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Research Article

Genetic Variability, Heritability and Genetic Advance in Potato (*Solanum Tuberosum* L.) for Processing Quality, Yield and Yield Related Traits

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Potato (Solanum tuberosum L.) used as fresh products and commercially processed foods such as French fries and chips.The objective of the experiment was to assess the nature and magnitude of variability in potato genotypes for tuber quality, yield and yield-related traits. Twenty four potato genotypes were evaluated at Holetta Agricultural Research Centre using a randomized complete block design with three replications during the growing season of 2017. The results of the analysis of variance indicated there was highly significant differences among the genotypes for all traits excepted peel content. The phenotypic (PCV) and genotypic (GCV) coefficient of variation ranged between 0.90 to 46.43% and 0.75 to 40.0%. Heritability in the broad sense (H^2) and genetic advance as percent of the mean (GAM) ranged from 38.13 to 91.64% and 1.28 to 73.50%. High phenotypic coefficients of variation and genotypic coefficients of variation coupled with high heritability and genetic advance as percent of mean were observed for shoot dry mass weight, average tuber number, average tuber weight, unmarketable tuber yield, small size tuber and large size tubers. Therefore, selection for these characters would be effective for the emerging processing industry and could be selected as parents for future crossing program in Ethiopia.

Keywords: *Tuber quality, potato variability, genotypic variation, phenotypic variation, co-efficient of variance*

INTRODUCTION

Potato (*Solanum tuberosum* L.) is the third most important food crop in the world after rice and wheat in terms of human consumption. More than a billion people eat potato worldwide, and global total production exceeds 300 million metric tons. Ther are more than 4,000 varieties of native potato and also over 180 wild species, mostly found in the Andes (CIP, 2020). In central highlands Ethiopia an adaptation trial of potato was conducted to identify potato varieties that is better to adaptation, yield and other agronomic traits and disease tolerant. The national average potato yield in Ethiopia is 13.9 t ha^{-1} (CSA., 2018), which is lower than the experimental yield of over 35 t ha^{-1} (Berihun, 2013), and world average yield to 20 t ha^{-1} (FAOSTAT., 2019). It is a nutritious vegetable containing 16% carbohydrates, 2% proteins, 1% minerals, 0.6% dietary fiber and a negligible amount of fat (Gumul *et al.*, 2011). In Eastern African potato is the high yield potential and plasticity to environmental regimes makes it on of the best crops for food and nutrition security (Kyamanywa *et al*., 2011). The large proportion (60 to 80%) of dry matter is composed of starches from 20% of the average dry matter content, it is a food rich in carbohydrate (Lutaladio and Castaidi, 2009). Besides being a rich source of carbohydrates, potato also contains some health-promoting compounds such as phenolic acids, ascorbic acid and carotenoids (Ezekiel *et al*., 2013).

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The genetic makeup, crop maturity, agronomic practices, environmental conditions, storage temperatures, pests and diseases are affecting tuber. Studying the genetic variability present among different potato genotypes for a given character is a basic precondition to design systematic breeding methods. Predominantly, genetic variability for a given character is a basic precondition for its improvement by systematic breeding (Engida *et al*., 2007; Arslanoglu *et al*., 2011).

Strategic potato research in Ethiopia began in 1975 with the understanding of the constraints challenging its production and productivity (Baye and Gebremedhin, 2013). The development and dissemination of more than 36 (Belete, Gudanie, Dagim and Jalene…) improved varieties, coupled with other technological packages, contributed greatly to the improvement and rapid expansion in potato production (MANR, 2016). The major objective of potato breeding has been to develop potato cultivars that have maximum yield potential, adaptable to wide agro-ecologies and resistant to late blight that has been the most devastating disease throughout the dominant potato producing highlands of the country (Wassu, 2016). Few studies have been conducted on processing quality potato genotypes (Elfnesh *et al*., 2011; Tesfaye *et al*., 2012; Wassu, 2016; Wassu, 2017). However, the released varieties have not satisfied the consumer for French fries and chips making process (Habtamu *et al*., 2016). Therefore, it is necessary to conduct a comprehensive study on genetic variability of available genotype for tuber quality, yield and yield-related traits and document information on the available varieties quality features. The present experiment was conducted to assess the nature and magnitude of variability in potato genotypes for tuber quality, yield and yield-related traits with the help of genetic parameters, such as phenotypic as well as genotypic coefficient of variation and genotypic coefficients of variation and estimate of heritability in the broad sense.

MATERIALS AND METHODS

Experimental Site, Design and Materials

A total of 24 potato genotypes were used for the experiment. These included 21 genotypes and three released varieties (Table 1). The 24 genotypes were planted at Holleta Agricultural Research Centre experiment station during the main cropping season of 2017. The experiment was laid out in randomized complete block design (RCBD) with three replications and each plot was 3.6 m (length) x 4.5 m (width) (16.2 m^2 gross plot size) consisted six rows each containing 12 plants and thus 72 plants per plot. The spacing between rows and plants was 0.75 m and 0.30 m, respectively. The spacing between plots and adjacent replications was 1 m and 1.5 m, respectively.

Table 1: List of experimental materials included in the study

No.	Accession code	No.	Accession code
1	CIP-396034.268	13	CIP-394611.112
2	CIP-393220.54	14	CIP-392617.54
3	CIP-395017.229	15	CIP-381381.20
4	CIP-392797.27	16	CIP-398180.289
5	CIP-395112.19	17	CIP-.398190.89
6	CIP-399075.7	18	CIP-398190.404
7	CIP-393280.64	19	CIP-391058.175
8	CIP-398098.65	20	CIP-396034.103
9	CIP-393385.39	21	CIP-391046.14
10	CIP-396027.205	22	Belete (CIP-393371.58)
11	CIP-393077.159	23	Gudanie (CIP-386423.13)
12	CIP-399002.52	24	Dagim (CIP-396004.337)

CIP = International Potato Center

Data Collection

Phenology and Growth Parameters

Data was recorded for phenology and growth parameters; days to 50% flowering, days to maturity, plant height (cm), average stems number and leaf area index (cm^{-3}).

Yield and Yield Components

Data was recorded for yield parameters; shoot dry mass weight (g), tubers dry mass weight (g): total biomass weight (g), average tuber number /hill, average tuber weight (g/tuber), tuber size distribution:- small (< 35mm), medium (35 to 50mm), and large (>50 mm) size tubers (%), total tuber yield (t/ha), marketable tuber yield(/ha) and unmarketable tuber yield(t/ha). The amount of tuber number in different size categories was changed to a percentage (Ekin *et al*., 2009).

Tuber Physical and Internal Quality Traits

Peel content (%): Ten fresh tubers were randomly selected from each plot, weight and peeled. The peel of the tubers was weighted. The mean weight of single tuber and peel content was recorded and then expressed as a percentage as follows:

$$\text{Peel content (\%)} = \frac{peel\ content}{Weight\ of\ tuber} \times 100$$

Geometric mean diameter (Dg) (mm): The sizes of ten randomly selected tubers from each plot were measured as length, width and thickness using a digital caliper with an accuracy of 0.01mm. The following equation calculated the geometric mean diameter (Dg):
$Dg = (LWT)^{0.333}$ **where**: L is length; W is width and T is the thickness of the tuber.

Length to width ratio: Recorded as the ratio of tubers length to width and then expressed in terms ratio.

Sphericity of tuber (Φ) (%): the sphericity was determined by the following formula as described by Ahmadi *et al*. (2008): $\Phi = (Dg/L) \times 100$
Where, Φ is the sphercity of the tuber, Dg is the geometric mean diameter and L is the length

Surface area (S) (mm^2): Tubers surface area was determined according to Bareh (2000) by the following formula: $S = \pi Dg^2$ where: S is surface area and Dg is the geometric mean diameter

Specific gravity of tubers (Sg) (gcm^{-3}): It was determined using the weight in air/weight in water methods. Five kilogram tubers of all shapes and sizes were randomly taken from each plot. The selected tubers were washed with water. First, it was weight in air and then re-weighed suspended in water and the specific gravity was determined according to the following formula (Gould, 1995).

$$\text{Specific gravity} = \frac{\text{weight in air}}{\text{weight in air} - \text{weight in water}}$$

Dry matter content (%): The total dry matter content (DMC) was calculated according to Porras *et al.* (2014). Five tubers of each plot were chopped (about 500g total) into small 1-2 cm cubes. They were mixed thoroughly and two subsamples of 200g each were taken. The exact weight of each subsample was recorded as fresh weight. Consequently, each subsample was placed in an oven set at 80°C for 48 hours and dried until constant weight. Each subsample were weighted immediately and recorded as dry weight. The dry matter content for each subsample was then computed with the following formula.

$$\text{Dry matter content (\%)} = \frac{\text{dry weight}}{\text{fresh weight}} * 100$$

Total starch content (g/100g): This was estimated from dry matter content. Total starch content (g/100g): This was estimated from dry matter. Starch content (%) = 17.55 + 0.891* (tuber dry weight % - 24.182) AOAC, 1980) where the dry matter was determined as indicated above it was measured from tubers of the five randomly selected plants to be used for tuber dry mass estimation was sliced and kept in an oven at 80°C for 48 hours and weighed after cooling in room temperature.

Data Analysis

Analysis of variance

The data was subjected to analysis of variance (ANOVA) using the SAS statistical software 9.2 (SAS, 2008). The comparison of the mean performance of genotypes was done the significance of mean squares using Duncan's multiple range test (DMRT). The traits that exhibited significant mean squares in general ANOVA was further subjected to genetic analyses.

Phenotypic and Genotypic Variability

The genotypic and phenotypic variability of each quantitative traits was estimated as genotypic and phenotypic variances and coefficients of variation. The genotypic and phenotypic coefficient of variation was determined by the formula as described by Burton and de Vane (1953)

Genotypic variance (σ^2g) $= \frac{MSg - MSe}{r}$

Where, σ^2g = genotypic variance, MSg = mean square of genotype, MSe = mean square of error, r = number of replications and environmental variance ($\sigma^2 e$) = mean square of the error
Phenotypic variance (σ^2p) = $\sigma^2g + \sigma^2e$
Where, σ^2g = genotypic variance, σ^2e = Environmental variance and σ^2p = Phenotypic variance

$$\text{PCV} = \left(\frac{\sqrt{\sigma_p^2}}{\bar{x}}\right) \times 100 \text{ And } GCV = \left(\frac{\sqrt{\sigma_g^2}}{\bar{x}}\right) \times 100$$

Where: PCV= Phenotypic coefficient of variation, GCV= Genotypic coefficient of variation and $\bar{\mathbf{x}}$ = population mean of the character being evaluated
PCV and GCV values were categorized as low, moderate, and high values, as indicated by Sivasubramaniah and Menon (1973) as follows.
0-10% = low, 10-20% moderate and also > 20% = High

Heritability and Genetic Advance

Broad sense heritability values were estimated using the formula adopted by Falconer and Mackay (1996) as follows:
$H^2 = (\sigma^2g/\sigma^2p) \times 100$
Where, H^2 = heritability in broad sense, σ^2p = Phenotypic variance and σ^2g = genotypic variance
The heritability percentage was categorized as low, moderate and high, as suggested by Robinson and Callbeck (1955).
0-30% = low, 30-60% = moderate and > 60% = high

Expected genetic advance under selection (GA):

Expected genetic advance (GA) at 5% percent selection intensity and genetic advance as percentage of mean (GAM) was calculated through the method of Johnson *et al*. (1955)
$GA = K*SDp*H^2$
Where, GA = Genetic advance, SDp = phenotypic standard deviation on mean basis, H^2 = Heritability in the broad sense and K = standardized selection differential at 5% selection intensity (K = 2.063)

Genetic advance as percent of the mean (GAM)

Genetic advance as percent of mean was estimated as follows:

$GAM = \frac{GA}{\bar{X}} X100$

Where GAM = Genetic advance as percent of the mean, GA = genetic advance and

$\bar{X}$ = Population mean of the character being evaluated

The magnitude of genetic advance as percentage of mean was categorized as low (0-10%), moderate (10-20%), and high (> 20%), as suggested by Johanson *et al.* (1955).

RESULT AND DISCUSSION

Analysis of Variance

The results of the analysis of variance indicated the presence of highly significant (p<0.01) differences among the tested potato genotypes for all traits excepted peel content (Table 2). This will provide a good opportunity for the breeder to select genotypes of varied maturity groups, tuber yield performance and traits related to processing aspects. Several workers, Misgana *et al*. (2015); Getachew *et al*. (2016); Habtamu *et al*. (2016); Wassu (2016); Wassu (2017) reported highly significant differences among genotypes, for phenology, tuber yield and processing quality traits.

Table 2: Mean squares from analysis of growth parameters yield and quality-related traits and yield of 24 potato genotypes evaluated at Holetta in 2017.

Traits	Mean	Replication (2)	Genotype (23)	Error (46)	CV (%)
Days to 50% flowering	54.19	7.51	54.72**	1.82	2.49
Days to maturity	95.92	18.38	117.86**	13.04	3.77
Plant height (cm)	80.48	385.17	495.62**	14.62	4.75
Average stems number	4.05	0.67	1.86**	0.24	12.06
Leaf area index	2.56	0.17	0.55**	0.05	8.95
Shoot dry mass weight (g/plant)	46.00	145.82	617.52**	69.66	18.14
Tuber dry mass weight (g/plant)	166.14	497.39	1918.32**	558.03	14.22
Total biomass weight (g/plant)	212.14	593.79	2790.60**	723.03	12.68
Average tuber number per hill	11.08	12.49	16.43**	1.58	11.34
Average tuber weight (g/tuber)	66.36	15.19	640.17**	34.77	8.89
Small size tubers (%)	34.12	259.42	248.00**	41.86	18.96
Medium size tubers (%)	39.93	143.46	105.25**	30.34	13.79
Large size tubers (%)	25.95	30.79	351.23**	28.03	20.41
Total tuber yield (t/ha)	31.63	59.35	91.85**	11.70	10.81
Marketable tuber yield (t/ha)	28.74	42.02	75.09**	11.65	11.88
Unmarkatable tuber yield (t/ha)	2.89	1.63	4.37**	0.52	24.82
Peel content (%)	14.85	5.73	4.73^{ns}	3.41	12.39
Geometric mean diameter (mm^3)	55.60	13.19	37.24**	13.07	6.50
Sphericity of the tuber (%)	80.20	0.01	179.79**	7.20	3.35
Surface area (mm^2)	9772.71	1626891.6	4480789.00**	1552507.4	12.75
Length to width ratio	1.27	0.002	0.122**	0.005	5.64
Specific gravity of tubers (g/cm^3)	1.09	0.00000768	0.00022599**	0.00002919	0.50
Dry matter content (%)	21.94	0.34	10.83**	1.39	5.37
Total starch content (g/100g)	15.55	0.26	8.60**	1.10	6.76

*** - Significant at P<0.01 and ns - non-significant, number in parenthesis represented degree of freedom for the respective source of variation, cm = centimeter, g= gram, t/ha= ton per hectare, mm^3 = millimeter cub, mm^2 = millimeter square and g/cm^3 = gram per centimeter cub*

Estimates of Variability Components

Phenotypic and Genotypic Variation

The phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) ranged from 0.90 to 46.43% and 0.75 to 40.0%, respectively (Table 3). Sivasubramaniah and Menon (1973) categorized PCV and GCV coefficient of variation values low (<10%), moderate (10-20), and high (>20%). Based on these categories, days to 50% flowering, days to maturity, geometric mean diameter, sphericity of the tuber, specific gravity of tuber and dry matter content showed low PCV and GCV except sphericity the tuber that had moderate PCV. Plant height, average stems number, leaf area index, tubers dry mass weight, total biomass weight, total tuber yield, marketable tuber yield, medium size tuber, surface area, length to width ratio and total starch content had both moderate PCV and GCV values except average stems number that had high PCV values.

Shoot dry mass weight, average tuber number, average tuber weight, unmarketable tuber yield, small size tubers and large size tuber traits had high PCV and GCV values. The high PCV and GCV indicated that the traits are controlled by genetic factors and hence there is a higher chance of improvement of the crop through selection. Singh (1990) suggested that traits that exhibited high estimates of GCV and PCV have a high probability of improvement through selection. However, the author indicated the improvement of traits is difficult and impractical through selection for traits that exhibited low estimates for both variability components due to the masking effect of the environment on the genotypic effect.

A similar study carried by Regassa and Basavaraj (2005); Addisu *et al*. (2013); Getachew *et al.* (2016); Tripura *et al.* (2016); Panigrahi *et al.* (2017) observed high GCV and PCV for average tuber number, average tuber weight, small size tubers, large size tubers and unmarketable tuber yield. Ummyiah *et al.* (2010) reported moderate PCV and GCV for total tuber yield and low PCV and GCV for specific gravity and dry matter content. Ara *et al.* (2009), Mishra *et al.* (2017) reported moderate PCV and GCV for total starch content, shoot dry mass weight and average stems number.

Table 3: Estimate of variability components for 23 traits in 24 potato genotypes evaluated at Holetta in 2017

	σ^2g	σ^2p	σ^2e	PCV (%)	GCV (%)	H^2 (%)	GA	GAM (5 %)	Difference between PCV & GCV
Days to 50% flowering	17.63	19.45	1.82	8.14	7.75	90.65	8.25	15.22	0.39
Days to maturity	34.94	47.98	13.04	7.22	6.16	72.82	10.41	10.85	1.06
Plant height (cm)	160.33	174.95	14.62	16.44	15.73	91.64	25.01	31.07	0.71
Average stems number	0.54	0.78	0.24	21.81	18.17	69.43	1.27	31.24	3.64
Leaf area index	0.17	0.22	0.05	18.30	15.97	76.10	0.74	28.73	2.33
Shoot dry mass weight (g/plant)	182.62	252.28	69.66	34.53	29.38	72.39	23.72	51.56	5.15
Tubers dry mass weight (g/plant)	453.43	1011.46	558.03	19.14	12.82	44.83	29.41	17.70	6.32
Total biomass weight (g/plant)	689.19	1412.23	723.04	17.71	12.38	48.80	37.83	17.83	5.33
Average tuber number per hill	4.95	6.53	1.58	23.06	20.08	75.80	4.00	36.06	2.98
Average tuber weight (g/tuber)	201.80	236.57	34.77	23.18	21.41	85.30	27.07	40.79	1.77
Small size tubers (%)	68.71	110.57	41.86	30.82	24.29	62.14	13.48	39.51	6.53
Medium size tubers (%)	24.97	55.31	30.34	18.62	12.51	45.15	6.93	17.35	6.11
Large size tubers (%)	107.73	135.77	28.03	44.90	40.00	79.35	19.07	73.50	4.90
Total tuber yield (t/ha)	26.72	38.42	11.70	19.60	16.34	69.54	8.89	28.12	3.26
Marketable tuber yield (t/ha)	21.14	32.80	11.65	19.93	16.00	64.47	7.62	26.50	3.93
Unmarketable tuber yield (t/ha)	1.29	1.80	0.52	46.43	39.23	71.41	1.98	68.39	7.20
Geometric mean diameter (mm^3)	8.06	21.13	13.07	8.27	5.10	38.13	3.62	6.50	3.17
Sphericity of the tuber (%)	57.53	64.73	7.20	10.03	9.46	88.87	14.75	18.39	0.57
Surface area (mm^2)	976093.87	2528601.27	1552507.40	16.27	10.11	38.60	1266.34	12.96	6.16
Length to width ratio	0.04	0.04	0.01	16.52	15.52	82.32	0.38	30.10	1.00
Specific gravity of tubers (g/cm^3)	0.0000656	0.0000948	0.00002919	0.90	0.75	69.21	0.01	1.28	0.15
Dry matter content (%)	3.15	4.54	1.39	9.71	8.09	69.40	3.05	13.90	1.62
Total starch content (g/100g)	2.50	3.60	1.10	12.20	10.16	69.35	2.72	17.46	2.04

σ^2g = genotypic variance, σ^2p = phenotypic variance. σ^2e = environment variance, PCV = phenotypic coefficient of variation, GCV = genotypic coefficient, H^2 = heritability in broad sense, GA = genetic advance, GAM = genetic advance as percent of mean, cm = centimeter, g= gram, t/ha= ton per hectare, mm^3 = millimeter cub, mm^2 = millimeter square and g/cm^3 = gram per centimeter cub

Estimate of Heritability and Genetic Advance

Estimates of heritability in the broad sense (H^2) and genetic advance as percent of the mean (GAM) for 23 traits of potato genotypes are presented in Table 3. The associated values for heritability in the broad sense and genetic advance as percent of mean ranged from 38.13 to 91.64% and 1.28 to 73.50%, respectively. Heritability and genetic advance as percent of mean values were high for plant height, average stem number, leaf area index, shoot dry mass weight, average tuber number, average tuber weight, total tuber yield, marketable tuber yield, unmarketable tuber yield, small size tubers, large size tubers and length to width ratio. A similar study carried by Ikbal and Khan (2003); Ummyiah *et al*. (2010); Getachew *et al.* (2016); Tripura *et al.* (2016) reported for plant height, average stem number, average tuber number, average tuber weight, total tuber yield and marketable tuber yield both high heritability (> 60%) and genetic advance (> 20%) as a percent of the mean.

High heritability values associated with moderate values of genetic advance as percent of mean were recorded for days to 50% flowering, days to maturity, sphericity of the tuber, dry matter content and total starch content. Heritability and genetic advance as percent of mean values moderate for tubers dry mass weight, total biomass weight, medium-size tubers, and geometric mean diameter. Ummyiah *et al.* (2010) reported high heritability (>60%) with moderate genetic advance (>20%) as a percent of the mean for dry matter content. Addisu *et al.* (2013); Getachew *et al*. (2016) reported moderate heritability (30-60%) associated with moderate genetic advance as percent of the mean (10-20%) for total biomass weight and medium-size tuber.

CONCLUSION

The difference between the values of PCV and GCV was low (<5%) for the majority of the traits. This suggested that most of the traits were less influenced by environmental factors and selection based on phenotype expression of the genotypes could be applied as breeding methods to improve the traits. The use of heritability and genetic advance is used to determining the degree of genetic gain from the selection of a trait. The selection efficiency for yield and processing quality can be obtained by identifying traits that exhibit high GA and heritability. The variation within the traits means that there is a possibility of maximizing gains during crop improvement. Average tuber number, average tuber weight, specific gravity of tubers, dry matter content and total starch content, are major traits used during selection for yield and processing quality.

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