Advances in Bioscience and Bioengineering
2024, Vol. 12, No. 1, 2024, pp. 19-28
https://doi.org/10.11648/j.abb.20241201.13

Research Article

Correlation and Path Analysis for Agronomic and Processing Quality Traits of Potato (*Solanum tuberosum* L.) at Holetta, Central Ethiopia

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Abstract

Potato is the third most important food crop in terms of consumption in the world after rice and wheat. It is a nutrient-rich vegetable with just a small amount of fat and contains 16% carbohydrates, 2% proteins, 1% minerals, and 0.6% dietary fiber. The literature on path and correlation analysis and its application as a potato breeding tool is limited in comparison to its significance for processing purpose and the knowledge it adds for upcoming breeding work. The objective of this study was to determine the relation among tuber yield and processing quality traits of potato using correlation and path coefficient analysis. This experiment was conducted at Holetta Agricultural research Centre, Ethiopia during the main crop season of 2017. The experiment was laid out in randomized complete block design (RCBD) with three replications using 24 potato genotypes. Strong positive and significant correlation were found between total tuber yield and marketable tuber yield (r=0.98) at both genotypic and phenotypic levels. Stronger positive correlations were found between dry matter content and starch content (r= 1) and specific gravity (r=1). Path coefficient analysis of tuber yield and its components shows that dry matter content and marketable tuber yield exerted positive highest direct influence on total tuber yield. Specific gravity of tuber had high positive direct effect on dry matter content. So, to increase the performance of these traits for tuber yield and processing quality traits path analysis can be used. As a conclusion, most of the traits had positive correlations and direct effects with total tuber yield and dry matter content at phenotypic and genotypic levels. Therefore, those traits had practical importance in selection of potato genotypes for high total tuber yield and processing purpose.

Keywords

Potato, Tuber Quality, Correlation, Direct Effect, Path Analysis

1. Introduction

The potato (*Solanum tuberosum* L.) is a flexible crop that can grow up to 4,700 meters above sea level, from southern Chile to Greenland [1]. According to Birch *et al* [2] and Hancock *et al* [3] reports, potato is the third most important food crop in the world in terms of consumption, after rice and wheat. Potato is a nutrient-rich vegetable with just a small amount of fat and contains 16% carbohydrates, 2% proteins, 1% minerals, and 0.6% dietary fiber [4]. One of the

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Received: 29 December 2023; **Accepted:** 25 January 2024; **Published:** 21 February 2024

best crops for food and nutrition security in Eastern Africa is the potato because of its high yield potential and adaptability to environmental regimes [5]. Potato tubers have a dry matter content of 20% on average and a major amount of their dry matter (60 to 80%) is composed of starches. As a result, it is a food high in carbohydrates [6]. In addition to being a good source of carbohydrates, potatoes also include nutrients that are beneficial to health, including phenolic acids, ascorbic acid, and carotenoids [7].

The association between two variables is measured by the correlation coefficient, which ranges from +1 to -1 and expresses the rate of change in the dependent variable for every unit of change in the independent variable, but it provides no information regarding the causal relationship between the variables [8]. Correlated traits are important in studies of plant genetics and breeding because genetic factors, such as pleiotropic activity, developmental interactions of genes, and environmental changes, can create correlations [9, 10]. Three types of association exist in quantitative genetics: genotypic, phenotypic and environmental correlation. Genotypic correlation between more than two characters may be caused by the pleiotropic effects of genes or by the linking of genes controlling the inheritance of more than two characters. While phenotypic correlation is an association between two characters that can be observed and measured, environmental correlation is a two-variable relationship that includes correlation due to environmental traits and non-additive genetic causes [8].

Path coefficient analysis is better than correlation because it can determine the direct and indirect causes of associations and can quantify the relative importance of each because correlation alone sometimes does not provide an accurate picture of the direct and indirect effects of characters upon one another [10]. The path analysis is the partitioning of the total correlation into direct and indirect effects of independent variable(s) on dependent variable [11, 12]. If the variable has positive correlation and the direct effect of the variable or trait is negative or negligible, the positive correlation of the trait is because of the indirect effects through other traits. In such situation, the indirect casual factors or traits are to be considered simultaneously for selection. The residual effect determines how much best the causal factors or in dependent variables account for the variability of the dependent variable [11]. In potato previous reports by Amadi and ne-Obong [13] indicated that simple correlation coefficients were useful to study the interrelationships between tuber yield and other characters. In addition, the literature on path and correlation analysis and its application as a potato breeding tool is limited in comparison to its significance for processing purpose and the knowledge it adds for upcoming breeding work. Therefore, the present study was to determine the association among traits and direct and indirect effect of traits on dry matter content and total tuber yield for further potato breeding program.

2. Materials and Methods

2.1. Experimental Site, Materials, and Design

The study was conducted at Holetta Agricultural research Center, Ethiopia during 2017 under rained growing season. For this investigation, 24 genotypes of potatoes were used. These included three newly released potato varieties as well as 21 genotypes selected from the material introduced from International Potato Center (CIP) (Table 1). A randomized complete block design (RCBD) with three replication was used to set up the experiment. Each genotypes was planted on a six-rows, 3.6 m × 4.5 m plot size that had a capacity for 12 plants per row and a total of 72 planter per plot. The spacing between rows and plants was 0.75 m and 0.30 m, respectively. The spacing between plots and adjacent blocks was 1m and 1.5m, respectively.

Table 1. *List of potato genotypes used for evaluation.*

No.	Genotypes	No.	Genotypes
1	CIP396034.268	13	CIP394611.112
2	CIP393220.54	14	CIP392617.54
3	CIP395017.229	15	CIP381381.20
4	CIP392797.27	16	CIP398180.289
5	CIP395112.19	17	CIP398190.89
6	CIP399075.7	18	CIP398190.404
7	CIP393280.64	19	CIP391058.175
8	CIP398098.65	20	CIP396034.103
9	CIP393385.39	21	CIP391046.14

No.	Genotypes	No.	Genotypes
10	CIP396027.205	22	Belete
11	CIP393077.159	23	Gudanie
12	CIP399002.52	24	Dagim

CIP- International Potato Center

2.2. Data Collection

Phenology and growth data were recorded as days to 50% flowering, days to maturity, plant height (cm), main stems/plant and leaf area index (cm^{-3}). The data collected yield and yield components included shoot dry weight (g), tubers dry weight (g), total biomass weight (g), number of tubers/plant, average tuber weight (g/tuber), tuber size distribution:- small (<35mm), medium (35 to 50mm) and large (>50mm) as a percent of total harvested tubers, total tuber yield (t/ha), marketable tuber yield (t/ha) and unmarketable tuber yield (t/ha). The amount of tuber number in different size categories was changed to percentage [14]. Tuber quality traits were collected as geometric mean diameter, tuber length to width ration, sphericity of the tuber, surface area, specific gravity (gcm^{-3}), dry matter content (%) and total starch content (g/100g).

2.3. Data Analysis

For analyzing test data from software SAS version 9.3 [15] was used. Phenotypic (r_p) and genotypic (r_g) correlation among two traits were estimated using the formal suggested by Singh and Chaudhary [11] and Johnson *et al* [16]. Based on genotypic and phenotypic correlations, path coefficient analysis which refers to the estimation of direct and indirect effects of the tuber yield and dry matter content attributing characters (independent character) on tuber yield and dry matter content (dependent character) was calculated based on the method used by Dewey and Lu [17]. Means of treatments were compared using Duncan's multiple range tests (DMRT) in 0.01 percent.

3. Result

3.1. Analysis of Variance

According to the variance findings, all tested potato genotypes indicated highly significant (P<0.01) differences in all traits (Table 2). This will give breeders a good chance to select genotypes with different maturity group, tuber yield performance and qualities relevant to processing purposes. Several researchers [18-24] reported highly significant genotype differences for phenology, tuber yield, processing purpose and biofortified parameters.

Table 2*. Range and means of agronomic and quality traits of potato genotypes grown at Holetta, 2017.*

Traits	Range	Mean	CV (%)	P-value
Days to 50% flowering	48-63	54.19	2.49	**
Days to maturity	86-106	95.92	3.77	**
Plant height (cm)	65.70-122.70	80.48	4.75	**
Average stems/plant	2.60-5.57	4.05	12.06	**
Leaf area index (cm^{-3})	1.55-3.41	2.56	8.95	**
Shoot dry mass weight (g/plant)	23.80 - 87.80	46.00	18.14	**
Tuber dry mass weight (g/plant)	119.13- 224.00	166.14	14.22	**
Total biomass weight (g/plant)	157.33-287.87	212.14	12.68	**
Average tuber number/plant	7.18-18.46	11.08	11.34	**
Average tuber weight (g/tuber)	40.41-89.11	66.36	8.89	**
Small size tubers (%)	18.19-56.67	34.12	18.96	**
Medium size tubers (%)	30.32-52.35	39.93	13.79	**
Large size tubers (%)	8.95-46.60	25.95	20.41	**

Traits	Range	Mean	CV (%)	P-value
Total tuber yield (t/ha)	21.48-42.68	31.63	10.81	**
Marketable tuber yield (t/ha)	19.65-37.36	28.74	11.88	**
Unmarkatable tuber yield (t/ha)	1.36-5.33	2.89	24.82	**
Geometric mean diameter (mm^3)	49.42-61.15	55.60	6.50	**
Surface area (mm^2)	7669-11753	9772.71	12.75	**
Sphericity of the tuber (%)	61.98-94.27	80.20	3.35	**
Length to width ratio	1.00-1.87	1.27	5.64	**
Specific gravity of tubers (gcm^{-3})	1.070-1.103	1.09	0.50	**
Dry matter content (%)	18.67-25.75	21.94	5.37	**
Total starch content (g/100g)	12.64-18.95	15.55	6.76	**

** - Significant at P<0.01

3.2. Phenotypic and Genotypic Correlation of Tuber Yield with Other Traits

The phenotypic and genotypic correlation coefficients for 23 traits are presented in Table 3. Tuber yield showed a positive and highly significant (p<0.01) correlation with leaf area index, tuber dry mass weight, total biomass weight, average tuber weight, marketable tuber yield, unmarketable tuber due to large unmarketable size tubers (cracked, diseased and insect damaged tubers), large size tubers, geometric mean diameter and surface area of tubers both at the genotypic and phenotypic levels. Additionally, days to maturity, specific gravity of tubers, total starch content and dry matter content showed positive and highly significant (p<0.01) correlation with total tuber yield per hectare at phenotypic level. Total tuber yield showed positive and significant (p<0.05) correlation with days to maturity, specific gravity of tubers, total starch content and dry matter content at genotypic level, and also shoot dry mass weight and average tuber number per hill at phenotypic levels. The presence of significant correlation of these traits with total tuber yield both at phenotypic and genotypic levels indicated the importance of these traits in selection program to identify potato genotypes with high tuber yield. Phenotypic correlation (r_p) measures the extent to which the two observed characters are linearly related while genotypic correlation (r_g) measures the extent to which degree the same genes or closely linked genes cause co-variation (simultaneous variations) in two different characters [9-11]. Total tuber yield showed negative and highly significant (p<0.01) correlation with small size tubers both at phenotypic and genotypic levels. Total tuber yield also showed negative and significant (p<0.05) correlation with average stems number and medium size tubers at phenotypic level. However, these traits hade negative and non-significant correlation at genotypic level.

3.3. Phenotypic and Genotypic Correlation of Dry Matter Content and Other Traits

Dry matter content showed positive and highly significant (P<0.01) correlation with days to maturity, shoot dry mass weight, total biomass weight, specific gravity of tubers and total starch content both at phenotypic and genotypic levels (Table 3). Plant height and marketable tuber yield also displayed a positive and highly significant (p<0.01) correlation with dry matter content at the phenotypic level. Dry matter content showed positive and significant (p<0.05) correlation with tuber dry mass weight and marketable tuber yield at genotypic levels and leaf area index and tuber dry mass weight at phenotypic levels. The characters specific gravity of tubers and total starch content had highest genotypic and phenotypic correlation coefficient levels. Thus, studies on correlation enable the breeder to know the mutual relationship between various characters and determine the characters on which selection can be made for genetic improvement.

Table 3. *Genotypic (above diagonal) and phenotypic (below diagonal) correlation coefficients among tuber quality, yield and yield related traits of 24 potato genotypes at Holetta in 2017.*

	DF	DM	PH	ASN	LAI	SDMW	TDM	TBW	ATN	ATW	MTY	UnMTY
DF		0.22^{ns}	-0.15^{ns}	-0.01^{ns}	0.30^{ns}	0.14^{ns}	0.18^{ns}	0.21^{ns}	0.22^{ns}	-0.02^{ns}	0.14^{ns}	0.37^{ns}

	DF	DM	PH	ASN	LAI	SDMW	TDM	TBW	ATN	ATW	MTY	UnMTY
DM	0.20^{ns}		0.62**	-0.48*	0.43*	0.75**	0.10^{ns}	0.44*	0.18^{ns}	0.14^{ns}	0.40^{ns}	0.26^{ns}
PH	-0.18^{ns}	0.53**		-0.09^{ns}	-0.06^{ns}	0.67**	-0.25^{ns}	0.10^{ns}	0.53**	-0.44*	-0.04^{ns}	-0.02^{ns}
ASN	-0.01^{ns}	-0.43**	-0.08^{ns}		-0.60**	-0.41*	-0.21^{ns}	-0.37^{ns}	0.24^{ns}	-0.43*	-0.31^{ns}	-0.29^{ns}
LAI	0.27*	0.40**	-0.06^{ns}	-0.51**		0.38^{ns}	0.48*	0.58**	-0.06^{ns}	0.55**	0.65**	0.36^{ns}
SDMW	0.12^{ns}	0.63**	0.63**	-0.34**	0.31**		0.12^{ns}	0.57**	0.43*	-0.14^{ns}	0.30^{ns}	0.20^{ns}
TDM	0.11^{ns}	0.10^{ns}	-0.14^{ns}	-0.14^{ns}	0.37**	0.14^{ns}		0.88**	-0.01^{ns}	0.44*	0.65**	0.16^{ns}
TBW	0.14^{ns}	0.35**	0.15^{ns}	-0.26*	0.45**	0.55**	0.91**		0.19	0.30^{ns}	0.68**	0.23^{ns}
ATN	0.17^{ns}	0.09^{ns}	0.49**	0.26*	-0.09^{ns}	0.37**	-0.01^{ns}	0.14^{ns}		-0.66**	0.09^{ns}	0.25^{ns}
ATW	-0.04^{ns}	0.16^{ns}	-0.38**	-0.41**	0.52**	-0.11^{ns}	0.37**	0.26*	-0.61**		0.64**	0.21^{ns}
MTY	0.08^{ns}	0.30**	0.03^{ns}	-0.21^{ns}	0.52**	0.27*	0.51**	0.55**	0.22^{ns}	0.59**		-0.34^{ns}
UnMTY	0.26^{ns}	0.18^{ns}	0.03^{ns}	-0.20^{ns}	0.28^{ns}	0.17^{ns}	0.00^{ns}	0.08^{ns}	0.28^{ns}	0.15^{ns}	-0.27^{ns}	
SST	0.14^{ns}	0.09^{ns}	0.43**	0.12^{ns}	-0.30**	0.26*	-0.28*	-0.13^{ns}	0.43**	-0.70**	-0.47**	0.06^{ns}
MST	0.10^{ns}	-0.34**	-0.14^{ns}	0.31**	-0.23*	-0.22^{ns}	0.08^{ns}	-0.02^{ns}	0.06^{ns}	-0.26*	-0.18^{ns}	-0.33**
LST	-0.19^{ns}	0.14^{ns}	-0.31**	-0.32**	0.43**	-0.10^{ns}	0.21^{ns}	0.13^{ns}	-0.44**	0.82**	0.56**	0.16^{ns}
Dg	0.01^{ns}	0.36**	-0.07^{ns}	-0.48**	0.48**	0.14^{ns}	0.26*	0.28*	-0.15^{ns}	0.56**	0.55**	0.15^{ns}
ST	-0.15^{ns}	-0.15^{ns}	0.03^{ns}	0.53**	-0.16^{ns}	-0.04^{ns}	-0.07^{ns}	-0.08^{ns}	0.20^{ns}	-0.16^{ns}	-0.07^{ns}	-0.08^{ns}
SA	0.01^{ns}	0.35**	-0.08^{ns}	-0.49**	0.47**	0.13^{ns}	0.26*	0.28*	-0.16^{ns}	0.56**	0.54**	0.15^{ns}
LWR	0.19^{ns}	0.14^{ns}	0.01^{ns}	-0.44**	0.08^{ns}	0.01^{ns}	-0.01^{ns}	-0.01^{ns}	-0.08^{ns}	0.00^{ns}	-0.03^{ns}	0.07^{ns}
SG	0.10^{ns}	0.49**	0.31**	-0.17^{ns}	0.29*	0.43**	0.28*	0.42**	0.14^{ns}	0.18^{ns}	0.39**	0.29^{ns}
TSC	0.10^{ns}	0.49**	0.31**	-0.17^{ns}	0.29*	0.44**	0.29*	0.43**	0.15^{ns}	0.17^{ns}	0.38**	0.29^{ns}
DMC	0.10^{ns}	0.49**	0.31**	-0.17^{ns}	0.29*	0.44**	0.29*	0.43**	0.15^{ns}	0.17^{ns}	0.38**	0.29^{ns}
TTY	0.15^{ns}	0.32**	0.04^{ns}	-0.24*	0.54**	0.28*	0.47**	0.52**	0.26*	0.57**	0.98**	0.17^{ns}

Table 3. *Continued.*

	SST	MST	LST	Dg	ST	SA	LWR	SG	TSC	DMC	TTY
DF	0.16^{ns}	0.08^{ns}	-0.18^{ns}	0.06^{ns}	-0.15^{ns}	0.06^{ns}	0.18^{ns}	0.12^{ns}	0.12^{ns}	0.12^{ns}	0.23^{ns}
DM	0.10^{ns}	-0.47*	0.17^{ns}	0.43*	-0.16^{ns}	0.42*	0.14^{ns}	0.52**	0.52**	0.52**	0.42*
PH	0.49*	-0.11^{ns}	-0.35^{ns}	-0.18^{ns}	0.04^{ns}	-0.19^{ns}	0.02^{ns}	0.37^{ns}	0.37^{ns}	0.37^{ns}	-0.05^{ns}
ASN	0.11^{ns}	0.49*	-0.36^{ns}	-0.53*	0.60**	-0.54**	-0.50*	-0.20^{ns}	-0.20^{ns}	-0.20^{ns}	-0.34^{ns}
LAI	-0.35^{ns}	-0.37^{ns}	0.50*	0.65**	-0.18^{ns}	0.64**	0.08^{ns}	0.28^{ns}	0.28^{ns}	0.28^{ns}	0.67**
SDMW	0.30^{ns}	-0.30^{ns}	-0.08^{ns}	0.13^{ns}	-0.02^{ns}	0.11^{ns}	0.00^{ns}	0.56**	0.56**	0.56**	0.31^{ns}
TDM	-0.37^{ns}	0.08^{ns}	0.26^{ns}	0.31^{ns}	-0.11^{ns}	0.31^{ns}	0.00^{ns}	0.41*	0.41*	0.41*	0.62**
TBW	-0.17^{ns}	-0.07^{ns}	0.18^{ns}	0.31^{ns}	-0.10^{ns}	0.31^{ns}	0.00^{ns}	0.61**	0.61**	0.61**	0.66**
ATN	0.48*	0.20^{ns}	-0.52**	-0.25^{ns}	0.22^{ns}	-0.25^{ns}	-0.10^{ns}	0.20^{ns}	0.20^{ns}	0.20^{ns}	0.14^{ns}
ATW	-0.77**	-0.41*	0.88**	0.64**	-0.16^{ns}	0.65**	-0.01^{ns}	0.18^{ns}	0.17^{ns}	0.17^{ns}	0.62**
MTY	-0.60**	-0.21^{ns}	0.62**	0.64**	-0.06^{ns}	0.64**	-0.05^{ns}	0.48*	0.47*	0.47*	0.98**
UnMTY	0.01^{ns}	-0.36^{ns}	0.19^{ns}	0.26^{ns}	-0.12^{ns}	0.26^{ns}	0.10^{ns}	0.33^{ns}	0.33^{ns}	0.33^{ns}	0.53**
SST		-0.01^{ns}	-0.84**	-0.53**	-0.02^{ns}	-0.53**	0.15^{ns}	0.00^{ns}	0.01^{ns}	0.01^{ns}	-0.54**

	SST	MST	LST	Dg	ST	SA	LWR	SG	TSC	DMC	TTY
MST	-0.24*		-0.54**	-0.49*	-0.08 ^{ns}	-0.49*	0.15 ^{ns}	-0.11^{ns}	-0.11^{ns}	-0.11 ^{ns}	-0.27 ^{ns}
LST	-0.77**	-0.43**		0.71**	0.06 ^{ns}	0.72**	-0.21^{ns}	0.06 ^{ns}	0.05 ^{ns}	0.05 ^{ns}	0.60**
Dg	-0.37**	-0.30**	0.54**		-0.31 ^{ns}	1.00**	0.23 ^{ns}	-0.03 ^{ns}	-0.03 ^{ns}	-0.03 ^{ns}	0.64**
ST	-0.02 ^{ns}	-0.05 ^{ns}	0.05 ^{ns}	-0.27*		-0.31^{ns}	-0.97**	0.01 ^{ns}	0.01 ^{ns}	0.01 ^{ns}	-0.08 ^{ns}
SA	-0.37**	-0.30**	0.54**	1.00**	-0.27*		0.23 ^{ns}	-0.03 ^{ns}	-0.04 ^{ns}	-0.04 ^{ns}	0.63**
LWR	0.14 ^{ns}	0.10 ^{ns}	-0.19 ^{ns}	0.20 ^{ns}	-0.97**	0.20 ^{ns}		-0.11^{ns}	-0.11 ^{ns}	-0.11^{ns}	-0.02 ^{ns}
SG	0.01^{ns}	-0.11 ^{ns}	0.07 ^{ns}	0.04 ^{ns}	-0.01 ^{ns}	0.03 ^{ns}	-0.07 ^{ns}		1.00**	0.98**	0.51*
TSC	0.02 ^{ns}	-0.12 ^{ns}	0.06 ^{ns}	0.03^{ns}	-0.01^{ns}	0.03 ^{ns}	-0.07 ^{ns}	1.00**		1.00**	0.50*
DMC	0.02 ^{ns}	-0.12 ^{ns}	0.06 ^{ns}	0.03 ^{ns}	-0.01^{ns}	0.03 ^{ns}	-0.07 ^{ns}	0.96106**	1.00**		0.50*
TTY	-0.42**	-0.24*	0.55**	0.54**	-0.08 ^{ns}	0.53**	-0.01^{ns}	0.42**	0.41**	0.41**	

** = correlation is significant at p< 0.01, * = correlation is significant at p< 0.05, ns = non-significant, DF=days to 50% flowering, DM=days to maturity, PH= plant height, ASN= average stems number, LAI= leaf area index, SDMW= shoot dry mass weight, TDM= tuber dry mass weight, TBW= total biomass weight, ATN= average tuber number, ATW= average tuber weight, MTY= marketable tuber yield, UnMTY= unmarketable tuber yield, SST= small size tuber, MST= medium size tuber, LST= large size tuber, Dg= geometric mean diameter, ST= sphericity of the tuber, SA= surface area, LWR= length to width ratio, SG= specific gravity of tubers, TSC= total starch content, DMC= dry matter content and TTY= total tuber yield

3.4. Path Analysis

The correlation coefficients of total tuber yield and tuber dry matter content with evaluated traits were significant. The use of dividing the correlation coefficients into direct and indirect effects on total tuber yield and dry matter content helps to determine the selection criteria for tuber yield and processing quality improvement. Therefore, using total tuber yield per hectare and dry matter content as dependent variables and the other traits as independent variables, the path coefficient analyses was computed at genotypic level for both traits.

3.4.1. Genotypic Path Coefficient Analysis of Tuber Yield with Other Traits

The results of path analysis at genotypic level are presented in Table 4. Days to maturity, total biomass weight, average tuber weight, marketable tuber yield, unmarketable tuber yield, large size tubers, geometric mean diameter, specific gravity of tubers and dry matter content exerted positive direct effect on total tuber yield per hectare. Lenka and Mishra [25] suggested five categories of direct and indirect effects based on range of values, viz., negligible (0.00-0.09), low (0.10-0.19), moderate (0.20-0.29), high (0.30-1.00) and very high (>1.00). According to these groups, dry matter content and marketable tuber yield exerted very high and high positive direct effect, respectively. Unmarketable tuber yield and geometric mean diameter exerted moderate and low positive direct effect on total tuber yield, respectively. On the other hand, days to maturity, total biomass weight, average tuber weight, large size tubers and specific gravity of tubers had exerted negligible positive direct effect on total tuber yield per hectare, respectively.

Leaf area index, tuber dry mass weight, and surface area showed exerted negative direct effect on total tuber yield per hectare. Total starch content and, surface area had exerted very high and low negative direct effect, respectively. Leaf area index and tuber dry mass weight had negligible negative direct effect on total tuber yield per hectare, respectively. Small size tuber exerted negative and negligible direct effect on total tuber yield per hectare. Total starch content had very high negative direct effect on tuber yield with very high negative indirect effects via all the characters except geometric mean diameter and tuber surface area. The results of genotypic path analysis showed that dry matter content and marketable tuber yield had practical importance in selection of potato genotypes for high tuber yield per hectare.

Table 4. *Estimates of direct (bold) and indirect effect (off diagonal) of different traits on total tuber yield at genotypic level in 24 potato genotypes tested at Holetta in 2017.*

	DM	LAI	TDM	TBW	ATW	MTY	UnMTY	SST	LST	Dg	SA	SG	DMC	TSC	r_g
DM	0.001	-0.001	-0.001	0.006	0.001	0.356	0.059	0.000	0.001	0.052	-0.054	0.004	7.790	-7.799	0.416*

	DM	LAI	TDM	TBW	ATW	MTY	UnMTY	SST	LST	Dg	SA	SG	DMC	TSC	r_g
LAI	0.000	-0.002	-0.006	0.009	0.003	0.586	0.081	0.001	0.002	0.079	-0.083	0.002	4.188	-4.192	0.668**
TDM	0.000	-0.001	-0.013	0.013	0.002	0.585	0.036	0.001	0.001	0.037	-0.040	0.003	6.191	-6.193	0.622**
TBW	0.000	-0.001	-0.011	0.015	0.001	0.610	0.051	0.000	0.001	0.038	-0.040	0.004	9.090	-9.096	0.662**
ATW	0.000	-0.001	-0.006	0.004	0.005	0.574	0.047	0.002	0.004	0.079	-0.083	0.001	2.604	-2.608	0.622**
MTY	0.000	-0.001	-0.008	0.010	0.003	0.900	0.077	0.001	0.003	0.078	-0.082	0.004	7.110	-7.116	0.979**
UnMTY	0.000	-0.001	-0.002	0.003	0.001	0.307	0.224	0.000	0.001	0.031	-0.034	0.003	5.023	-5.031	0.527*
SST	0.000	0.001	0.005	-0.002	-0.004	-0.542	0.002	-0.002	-0.004	-0.064	0.068	0.000	0.199	-0.199	-0.543**
LST	0.000	-0.001	-0.003	0.003	0.004	0.559	0.043	0.002	0.005	0.087	-0.092	0.000	0.732	-0.735	0.604**
Dg	0.000	-0.001	-0.004	0.005	0.003	0.577	0.058	0.001	0.003	0.122	-0.129	0.000	-0.503	0.504	0.635**
SA	0.000	-0.001	-0.004	0.005	0.003	0.573	0.059	0.001	0.003	0.122	-0.129	0.000	-0.553	0.554	0.632**
SG	0.001	-0.001	-0.005	0.008	0.001	0.415	0.083	0.000	0.000	-0.003	0.004	0.008	14.787	-14.801	0.498*
DMC	0.001	-0.001	-0.005	0.009	0.001	0.426	0.075	0.000	0.000	-0.004	0.005	0.008	15.013	-15.026	0.502*
TSC	0.001	-0.001	-0.005	0.009	0.001	0.426	0.075	0.000	0.000	-0.004	0.005	0.008	15.013	-15.026	0.502*

Residual factor= 0.009, ** = correlation is significant at p< 0.01, * = correlation is significant at p< 0.05, DM= days to maturity, LAI= leaf area index, TDM= tuber dry mass weight, TBW= total biomass weight, ATW= average tuber weight, MTY= marketable tuber yield, UnMTY= unmarketable tuber yield, SST= small size tuber, LST= large size tuber, Dg= geometric mean diameter, SA= surface area, SG= specific gravity of tubers, DMC= dry matter content, TSC= total starch content and r_g= Genotypic correlation coefficient.

3.4.2. Genotypic Path Coefficient Analysis of Dry Matter Content with Other Traits

The results of path analysis at genotypic level are presented in Table 5. Specific gravity of tubers had high positive direct effect, total biomass weight had moderate positive direct effect and marketable tuber yield had low positive direct effect with dry matter content. Specific gravity of tuber had high positive direct effect on dry matter content with high positive indirect effects through all the characters. Days to maturity, tuber dry mass weight and total tuber yield had low negative direct effect on dry matter content and shoot dry mass weight had exerted negligible negative direct effect on dry matter content. Total tuber yield had negligible negative direct effect on dry matter content with negligible negative indirect effects through all the characters.

Table 5. *Estimates of direct (bold) and indirect effect (off diagonal) of different traits on dry matter content at genotypic level in 24 potato genotypes tested at Holetta 2017.*

Variable	DM	SDMW	TDMW	TBW	TTY	MTY	SG	r_g
DM	-0.1018	-0.0119	-0.0187	0.1074	-0.0627	0.0660	0.5406	0.5189**
SDMW	-0.0760	-0.0159	-0.0211	0.1394	-0.0470	0.0493	0.5316	0.5603**
TDMW	-0.0106	-0.0019	-0.1801	0.2172	-0.0939	0.1083	0.3732	0.4124*
TBW	-0.0445	-0.0090	-0.1592	0.2457	-0.1000	0.1130	0.5595	0.6055**
TTY	-0.0423	-0.0050	-0.1120	0.1627	-0.1509	0.1631	0.4860	0.5015*
MTY	-0.0403	-0.0047	-0.1170	0.1666	-0.1477	0.1666	0.4501	0.4736*
SG	-0.0564	-0.0087	-0.0688	0.1408	-0.0751	0.0768	0.9764	0.9850**

Residual effect = 0.15, ** = is correlation significant at p< 0.01, * = Correlation is significant at p< 0.05, DM= days to maturity, SDMW= shoot dry mass weight, TDMW= tuber dry mass weight, TBW= total biomass weight, TTY= total tuber yield, MTY= marketable tuber yield, SG= specific gravity of tubers and r_g= genotypic correlation coefficient.

4. Discussion

4.1. Phenotypic and Genotypic Correlation of Tuber Yield with Other Traits

The evaluated genotypes in this study provided baseline information that would simplify decision for releasing improved processing quality potato varieties in Ethiopia. The observed highly significant (P<0.01) variation in processing and tuber yield traits among the 24 potato genotypes assessed (Table 2). Tuber yield showed a positive and significant correlation with yield components, yield and tuber quality both at the genotypic and phenotypic (Table 3). In a similar kind of study [26-29] reported a positive and significant correlation of total tuber yield with leaf area index, days to maturity, average tuber weight, tuber dry mass weight, total biomass weight, larger size tubers, geometric mean diameter and dry matter at both phenotypic and genotypic levels. Highly significant positive correlation coefficient between marketable tuber yield and total tuber yield at both phenotypic and genotypic levels [30, 31]. The findings of these researchers were in agreement with the current study results and hence these traits had greater practical values for selection of potato genotypes for high tuber yield. Tuber yield per hectare showed negative and significant correlations with average stems number, small size tubers and medium size tubers both at genotypic and phenotypic levels. The presence of negative correlation indicated the associated traits are in opposite direction and selection of genotypes for high performance of one trait leads to the reduction of performance in the other traits. Therefore, it is important to give attention to phenology of the crops in the process of the selection of potato genotypes for high tuber yield. The sign of genetic correlations between two characters can either facilitate or impede selection progress and r = 0 or non-significant carries the implication of no correlation between the two characters [9-11]. Correspondingly, [32] reported highly significant negative correlation of total tuber yield with small size of tubers at genotypic and phenotypic levels. In agreement with the results of the present study, [33] reported a negative and significant correlation between total tuber yield per hectare and medium size tubers.

4.2. Phenotypic and Genotypic Correlation of Dry Matter Content and Other Traits

Dry matter content showed positive and significant correlation with plant height, days to maturity, shoot dry mass weight, tuber dry mass weight, total biomass weight, marketable tuber yield, specific gravity of tubers, total starch content both at genotypic and phenotypic levels (Table 3). Highly significant correlation among specific gravity, dry matter and tuber starch contents was reported by [20] and the observed correlation was near to perfect (r = 0.97 to 0.99). [33, 34] reported strong positive and significant correlations between starch content and dry matter content (r=1). Dry matter content at the genotypic and phenotypic levels was highly significant and positively correlated with specific gravity and total starch content [35]. Owing to these consistent reports of different workers including the present study result, strongly select the variety of interest based on either specific gravity or dry matter content of the tuber without any need for further examination of the rest traits.

4.3. Genotypic Path Coefficient Analysis of Tuber Yield with Other Traits

The results of path analysis at genotypic level are presented in Table 4. Days to maturity, total biomass weight, average tuber weight, marketable tuber yield, unmarketable tuber yield, large size tubers, geometric mean diameter, specific gravity of tubers and dry matter content exerted positive direct effect on total tuber yield per hectare. Total starch content, leaf area index, tuber dry mass weight, surface area and small size tuber showed exerted negative direct effect on total tuber yield per hectare. The results of genotypic path analysis showed that dry matter content and marketable tuber yield had practical importance in selection of potato genotypes for high tuber yield per hectare. Similarly, [29, 30, 33, 36] reported a positive direct effect of days to maturity, total biomass weight, average tuber weight, big tuber percentage, marketable tuber yield, unmarketable tuber yield, geometric mean diameter and dry matter content on total tuber yield. When the trait has positive correlation coupled with negative or negligible direct effect of the dependent variable, the positive correlation of the trait is because of the indirect effects through other traits. The indirect casual traits are to be considered simultaneously for selection [11]. Therefore, days to maturity, total biomass weight, average tuber weight, large size tubers, specific gravity of tubers, total starch content, surface area, leaf area index and tuber dry mass weight traits had positive and significant genotypic correlation with total tuber yield per hectare were due to the positive indirect effect through other traits. The genotypic and phenotypic correlation coefficient only indicates that the association of traits which is the total effect that does not show the direct and indirect effects of traits. The genotypic and phenotypic path analysis indicates the parting of the total correlation into direct and indirect effects of independent variable(s) on dependent variable [11, 12]. In the present study residual effect was 0.009 (Table 4) showing that 99.10% of the variability in total tuber yield was explained by the identified traits while the remaining 0.90 % is explained by other traits not considered in this study.

4.4. Genotypic Path Coefficient Analysis of Dry Matter Content with Other Traits

The results of path analysis at genotypic level are presented in Table 5. Specific gravity of tubers, total biomass weight and marketable tuber yield had positive direct effect with dry matter content. Days to maturity, shoot dry mass weight, tuber dry mass weight and total tuber yield had negative direct effect on dry matter content. [11] reported the correlation coefficient between causal or dependent factor and the effect is almost equal to its direct effect, the correlation explains the true relationship and the direct selction through these trait will be effective. In this study, the dependent traite dry matter content (r_g = 0.9850**) had positive significant genotypic correlation was near equal to the specific gravity of tuber (0.9764) positive direct effect. Wassu [20] reported that the correlation was highly significant among tubers specific gravity and dry matter. In most cases the correlation was perfect (r = 1.00) or near to perfect (r = 0.97 to 0.99). Therefore, the results of path coefficient analysis showed that specific gravity of tuber used as selection criteria for high dry matter content in potato genotypes. The genotypic residual effect in the present study (0.15) indicated that about 85.00% of the variability in dry matter content was contributed by the seven characters studied in path analysis (Table 5). The remaining 15.00% of the variability towards dry matter content is explained by other traits not considered in the present study such as other characters which were not studied, environmental factors and sampling errors as stated by [37].

5. Conclusions

In conclusion, most of the traits had positive genotypic and phenotypic correlations with total tuber yield and dry matter content. Total biomass weight, average tuber weight and marketable tuber yield had positive and highly significant correlations with total tuber yield and had positive direct effects at genotypic level. Similarly dry matter content had positive and significant correlation with marketable tuber yield, specific gravity and the traits had positive direct effects at genotypic levels. As a recommendation, the positive and significant correlation with direct effect traits will have practical importance in selection of potato genotypes for high total tuber yield per hectare and processing purpose.

Acknowledgments

I am grateful to the Ethiopian Institute Agricultural Research and Holetta Agricultural Research Centre for fanatical support and providing all necessary facilities.

Conflicts of Interest

The authors declare no conflicts of interest.

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