ISSN: 2224-0616
Int. J. Agril. Res. Innov. Tech. 12(2): 144-154, Dec 2022
DOI: https://doi.org/10.3329/ijarit.v12i2.64102

OPEN ACCESS
Available online at https://ijarit.webs.com
https://www.banglajol.info/index.php/IJARIT

Correlation and path coefficient analyses of tuber yield and yield components among potato (*Solanum tuberosum* L.) genotypes at Bekoji, Southeastern Ethiopia

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Received 31 October 2022, Revised 13 December 2022, Accepted 22 December 2022, Published online 31 December 2022

ABSTRACT

The aim of the experiment was to determine the correlations between tuber yield and yield components and to measure the direct and indirect effects of yield components on tuber yield of potato genotypes. The experiment was conducted using eleven potato genotypes with one standard check variety (Belete) and a local check at Kulumsa Agricultural Research Center, Bekoji sub-station during 2020-2021. Data were collected for tuber yield, tuber dry matter content (%), plant height (cm), stem number, specific gravity, and phenological parameters. Since the two seasons had heterogeneous error variance, analysis was carried out separately. In 2020, correlation analysis indicated that the tuber yield was positively and significantly associated with stem height (0.608), marketable tuber (0.997) and positively associated with tuber dry matter content, stem number per plant, days to maturity, while it was negatively correlated with specific gravity, days to emergence and days to flowering at the genotypic level. Total tuber yield was positively and significantly correlated with days to maturity (0.640), stem height (0.791), marketable tuber (0.977) and stem number at the genotypic level. While specific gravity was positively and significantly correlated at the phenotypic level; and negatively at the genotypic level in the second season. Results of path analyses indicated that marketable tubers had the highest positive direct effect (+1.059) on total tuber yield followed by days to flowering (+0.057) and specific gravity (+0.026) in 2020 while marketable tuber (0.7107), stem height (0.2842), tuber dry matter content (0.0078), days to maturity (0.1250) had also positive direct effect in 2021. In addition, most of the indirect effects of yield components on tuber yield were significant and positive. Significant effects of marketable tuber, tuber dry matter content, days to maturity and stem height on total tuber yield, indicated that they could be used as the criteria for potato improvement and breeding programs.

Keywords: Correlation, Direct effect, Potato, Tuber yield, Season

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Cite this article as: Hunde, N.F., Galalcha, D.T., Limeneh, D.F. 2022. Correlation and path coefficient analyses of tuber yield and yield components among potato (*Solanum tuberosum* L.) genotypes at Bekoji, southeastern Ethiopia. *Int. J. Agril. Res. Innov. Tech.* 12(2): 144-154. https://doi.org/10.3329/ijarit.v12i2.64102

Introduction

Potato (*Solanum tuberosum* L.) is one of the major world's agricultural root crops, which plays important role in feeding the world. It is a very important food and cash crop especially on the highland and mid altitude areas of Ethiopia (Gebremedhin *et al.,* 2008). The potential for high yield, early maturity, and excellent food value give the potato great potential for improving food security, increasing household income, and reducing poverty (Devaux *et al.,* 2014). The success of any breeding programme for increased productivity depends upon the quantum of genetic variability present in the population. Correlation studies provide an opportunity to study the magnitude and direction of association of yield with its components and among various components. Knowledge of correlations among different characteristics is fundamental to designing an effective breeding program in selecting the breeding materials for improving complex characters through indirect selection (Teklewold *et al.,* 2000). Tuber yield is a complex character and economically important, but it is associated with many interrelated components (Tuncturk and Çiftci, 2005). In addition, tuber yield being quantitative trait, which is the product of several directly or indirectly, affecting factors. Effective selection has a significant impact on crop improvement programs therefore; selection can play a substantial role in achieving breeding goals (Al-Tabbal, 2016). The correlation coefficient is very important for measuring the degree and direction of linkage of either different parameters that affect positively or negatively the yield (Kumar *et al.,* 2013). Path coefficient is essential to accumulate optimum combination of yield contributing characters and to know the implication of the interrelationships of various characters in a single genotype, because correlation coefficients describe relationships in a simple manner. Path coefficient analysis shows the extent of direct and indirect effects of the causal components on the response component (Singh *et al.,* 2004). In most studies involving path analysis, researchers considered the predictor characters as first-order variables to analyze their effects over a dependent or response variable such as yield (Bhagowat and Saikia, 2003). Therefore, path coefficient analysis is optional to utilize for more and complete determination of impact of independent variable on dependent one. So direct and indirect effects can clearly be understood by path analysis. The change in one character brings about a series of changes in the other characters, since they are interrelated. Therefore, the correlation studies are of considerable importance in any selection programme as they provide degree and direction of relationship between two or more component traits. Path coefficient analysis provides a thorough understanding of contribution of various characters by partitioning the correlation coefficient into components of direct and indirect effects (Wright, 1921), which helps the breeder in determining the yield components. Many researchers have widely used this analysis to explain the direct and indirect effects of different traits on yield in different crop species. Hence, the present study was conducted for two years with thirteen potato genotypes to investigate the relationship between tuber yield and its associated traits through correlation and path analyses among potato genotypes grown in southeastern Ethiopia.

Materials and Methods

Description of the study area

The field experiment was conducted at Bekoji sub-station, Southeastern Ethiopia during the rain-growing season in 2020 and 2021. Bekoji is located between latitude and longitude of 070 32' 37'' N and 390 15' 21'' E coordinates. The altitude of Bekoji is 2810 meters above sea level and the annual maximum and minimum temperature of 20.4 and 3.8 ^{o}C respectively with annual rain fall of 939 mm. The rainy season over the sites extends from June on October and is sufficient for crops with a maturity period of 120–150 day. The soil type of the area was clay soil (Nitosols) with pH of 5.23 as indicated in Tables 1 and 2.

Table 1. Physicochemical properties of soils of Bekoji experimental site.

Altitude	Soil physical and chemical properties						
Above sea level (m)	Soil pH	Total N (%)	Available P (ppm)	Available K ($Cmol^{+}. kg^{-1}$)	CEC (Meq per 100 g)	Organic matter (%)	Texture
2810	5.23	0.21	9.72	0.83	23.72	1.89	Nitosols

Source: Kulumsa Agricultural Research Center, Bekoji Station soil properties, 2020

Table 2. Mean temperature, rainfall, and relative humidity of two seasons at Bekoji experimental site.

Cropping season	Cropping season months	Mean monthly Rainfall (mm)	Mean air temperature (^{O}C)		Relative humidity (%)
			Minimum	Maximum	
2020	May	83.9	6.3	20.6	54
	June	155.2	3.8	20.1	70
	July	296.3	3.9	18.9	79
	August	190.9	4.0	18.7	80
	September	109.0	4.2	19.0	72
	October	87.2	2.3	20.0	66
2021	May	74.2	3.5	21.0	72
	June	82.6	3.1	23.3	78
	July	213.0	3.1	23.2	81
	August	193.3	3.5	20.8	82
	September	100.1	3.2	19.4	77
	October	57.5	3.1	20.3	78

Source: Kulumsa Agricultural Research Center, Bekoji Meteorology station, 2020 & 2021.

Experimental design and materials

The experiment was laid out in Randomized Complete Block Design (RCBD) replicated three times. A total of 13 potato genotypes including one released variety as standard check and one local check were used for the experiment (Table 3). The Eleven genotypes were obtained from a crosses of Adet Agricultural Research Centre. The gross plot area was 3 m x 3 m = 9 m^2 consisting of four rows, which accommodated 10 plants per row and 40 plants per plot. The net plot size is 1.5 m x 2.4 m=3.6 m^2. The spacing between plots and adjacent replications were 1.0 and 1.5 m, respectively. Medium-sized and well-sprouted potato tubers were planted at the spacing of 75 cm between rows and 30 cm between plants with planting depth of 5 to 10 cm. The completely recommended rate of 242 kg NPS ha^{-1} was applied at planting as source of phosphorous and 75 kg Nha^{-1} in the form of Urea in two splits, half rate after full emergence and half rate at the initiation of tubers. All other non-variable agronomic practices were applied uniformly as per the recommendation made by the research center for the area.

Table 3. List of experimental materials included in the study.

No.	Genotype	Pedigree	No.	Genotype	Pedigree
1	AD515606.16	Belete x Aterababa	8	AD515578.102	Jalene x Aterababa
2	AD515606.44	Belete x Aterababa	9	AD515606.15	Belete x Aterababa
3	AD515578.77	Jalene x Aterababa	10	AD515578.187	Jalene x Aterababa
4	AD515578.49	Jalene x Aterababa	11	AD51645.9	Belete x CIP-396034.263
5	AD515270.96	Gera x Shenkola	12	Belete	Standard check
6	AD515606.213	Belete x Aterababa	13	Local check	Farmer's cultivar
7	AD515606.164	Belete x Aterababa			

Source of all genotypes except the local cultivar and Belete was Adet Agricultural Research Center.

Data collection

Data were recorded for phenology and growth parameters; day to emergence, days to 50% flowering, days to maturity, stem height (cm) and average stems number, and yield parameters; total tuber yield (t ha^{-1}), marketable tuber yield (t ha^{-1}) and as quality attributes including tubers dry matter content (%), specific gravity.

Data analysis

Data were subjected to analysis of variance using proc GLM procedure of SAS 9.2 software (SAS 2009). The means were compared with Duncan's Multiple Rage Test at 5% significance level.

Correlation analysis

Phenotypic correlation is the relationship between two variables, which includes both genotypic and environmental effects, and genotypic correlation is the inherent association between two variables. These were estimated using the formula suggested by Miller *et al*., (1958).

$$\mathbf{r}_p = \frac{Pcov\ x.y}{\sqrt{(\delta_g^2 x * \delta^2 pY)}} \qquad \mathbf{r}_g = \frac{G\ cov\ x\ .\ y}{\sqrt{(\delta_g^2 x * \delta_g^2 y)}}$$

Where, $\mathbf{r}_p$ = phenotypic correlation coefficient, Pcov x.y = phenotypic covariance between character x and y, $\delta_p^2 x$ = phenotypic variance for character x, and $\delta_p^2 y$ = phenotypic variance for character y; $\mathbf{r}_g$ = genotypic correlation coefficient, Gcov x.y = genotypic covariance between characters x and y, $\delta_g^2 x$ = genotypic variance for character x, and $\delta_g^2 y$ = genotypic variances for the character y.

Path coefficient analysis

In path-coefficient analysis, tuber yield per plant was taken as the resultant (dependent) variable while rest of the characters considered as causal (independent) variables. The direct and indirect effects of the independent characters on tuber yield per plant were estimated by the simultaneous solution of the following general formula suggested by Dewey and Lu (1959):

rij = pij + Σrik pkj where, **rij** = mutual association between the independent character (i) and dependent character (j) as measured by the genotypic correlation coefficients, **pij** = components of direct effects of the independent character (i) on the dependent character (j) as measured by the genotypic path coefficients, and **Σrikpkj** = summation of components of indirect effects of a given independent character (i) on the given dependent character (j) via all other independent characters (k).

To determine pij values, square matrices of the correlation coefficients between independent characters in all possible pairs inverted and then multiplied by the correlation coefficients between the independent and dependent characters using Agrobase statistical package. Residual effects were estimated using the formula:

$\sqrt{1-R^2}$ where, $R^2 = \sum P_{ij} r_{ij}$

Results and Discussion

Analysis of variance

A homogeneity test was conducted since the experiment was multi-seasonal that needs to be analyzed with combined ANOVA. Homogeneity of error variances assured that the data of both seasons were homogenies; so that separate data analysis was preferred rather than combined analysis over years. The analysis of variance (ANOVA) showed that there was significant difference in potato tuber yield during both cropping seasons. Thus, the mean squares from analysis of variance for all traits of 13 potato genotypes are presented in (Table 4). Total tuber yield was highly significantly ($P<0.05$) affected by genotypes in both cropping seasons, The results revealed that the presence of significant differences among potato genotypes for all traits except for days to flower and specific gravity, dry matter content for 2020 and 2021 respectively. As a result, most of the genotypes performed significantly ($P \leq 0.05$) variable for stem height, days to flowering, days to maturity, stem number, marketable tuber yield, and total tuber yield ha^{-1} registering the significant genetic variability among the genotypes evaluated. The yield difference between the cropping seasons may be the seasonal environment effect on the genotypes that gave maximum mean values of total tuber yield, marketable tuber yield, stem height, stem number per hill in 2020 and total tuber yield, marketable tuber yield, stem height and days to maturity, this suggesting the presence of genetic variability among the genotypes for the characters studied which shows an ample scope for selection of promising genotype from the present gene pool for increasing tuber yield; while the lowest mean value of these traits was recorded from the local check in second season 2021 (Table.4). The presence of large amount of variability might be due to diverse source of material taken as well as seasonal influence affecting the phenotypes. Many authors also reported the existence of significant variation among potato genotypes for different traits as Rahman (2015); Getachew *et al.* (2016); Ebrahim *et al.* (2018).

Mean performance of genotypes

In both season the mean performance of all genotypes exhibited significantly ($P \leq 0.05$) variable for all parameters except, dry matter content and specific gravity. The first season 2020 the genotypes of total tuber yield and marketable tuber yield were ranged from 21.63 to 48.69 and 11.94 to 38.01 t ha^{-1} with the overall mean total tuber yield of 31.37 t ha^{-1}, whereas the second year 2021 the total tuber yields and marketable yields were ranged from 25.93 to 73.78 and 22.59 to 65.93 t ha^{-1}, respectively (Table 5). Total tuber yield was significantly ($P < 0.05$) affected by genotypes in both cropping seasons. Since there were no interaction effect between genotypes and year, tuber yield was put in the form of one-way table. Total tuber yield (t ha^{-1}) was significantly ($P < 0.05$) affected by cropping season. Relatively, higher yield was recorded during 2021 cropping season compared to 2020 cropping season because of may be the heavy rainfall and relative humidity condition during 2020 cause high pressure of late blight severity. In 2020 cropping season, significantly the highest total tuber yield (48.69 t ha^{-1}) was recorded from genotype AD51645.9 followed by AD515606.164 genotype (44.49 t ha^{-1}) and Belete variety (37.48 t ha^{-1}) which was statistically similar, while the lowest total tuber yield (21.63 t ha^{-1}) was recorded from genotype AD515578.77 followed by 22.53 and 24.74 t ha^{-1} were recorded from the genotypes of AD515578.102 and AD515578.187 respectively. In 2021 cropping season significantly, the highest total tuber yield (73.78 t ha^{-1}) was recorded from standard check Belete variety followed by AD515606.164 genotype (60.00 t ha^{-1}) were recorded but statically there is no significant differences between them, while the lowest total tuber yield (25.93 t ha^{-1}) was recorded from the local check followed by 28.74 and 34.96 t ha^{-1} were recorded from the genotypes of AD515606.44 and AD515578.102 respectively (Table 5).

Table 4. Mean squares from analysis of variance for agronomic and yield traits of 13 potato genotypes tested for two years at Bekoji.

Source of variation	Year 2020									
	DF	DE	DF	DM	STN	STH	MY	TY	SG	DM
Replications	2	1.64	37.33	4.18	0.28	1.46	1.87	4.66	0.02	0.41
Genotypes	12	15.91**	23.08ns	45.61**	2.50**	252.08**	198.92**	206.21**	0.002**	8.85**
Error	24	1.73	20.97	7.01	0.59	36.85	38.75	44.58	0.002	4.12
Mean		18.89	70.64	116.28	2.93	60.69	27.45	31.37	1.22	25.13
CV %		6.95	6.48	2.28	26.3	10.00	29.02	21.28	3.99	8.07
R^2		0.83	0.42	0.77	0.68	0.78	0.72	0.69	0.33	0.52
		Year 2021								
	DF	DE	DF	DM	STN	STH	MY	TY	SG	DM
Replications	2	16.23	0.54	3.00	3.48	75.00	49.84	107.01	0.001	44.81
Genotypes	12	33.03**	50.31**	59.75**	7.30**	617.06**	445.55**	537.42**	0.001ns	16.86ns
Error	24	3.93	5.37	10.89	1.58	42.5	64.72	76.58	0.001	11.81
Mean		19.15	67.54	120.31	6.49	82.07	42.98	47.9	1.05	19.82
CV %		10.34	3.43	2.75	19.37	7.94	18.63	18.27	1.13	17.34
R^2		0.82	0.84	0.74	0.72	0.88	0.78	0.78	0.37	0.51

** and ** significant at $p<0.05$ and $p<0.01$, respectively. ns= non-significant difference, CV (%) = coefficient of variation in percent, R^2 = r- square, DE=Days to emergence, DF= Days to flower, DM=Days to maturity, STN=steam number per plant, STH = Plant height (cm), MY (t ha^{-1}) = marketable tuber yield, TY (t ha^{-1}) = total tuber yield tons per hectare, SG= specific gravity DM (%) = tuber dry matter content*

Table 5. Mean performances of 13 potato genotypes for tuber yield and other traits evaluated at Bekoji for two seasons 2020 & 2021.

Genotypes	Year 2020								
	DE	DF	DM	STN	STH	MY	TY	SG	DMC
AD515606.16	19.33^{cd}	73.00	120.67^{ab}	2.33^{cde}	50.67^{ef}	21.56^{cd}	30.58^{cd}	1.23	25.00
AD515606.44	22.67^{a}	74.00	114.67^{cde}	2.00^{de}	42.00^{f}	17.78^{cd}	29.47^{cd}	1.26	26.67
AD515578.77	17.67^{de}	69.67	114.00^{de}	2.93^{bcde}	57.67^{bcde}	11.94^{d}	21.63^{d}	1.22	23.00
AD515578.49	16.67^{e}	74.00	118.67^{abc}	3.27^{bcd}	67.33^{ab}	25.69^{bc}	36.05^{bc}	1.22	26.50
AD515270.96	17.67^{de}	72.67	112.67^{e}	2.93^{bcde}	69.33^{a}	17.78^{cd}	27.47^{cd}	1.24	22.17
AD515606.213	17.67^{de}	71.33	116.33^{bcde}	2.60^{bcde}	53.00^{de}	14.31^{d}	23.99^{d}	1.26	24.50
AD515606.164	19.00^{cd}	68.33	121.00^{a}	3.47^{bc}	71.00^{a}	34.76^{ab}	44.49^{ab}	1.18	26.17
AD515578.102	21.67^{ab}	72.00	118.67^{abc}	2.00^{de}	53.67^{cde}	12.84^{d}	22.53^{d}	1.20	25.50
AD515606.15	18.00^{de}	69.33	112.00^{ef}	2.53^{bcde}	63.67^{abc}	21.48^{cd}	31.17^{cd}	1.22	24.67
AD515578.187	16.33^{e}	64.33	107.67^{f}	3.80^{b}	61.33^{abcd}	15.05^{d}	24.74^{d}	1.18	22.67
AD51645.9	16.00^{e}	70.33	119.33^{ab}	5.13^{a}	70.33^{a}	38.01^{a}	48.69^{a}	1.19	25.17
Belete (St. Check)	22.67^{a}	67.67	118.67^{abc}	1.73^{e}	71.00^{a}	27.79^{abc}	37.48^{abc}	1.20	27.67
Local (check)	20.33^{bc}	71.67	117.33^{abcd}	3.40^{bc}	58.00^{bcde}	19.84^{cd}	29.53^{cd}	1.22	27.00
Mean	18.89	70.64	116.28	2.93	60.69	21.45	31.37	1.22	25.13
LSD (5%)	2.213	Ns	4.4626	1.3001	10.23	10.491	11.252	ns	ns
CV (5%)	6.95	6.48	2.27	26.31	10.001	29.02	21.28	3.99	8.07
				Year 2021					
AD515606.16	15.67^{de}	71.00^{a}	125.00^{a}	5.8^{cd}	78.33^{de}	50.15^{bcd}	53.85^{bcde}	1.04	19.78
AD515606.44	27.67^{a}	73.33^{a}	121.67^{ab}	3.27^{e}	47.67^{f}	24.15^{fg}	28.74^{gh}	1.05	20.73
AD515578.77	18.00^{cde}	58.67^{e}	117.67^{bcd}	6.07^{cd}	87.67^{bcd}	46.52^{bcde}	51.33^{bcde}	1.04	18.40
AD515578.49	20.67^{bc}	71.67^{a}	126.33^{a}	6.33^{bcd}	80.33^{cde}	52.74^{abc}	57.85^{bc}	1.05	22.53
AD515270.96	20.33^{bc}	64.0^{d}	117.67^{bcd}	8.73^{a}	91.00^{bc}	43.04^{cde}	50.67^{bcde}	1.05	17.27
AD515606.213	18.00^{cde}	66.67^{bcd}	117.00^{bcd}	6.27^{bcd}	80.33^{cde}	37.48^{def}	44.67^{cdef}	1.05	18.70
AD515606.164	16.67^{de}	64.33^{d}	125.33^{a}	6.33^{bcd}	87.67^{bcd}	57.63^{ab}	60.00^{ab}	1.05	23.40
AD515578.102	21.67^{b}	71.33^{a}	121.00^{abc}	5.00^{de}	72.33^{e}	33.48^{efg}	34.96^{fgh}	1.06	19.83
AD515606.15	16.67^{de}	69.67^{abc}	114.33^{d}	8.33^{ab}	77.33^{de}	40.89^{cde}	41.71^{efg}	1.04	16.17
AD515578.187	21.33^{bc}	66.00^{cd}	115.67^{cd}	7.87^{abc}	92.67^{b}	37.26^{def}	42.29^{defg}	1.04	17.43
AD51645.9	18.67^{bcd}	70.00^{ab}	123.33^{a}	7.07^{abcd}	97.67^{ab}	45.56^{bcde}	56.96^{bcd}	1.04	21.78
Belete (St. Check)	15.00^{e}	66.67^{bcd}	125.00^{a}	5.07^{de}	104.33^{a}	65.93^{a}	73.78^{a}	1.04	23.25
Local (check)	18.67^{bcd}	64.67^{d}	114.00^{d}	8.27^{ab}	69.67^{e}	22.59^{g}	25.93^{h}	1.04	18.42
Mean	3.3387	3.9057	5.5608	2.1195	10.986	42.877	14.747	ns	ns
LSD (5%)	19.15	67.54	120.31	6.49	32.07	13.459	47.9.3	1.05	19.82
CV (5%)	10.34	3.43	2.74	19.37	7.94	18.63	18.27	1.13	17.34

Means with similar letter(s) in a column are not significantly different, LSD (5%), least significant difference, ns= non-significant difference, CV (5%) = coefficient of variation in percent, DE=Days to emergence, DF= Days to flower, DM=Days to maturity, STN=steam number per plant, STH=Plant height (cm), MY(t ha^{-1}) = marketable tuber yield, TY(t ha^{-1}) = total tuber yield tons per hectare, SG= specific gravity DM (%) = tuber dry matter content.

Phenotypic and genotypic correlations

In this study, genotypic correlation (r_g) coefficients were computed in addition to phenotypic correlation (r_p) coefficients to obtain better estimates of the associations between tuber yield and related traits for two seasons (Table 6 & 7). Many researcher was reported the existence of association between different traits in potato genotype (Khayatnezhad *et al.,* 2011, Lavanya *et al.,* 2019, Gebreselassie and Ajema, 2022). Accordingly the result in 2020, total tuber yield per hectare was highly significantly and positively correlated with marketable tubers (r_g = 0.99 and r_p = 0.96), steam height (r_g = 0.608 and r_p = 0.357) both at genotypic and phenotypic level. Positive correlations are due to control of the traits, which are under control of genes responsible for direct production of ancestors. Above results were similarly reported by Workayehu *et al.* (2021) who found marketable tubers have positive and significant association with total tuber yield. While, negative correlations occur due to the restricted supply of ancestor for which traits compete against each other (Madhur and Jinks, 1994).Total tuber yield is significantly correlated (r_g = 0.608) with steam height at genotypic level but non-significantly correlated (r_p = 0.357) at phenotypic level. Marketable tuber yield also positively and significantly correlated with days to maturity (r_g = 0.557), steam height (r_g = 0.637) and steam number per plant (r_g = 0.159) whereas, negatively correlated with days to emergence (r_g = -0.136) days to flowering (r_g = -0.106) at genotypic level. Characters such as days to maturity (r_g =0.544), stem number per plant (r_g =0.152) and dry matter content (r_g =0.468) showed positive genotypic association with total tuber yield, while days to emergence (r_p =0.127), days to flowering (r_p =0.144), stem number per plant (r_p =0.357), height and specific gravity (r_p =0.075) showed positive and low phenotypic association with total tuber yield. Days to emergence (r_g = -0.121), days to flowering (r_g = -0.078), specific gravity (r_g = -0.483), and days to maturity (r_p = -0.097), dry matter content (r_p = -0.132) were showed negatively and low genotypic and phenotypic association respectively with total tuber yield per hectare (Table 6). This implied that keeping others components constant any decrease in those above factors would leads to increase total tuber yields.

In 2021 season, total tuber yield per hectare was highly significantly and positively correlated with marketable tuber yield (r_g =0.977 and r_p = 0.951), steam height (r_g = 0.791), specific gravity r_p = 0.594) both at genotypic and phenotypic level, while significantly and positively correlated with days to maturity (r_g =0.640) at genotype level (Table 7). Similarly, Panigrahi *et al.* (2017) reported that total tuber yield showed positive and significant correlation with marketable tuber yield at both phenotypic as well as at genotypic levels. These positive correlations indicating that selection for improving one character will lead to increase the other one, which is positively correlated with that character. Total tuber yield was significantly and negatively correlated with days to emergency (r_g = -0.612) and negatively correlated with days to flowering (r_g= -0.177) and steam number (r_g= -0.043) at genotypic level and highly significantly and negatively associated with days to emergence (r_p = - 0.630) at phenotypic level. Negative correlation between two traits implies selection for improving one character will likely cause decrease in the other traits. In present study marketable yield also had exhibited positively and highly significantly correlated with specific gravity (r_g =0.492**) at genotypic correlation. This suggested that the simple selection to improve one trait simultaneously increase the second character. Tuber yield was positively and low association with days to flowering (r_g = 0.04 and r_p =0.009), steam number per plant (r_g = 0.34 and r_p = 0.348) and plant height (r_g = 0.35 and r_p =0.26) at phenotypic level (Table 7).

Table 6. Genotypic (**below** diagonal) and phenotypic (**above** diagonal) correlation coefficients among potato genotype in 2020.

Variable	DE	DF	DM	STN	STH	MY	SG	DMC	TY
DE	1	0.301	0.270	0.163	0.281	0.105	-0.146	-0.257	0.127
DF	0.210	1	0.214	0.035	0.032	0.167	-0.182	0.186	0.144
DM	0.300	0.410	1	0.020	-0.222	-0.102	-0.372	-0.004	-0.097
STN	-0.724**	-0.517	-0.398	1	0.323	0.206	-0.094	-0.099	0.164
STH	-0.406	-0.415	0.098	0.351	1	0.507**	0.048	-0.045	0.357
MY	-0.136	-0.106	0.557*	0.159	0.637*	1	0.049	-0.080	0.960**
SG	0.135	0.646*	-0.137	-0.478	-0.626*	-0.507	1	0.042	0.075
DMC	0.626*	0.240	0.658*	-0.417	-0.032	0.452	-0.126	1	-0.132
TY	-0.121	-0.078	0.544	0.152	0.608*	0.997**	-0.483	0.468	1

*Keys, * significant at the 0.05 probability level, ** significant at the 0.01 probability level, TY=Total tuber yield (t ha^{-1}), MY=Marketable tuber yield (t ha^{-1}), DE=Days to emergence, DF=Days to 50% Flowering, DM=Days to maturity, STN=Steam number per plant, PH=Plant height (cm), SG=specific gravity (%), DMC=Tuber dry Matter content (%).*

Table 7. Genotypic (**below** diagonal) and phenotypic (**above** diagonal) correlation coefficients among potato genotype in 2021.

Variable	DE	DF	DM	STN	STH	TY	SG	DMC	MY
DE	1	-0.055	0.389	-0.164	-0.360	-0.630**	-0.359	-0.134	-0.580*
DF	0.388	1	-0.197	0.156	-0.100	0.040	-0.010	-0.354	0.009
DM	-0.089	0.397	1	-0.133	0.032	-0.353	-0.307	0.043	-0.369
STN	-0.355	-0.411	-0.574*	1	0.097	0.342	0.304	-0.236	0.348
STH	-0.655*	-0.462	0.160	0.397	1	0.356	0.381*	-0.007	0.260
TY	-0.612*	-0.177	0.640*	-0.043	0.791**	1	0.594**	0.123	0.951**
SG	0.468	0.290	0.368	-0.545	-0.416	-0.175	1	0.252	0.492**
DMC	-0.080	0.252	0.893**	-0.565*	0.175	0.571*	0.357	1	0.104
MY	-0.655*	-0.172	0.643*	-0.057	0.734*	0.977**	-0.168	0.557*	1

*Keys, * significant at the 0.05 probability level, ** significant at the 0.01 probability level, TY=Total tuber yield (t ha^{-1}), MY=Marketable tuber yield (t ha^{-1}), DE=Days to emergence, DF=Days to 50% Flowering, DM=Days to maturity, STN=Steam number per plant, PH=Plant height (cm), SG=specific gravity (%), DMC=Tuber dry Matter content (%).*

Table 8. Genotypic and phenotypic path coefficient of direct (bold and diagonal) and indirect (off diagonal) effects yield components on tuber yield in potato genotypes during 2020 season.

Traits		DE	DF	DM	STN	STH	MY	DMC	SG	rg/rp
DE	G	**0.00281**	0.01196	-0.02658	0.00316	0.01874	-0.14451	-0.00318	0.01610	-0.121
	P	**0.09696**	-0.01066	-0.01291	0.00053	-0.06192	0.11115	-0.00357	0.00692	0.127
DF	G	0.00059	**0.05705**	-0.03627	0.00225	0.01918	-0.11190	-0.01518	0.00617	-0.078
	P	0.02917	**-0.03543**	-0.01022	0.00012	-0.00697	0.17632	-0.00445	-0.00500	0.143
DM	G	0.00085	0.02339	**-0.08846**	0.00173	-0.00454	0.59054	0.00323	0.01691	0.543
	P	0.02619	-0.00758	**-0.04777**	0.00006	0.04893	-0.10808	-0.00912	0.00010	-0.097
STN	G	-0.00204	-0.02951	0.03523	**-0.00436**	-0.01621	0.16820	0.01122	-0.01072	0.152
	P	0.01581	-0.00125	-0.00093	**0.00327**	-0.07107	0.21788	-0.00230	0.00266	0.164
STH	G	-0.00114	-0.02368	-0.00869	-0.00153	**-0.04622**	0.67503	0.01469	-0.00082	0.608*
	P	0.02727	-0.00112	0.01062	0.00106	**-0.22013**	0.53686	0.00118	0.00121	0.357
MY	G	-0.00038	-0.00603	-0.04932	-0.00069	-0.02945	**1.05929**	0.01191	0.01162	0.997**
	P	0.01018	-0.00590	0.00488	0.00067	-0.11164	**1.05858**	0.00121	0.00215	0.960**
DMC	G	0.00038	0.03687	0.01216	0.00208	0.02892	-0.53713	**-0.02349**	-0.00325	-0.483
	P	-0.01411	0.00644	0.01779	-0.00031	-0.01059	0.05221	**0.02449**	-0.00113	0.075
SG	G	0.00176	0.01368	-0.05820	0.00182	0.00148	0.47882	0.00297	**0.02571**	0.468
	p	-0.02495	-0.00659	0.00018	-0.00032	0.00987	-0.08459	0.00103	**-0.02689**	-0.132

*Keys, G=phenotypic path coefficient analysis; P=phenotypic path coefficient analysis; ns, *, ** = non-significant, Significant at 5% and 1%, respectively; rg-Genotypic correlation with total tuber yield (t ha-1); rg-Phenotypic correlation with total tuber yield (t ha-1); Genotypic Residual effect = 0.998 & Phenotypic Residual effect 0.956; MY=Marketable tuber yield (t ha-1), DE=Days to emergence, DF=Days to 50% Flowering, DM=Days to maturity, STN=Steam number per plant, PH=Plant height (cm), SG=specific gravity (%), DMC= tuber try Matter content (%)*

Table 9. Genotypic and phenotypic path coefficient of direct (bold and diagonal) and indirect (off diagonal) effects yield components on tuber yield in potato genotypes during 2021 season.

Traits		DE	DF	DM	STN	STH	SG	DMC	MY	rg/rp
DE	G	**0.052433**	-0.00074	-0.01114	0.013578	-0.18608	-0.01437	-0.00063	-0.46544	-0.61*
	P	**-0.08912**	-0.00239	0.015052	0.002281	-0.02019	-0.0532	0.000216	-0.48177	-0.63**
DF	G	0.02034	**-0.0019**	0.049633	0.015712	-0.13141	-0.00892	0.001965	-0.12234	-0.17
	P	0.004862	**0.043798**	-0.00761	-0.00217	-0.00561	-0.00142	0.00057	0.007574	0.04
DM	G	-0.00467	-0.00075	**0.12501**	0.021972	0.045523	-0.01131	0.006975	0.456944	0.64*
	P	-0.03471	-0.00861	**0.038649**	0.00184	0.001804	-0.04553	-6.9E-05	-0.30642	-0.35
STN	G	-0.01861	0.000779	-0.07181	**-0.03825**	0.112787	0.016745	-0.00441	-0.04048	-0.04
	P	0.014648	0.006839	-0.00512	**-0.01388**	0.005444	0.045146	0.00038	0.288664	0.34
STH	G	-0.03433	0.000877	0.020024	-0.01518	**0.284198**	0.012783	0.001369	0.52161	0.79**
	P	0.032101	-0.00438	0.001244	-0.00135	**0.056057**	0.056536	1.14E-05	0.215608	0.36
SG	G	0.024518	-0.00055	0.046009	0.020846	-0.11824	**-0.03073**	0.002789	-0.11917	-0.17
	P	0.031968	-0.00042	-0.01186	-0.00422	0.021368	**0.14832**	-0.00041	0.408867	0.59**
DMC	G	-0.00421	-0.00048	0.111673	0.021603	0.049814	-0.01097	**0.007808**	0.396053	0.57*
	P	0.011971	-0.01552	0.001658	0.003279	-0.0004	0.037428	**-0.00161**	0.086162	0.12
MY	G	-0.03434	0.000327	0.080368	0.002178	0.208564	0.005152	0.004351	**0.710766**	0.97**
	p	0.051701	0.000399	-0.01426	-0.00482	0.014553	0.073022	-0.00017	**0.830474**	0.95**

*Keys, G=phenotypic path coefficient analysis; P=phenotypic path coefficient analysis; ns, *, ** = non-significant, Significant at 5% and 1%, respectively; rG-Genotypic correlation with total tuber yield (t ha-1); rP-Phenotypic correlation with total tuber yield (t ha-1); Genotypic Residual effect = 0.9792 & Phenotypic Residual effect 0.9369; MY=Marketable tuber yield (t ha-1), DE=Days to emergence, DF=Days to 50% Flowering, DM=Days to maturity, STN=Steam number per plant, PH=Plant height (cm), SG=specific gravity (%), DMC=Dry Matter content (%)*

Path analysis

Path coefficient analysis was performed to divide the correlation coefficients between tuber yield and yield related traits into direct and indirect effects via pathways. In 2020 cropping season also revealed that marketable tuber yield (1.059 and 1.058) utilized maximum positive direct effect on total tuber yield per hectare at genotypic and phenotypic levels, respectively (Table 8). This indicates that direct selection for this trait will be effective for improvement of tuber yield and if other factors are constant, an increase in marketable tuber yield will reflect on increased total tuber yield. Tuber dry matter content (0.025), stem number (0.003), marketable tuber yield (1.058) and days to emergence (0.097) had positive direct effect on total tuber yield at phenotypic level, while specific gravity (0.026), days to emergence (0.003), days to flowering (0.057) and marketable tuber yield (1.059) had positive direct effect on total tuber yield at genotypic level. These results indicate that an increase in any of these yield components causes some increase in tuber yield. These results are in line with the previous results of (Sultana and Islam, 2007; Sv and Sm. 2022). On the other hand tuber dry matter content (-0.023), steam height (-0.046), steam number (-0.004) and days to flowering (-0.088) had negative direct effect on total tuber yield at genotypic level, and also specific gravity (-0.026), stem height (-0.220), days to maturity (-0.047), days to flowering (-0.035) had negative direct effect on total tuber yield per plot at phenotypic level (Table 8).

In 2021 cropping season also revealed that marketable tuber yield (0.71 and 0.83) utilized maximum positive direct effect on total tuber yield per hectare at genotypic and phenotypic levels, respectively (Table 9). This indicates that if other factors are held constant, an increase in marketable tuber yield will reflect on increased total tuber yield per hectare. Dry matter content (0.0078), stem height (0.2841), days to maturity (0.1250) and days to emergence had positive direct effect on total tuber yield at genotypic level and specific gravity (0.1483), plant height (0.0560), days to maturity (0.0386), days to flowering (0.0437) and marketable tuber yield (0.8304) had positive direct effect on total tuber yield at phenotypic level. These results indicate that an increase in any of these yield components causes some increase in tuber yield. Other researcher who conducted studies on different potato genotypes and determined the direct effects of different yield components on tuber yield (Gebreselassie and Ajema, 2022) reported similar results. On the other hand specific gravity (-0.0307) steam number (-0.0382), and days to flowering (-0.0019) had negative direct effect on total tuber yield at genotypic level, and dry matter content (-0.0016), stem number (-0.0138) and days to emergence (-0.0891) had negative direct effect on total tuber yield per plot at phenotypic level (Table 7).

Summary and Conclusion

Correlation and path coefficient analysis were conducted in order to get a clear picture of the interrelationships and the effects of the causal components on the response variables tuber yield. In the present study, in first season total tuber yield was significantly and positively correlated with marketable tuber, days to maturity, stem number, and tuber dry matter content at genotypic level and stem height at phenotypic level; while it was negatively and significantly correlated with days to emergence, days to flowering, specific gravity at genotypic level. In second season positive and significant correlation coefficients between total tuber yield and the yield components as days to maturity, stem height, marketable tuber and specific gravity at genotypic and phenotypic level respectively were observed. Positively correlations appeared between total tuber yield and stem number, tuber dry matter content, days to flowering; while negatively association with days to emergence and specific gravity. Generally, correlation analysis result indicated that marketable tuber, stem number, stem height, day to maturity and tuber dry matter content were the main components to total tuber yield. For this reason, these traits could be used more significantly for potato improvement. Further, Path analysis indicated that total tuber yield was directly influenced by marketable tuber, stem height, specific gravity, days to flowering, days to maturity at phenotypic and marketable tuber days to maturity, days to emergence, stem height, tuber dry matter content at genotypic level; in the second cropping season. The traits with direct effect (positive) on total tuber yield would be considered in selection at potato improvement programs that aim to increasing total tuber yield of potato, they would be regarded as criteria for improvement and breeding programs.

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