbiology and Applied Sciences* **6**(7): 2558–2566.

Panja, S., Mandi, V., Bhattacharya, C and Sarkar, K.K. (2016). Studies on the scope of genetic improvement for yield and yield related traits in potato (*Solanum tuberosum* L.) production. *International Journal of Current Research* **08**(05): 31427–31433.

Robertson, A. (1959). Experimental design in the evaluation of genetic parameters. *Biometrics* **15**(2): 219–226.

SAS Institute (2010). The SAS System for Windows. SAS Inst., Cary, NC.

Sattar, M.A., Sultana, N., Hossain, M.M., Rashid, M.H and Islam, A.K.M.A. (2007). Genetic variability, correlation and path analysis in potato (*Solanum tuberosum* L.). *Bangladesh Journal of. Plant Breeding and Genetics* **20**(1): 33–38.

Scott, G.J., Rosegrant, M.W and Ringler, C. (2000). Global projections for root and tuber crops to the year 2020. *Food Policy* **25** (5): 561–597.

Sharma, J.R. (1998). Statistical and biometrical techniques in plant breeding. New age International (P) limited, Publishers, New Delhi.

Singh, G. (2008). Studies on genetic variability, association and divergence in potato (*Solanum tuberosum* L.). MSc. Thesis, Indira Gandhi Krishi Vishwavidyalaya, Raipur, India.

Singh, R.K and Chaudhary, B.D. (1985). Biometrical methods in quantitative genetics analysis, Kalyani Publishers, Ludhiyana.

Tesfaye Abebe, Wongchaochant, S., Taychasinpitak, T and Leelapon, O. (2012). Dry matter content, starch content and starch yield variability and stability of potato varieties in Amhara Region of Ethiopia. *Kasetsart Journal (Natural Science*) **46**: 671 – 683.

Tuncturk, M and Çiftci, V. (2005). Selection criteria for potato breeding. *Asian Journal of Plant Sciences* **4**(1): 27–30.

Wassu Mohammed. (2016). Specific gravity, dry matter content, and starch content of potato (*Solanum tuberosum* L.) Varieties Cultivated in Eastern Ethiopia. *East African Journal of Sciences* **10**(2): 87–102.

Wondimu Fikadu, Amsalu Ayana, Habtamu Zeleke. (2013). Improvement in grain yield and malting quality of barley (*Hordeum vulgare* L.) in Ethiopia. *Ethiopian Journal of Applied Science and Technology* **4**(2): 37 – 62.

Wright, S. 1921. Correlation and causation. *Journal of Agricultural Research* **20**: 557–587.

Yerima, I. 2016. The effect of correlation and path coefficient analysis on yield and six vegetative parametres in Irish potato (*Solanum tuberosum* L.). *Journal of Global Biosciences* **5**(2): 3683–3693.