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Estimation of Variability, Heritability, and Genetic Advance Among Released Varieties and Local Cultivar of Potato (*Solanum tuberosum* L.) in Eastern Ethiopia

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Abstract: Investigation and a deeper comprehension of the genetic variability, heritability, and genetic advance are necessary for breeding program for crop improvement. This study was conducted at Haromaya, in Eastern Ethiopia, to estimate the magnitude of genetic variability, heritability, and genetic advance for sixteen released varieties and two local cultivars of potatoes. The experiment was set up using a randomized complete block design with three replications. Fifteen yield and yield component characteristics data were collected. The analysis of variance was carried out, and the estimation of variance components, heritability in a broad sense, and genetic advance were conducted. The mean squares due to genotypes were highly significant (P<0.0) for all the characters examined, demonstrating the presence of considerable variability in tested varieties and local cultivars for economically important traits. In this study, genotypic variance values ranged from 0.45 for total soluble solid to 296.88 for average tuber weight, while phenotypic variance values ranged from 0.48 for total soluble solid to 299.59 for average tuber weight. The GCV values ranged from 6.17% for dry matter content to 41.42% for large tuber number, while, the PCV values ranged from 6.36% for sphericity of the tuber to 41.48 % for large tuber number. Estimates of heritability in a broad sense ranged from 71.95 for dry matter content to 99.87 for large tuber number, whereas genetic advance as a percentage of mean ranged from 99.87% for large tuber number to 71.95% for dry matter content. According to the study results, a high range of variability for most of the investigated traits was observed, indicating an ample chance of selecting the best genotypes to improve crop productivity through selection. In the present study, high heritability coupled with high-expected genetic advance as a percentage of mean was recorded for large tuber number, average tuber weight, small tuber number, large tuber weight, medium tuber weight, marketable tuber yield, and total tuber yield, and those characters could be used as good criteria for selection in the potato improvement program.

Keywords: Potato, Genotypic Coefficient, Phenotypic Coefficient, Variance, Broad Sense Heritability, Genetic Advance, Selection

1. Introduction

Potatoes (Solanum tuberosum L.) are the third-largest food crop in the world in terms of human consumption, next to rice and wheat [20]. It originated and first domesticated in the Andes Mountains of South America [13]. Global crop production surpasses 359 million metric tons, and more than a billion people eat potatoes [16]. It was grown over 25 million hectares of land in about 161 different countries, and it is a significant choice for food security in many developing countries [15].

In Ethiopia, potatoes could be grown on 70% of the 10 million hectares of fertile land [14]. The edaphic and climatic conditions in Ethiopia are favorable for the production of potatoes. With a total annual production of 924,728 metric tons in 2019, the entire area in Ethiopia under potato production is anticipated to be around 70,362 hectares [10]. When compared to the global average of 20.36 tons per hectare [10, 15], the national average yield of 13.14 t ha-1 is incredibly low. The low national yield and limited area planted with potatoes in Ethiopia are glaring examples of how the crop's potential has not been fully realized. Many

factors contributed to low production and productivity, including biotic (disease, insect), abiotic (low soil fertility, poor agronomic management), and failure to use appropriate technology (improved variety, fertilizer). Therefore, tailoring a new variety of potato having high yield potential, resistance to disease and adaptable to wide agro-ecological zones through breeding work must be a high priority.

A number of phases were engaged in the systematic breeding process, including the collection of germplasm, the evaluation of genetic variability, the creation of genetic variability, the application of selection, and the promotion of selected genotypes to be released as commercial varieties [9]. Genetic diversity in a population is a prerequisite for an effective plant-breeding program. Investigation and a deeper comprehension of the variability are necessary for efficient and effective breeding activities existing in a population base of a crop is required so that it can be exploited by plant breeders for crop improvement. Additionally, the degree of genetic variability in a crop and the quantity of heritable variation from parents to offspring are both important factors in the success of any crop improvement work [6].

Knowledge of the genetic parameters of traits, such as heritability and genetic advance, is essential to help guide an effective breeding strategy. Such information will allow plant breeders to predict the response to the selection of breeding programs [7]. In practice, the true variance components are unknown but are estimated from the data [4]. Therefore, estimating genetic coefficient of variation, genetic advance, and broad-sense heritability (h^2) would be useful for plant breeders to execute selection in breeding programs [19]. Most selection methods would be used high heritability associated with high genetic advance as a clue in most selection programs [22].

The degree to which a character may be passed down from parent to offspring is typically assessed using heritability, which is a measure of the genetic link between parent and progeny. It is important for plant breeders because it provides information on the extent to which a particular character can be transmitted from the parent to the progeny [9]. Heritability estimates on some important characteristics of potatoes have been carried out by several researchers [4, 17, 34, 38]. Similar to this, genetic advance is also essential since it demonstrates the level of improvement in a character that resulted from one cycle of selection. High genetic advance combined with high heritability estimates provides the ideal condition to decide the criteria of selection [9]. Therefore, estimating genetic variance aids plant breeders in selecting the most effective breeding strategy for enhancing crops while utilizing available resources.

It is necessary to study and generate information on genetic variability, genotypic coefficient of variation, heritability, and genetic advance of the potato to estimate the progress of their breeding program in the future. Therefore, the current study was carried out with the objective of estimating the nature and extent of genetic variability, heritability, and genetic advance in yield and yield components among 16 released varieties and 2 local cultivars.

2. Material and Methods

2.1. Description of the Study Area and Experimental Material

The study was conducted in the Eastern Hararghe zones at Rare, Haramaya University's Horticulture section's research field, during the main cropping season of 2012. The location of the site is geographically suited at 9°26' N latitude, 42°3' E longitude, and 1980 meters above sea level. The average annual rainfall is 760 mm, the average annual maximum temperature is 23.40°C, and the average annual lowest temperature is 8.250°C [5]. The experimental site's soil is a deep alluvial that drains well, with subsoil that is stratified with loam and sandy loam [32]. The experiment consisted of 16 released varieties and 2 local potato cultivars (Table 1).

Table 1. *Description of Experimental Materials.*

No	Variety	Description	Recommended Altitude (m.a.s.l.)
1	Moti	Released variety	2400-3350
2	Belete	Released variety	1600-2800
3	Bubu	Released variety	1700-2000
4	Ararsa	Released variety	2400-3350
5	Gudenie	Released variety	1600-2800
6	Bule	Released variety	1700-2700
7	Gabisa	Released variety	1700-2000
8	Marachere	Released variety	1700-2700
9	Harchasa	Released variety	1700-2000
10	Gera	Released variety	2700-3200
11	Gorebella	Released variety	2700-3200
12	Guassa	Released variety	2000-2800
13	Jalenie	Released variety	1600-2800
14	Bedasa	Released variety	1700-2400
15	Zemen	Released variety	1700-2400
16	Chiro	Released variety	1700-2400
17	Bete	Local cultivar	-
18	Jarso	Local cultivar	-

2.2. Experimental Design

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Each plot was 3.60m x 4.50m = 16.2m^2 wide, consisting of six rows, which accommodated 12 plants per row and thus 72 plants per plot. The spacing between plots and adjacent replication were 1 m and 1.5 m, respectively. There was a total of 669.3m^2 of area for the experimental site.

2.3. Experimental Procedures

Land preparation: The experimental fields were cultivated by a tractor to a depth of 25-30cm. The land was leveled and ridges were made by hand.

Planting: Well-sprouted, medium-sized (39-75g) tubers were planted along the edges of ridges and the depth of the planting was kept at 5 cm [21].

Fertilizer application: Phosphorus fertilizer was applied at the rate of 92kg P2O5 ha^{-1} in the form of Diammonium Phosphate (200kg ha-1) and the whole rate was applied at

planting as the per the recommendation made by Haramaya University. Nitrogen fertilizer in the form of urea was applied at a rate of 75kg ha-1 in two splits, half-rate after full emergence (two weeks after planting) and half-rate at tuber beginning (start of flowering).

Crop protection: Potato plants were treated with Mancozeb 80% WP at the rate of 1.5 kg ha-1 diluted at the rate of 40 g per 20 litre of water once a week to control late blight disease. All the remaining cultural practices were carried out in accordance with regional (Haramaya University) guidelines [33].

Harvesting: The haulm were mowed two weeks prior to harvesting to thicken the tuber periderm; when the plants achieved physiological maturity, yellowing or senescence was visible on the lower leaves, which was helpful to reduce bruising and peeling during harvesting and post-harvest handling. For yield estimation, tubers were harvested from forty plants from the four middle rows, leaving the plants growing in the two border rows as well as those growing at both ends of each row to avoid edge effects.

2.4. Data Collection

To evaluate the genotypes, observations on total tuber yield (t ha^{-1}), marketable tuber yield (t ha-1), tuber size distribution in number (%), tuber size distribution in weight (%), tuber dry matter content (%), total starch content (%-), geometric mean diameter (mm), and sphericity of the tuber (%) were collected.

Total tuber yield t ha-1): At harvest, the total tuber yield weight of 40 plants per plot was recorded and converted into yield per hectare.

Marketable tuber yield (g): All marketable tubers weighing more than 20 grams and free of pests and diseases were counted.

Average tuber weight (g tuber-): The average tuber weight was determined by dividing the total fresh tuber yield to the respective total tubers number.

Tuber size distribution in number (%): Tubers were recorded by counting the number of tuber that are large (>75g); medium (39-75g) and small (<39g) at harvest according to Lung'aho [21].

Tuber size distribution in weight (%): Yield sample was graded in to three groups considering weight of tubers. Grading were recorded by weighing the number of total tubers that were categorized as large (>75g); medium (39-75g) and small (<39g) according to Lung'aho [21] and the proportion of these groups of tubers were calculated in percentage.

Tuber dry matter content (%): Five fresh tubers were randomly selected from each plot and weighed at harvest, sliced and dried in oven at 65°C until a constant weight is obtained and dry matter percent were calculated according to Williams [33].

$$\text{Dray Matter (\%)} = \frac{\text{Weigh of sample after drying (g)}}{\text{Intial weight of sample(g)}} \times 100$$

Total starch content (g/100g): The percentages of starch were calculated from the specific gravity as according to [18].

$$\text{Starch (\%)} = 17.546 + 199.07 \times (\text{specific gravity} - 1.0988)$$

Whereas, specific gravity was calculated using the weight in air over weight in water method as described by Kleinkopf [18]. A random five kilogram tuber of any form or size was chosen from each plot, washed with water then weighted first in air then in water.

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

Total soluble solids (^{0}Brix): The total soluble solids of the raw potato samples were determined using a method as described by Pardo *et al* [25] using a hand refractometer. The Brix was measured in the juice obtained after washing, crushing, and extracting the juice from the tuber samples.

Geometric mean diameter (Dg): Using a digital caliper with a 0.01 mm accuracy, ten randomly chosen tubers from each plot were measured for length, breadth, and thickness. According to Mohsenin [23], the geometric mean diameter (Dg) was calculated as follow:

$$\text{Dg} = \sqrt[3]{\text{LWT}}$$

Where, Dg is the geometric mean diameter, L is length, W is width, and T is thickness

Sphericity of the tuber (Φ) (%): Tuber sphericity was determined by the following formula, as described by Ahmadi et al. [2]: Φ= (Dg/ L) ×100

Where Φ is the sphercity of the tuber, Dg is the geometric mean diameter, and L is length.

2.5. Data Analysis

Analysis of variance (ANOVA) was used to assess the differences between genotypes on the data. Statistical Analysis System (SAS) version 9.4 software was used to compute the analysis of variance. After testing the ANOVA, treatment means were separated with a List Significance Difference (LSD) at 5% probability levels.

2.5.1. Estimation of Variance Component

The genotypic and phenotypic coefficients of variation were estimated using the formula suggested by [3, 31] as follows:

$$\sigma^2 \text{G} = \frac{\text{MSg} - \text{MSe}}{\text{r}}$$

$$\sigma^2 \text{P} = \sigma^2 \text{G} + \frac{\text{MSg} - \text{MSe}}{\text{r}}$$

where σ^2_G = genotypic variance, σ^2_P = phenotypic variance, σ^2_E = Environmental variance, MSg = mean square of genotypes, MSe = mean square of error, and r = number of replications

$$PCV = \frac{(\sigma^2 p)^{1/2}}{\bar{X}} \times 100$$

$$GCV = \frac{(\sigma^2 G)^{1/2}}{\bar{X}} \times 100$$

Where: GCV= Genotypic coefficient of variation, PCV= Phenotypic coefficient of variation, and $\bar{X}$ is grand mean of a character.

2.5.2. Estimation of Heritability in Broad Sense

Heritability in broad sense (h^2) of the traits were calculated according to the formula as described by Allard [3] as follows:

$$H(h^2b) = \frac{\sigma^2 G}{\sigma^2 P} \times 100$$

Where: $H(h^2_b)$ = Heritability in broad sense, σ^2G= Genotypic variance, σ^2P= Phenotypic variance

2.5.3. Estimation of Genetic Advance

Genetic advance (GA) was determined as described by Johnson *et al.* [19];

$$GA = K \times \sigma P \times h^2$$

Where: K = constant (which varies depending upon the selection intensity and, 2.06 at 5% selection intensity), σp = Phenotypic standard deviation calculated as square root of phenotypic variance, h^2= Heritability in broad sense, GA = Genetic advance.

The genetic advance as percentage of the mean (GAM): According to Johnson *et al*. [19], the genetic advance as percentage of the mean (GAM) was calculated as follows:

$$GAM(\%) = \frac{(GA)}{\bar{X}} \times 100$$

where: GAM = genetic advance as percentage of the mean, GA= genetic advance, and $\bar{X}$ = grand mean of a character.

3. Results and Discussion

3.1. Analysis of Variance

Analysis of Variance results indicated that the genotype mean squares for all traits studied were highly significant (Table 2). This reflected that there are high variability among sixteen released varieties and two local cultivars of potato and this variation could be exploited in the potato yield improvement program. Many researchers also reported statistically significant variation for various characters [1, 4, 12, 24, 34, 37, 38].

Table 2. *Mean squares for tuber yield and yield component traits obtained from variance analysis.*

Trait	Rep (2)	Genotype (17)	Error	LSD (5%)	CV (%)
Total tuber yield (t ha-1)	2.12	184.42**	3.13	2.94	5.28
Marketable tuber yield (t ha-1)	0.33	181.94**	1.11	1.74	3.35
Marketable tuber number (%)	12.74	193.51**	4.75	3.62	2.75
Average tuber weight (gm)	19.64	898.75**	8.12	4.73	4.61
Large tuber number (%)	0.02	498.17**	1.26	1.86	3.62
Medium tuber number (%)	1.26	51.24**	10.46	5.37	10.57
Small tuber number (%)	1.02	477.26**	8.64	4.88	7.67
Large tuber weight (%)	4.12	724.94**	3.29	3.01	3.30
Medium tuber weight (%)	2.32	237.21**	1.52	2.05	4.06
Small tuber weight (%)	2.34	169.68**	3.11	2.93	12.05
Geometric mean diameter (mm)	23.38	108.25**	7.00	4.39	4.20
Sphericity of the tuber (%)	0.72	78.07**	4.04	3.34	2.51
Dry Matter content (%)	12.33	16.42*	7.92	4.67	10.33
Total Soluble Solid (^{0}Brix)	0.02	1.45**	0.09	0.50	4.06
Starch Content (%)	1.97	15.93**	0.81	1.49	6.28

Where, & ** = Significant at P<0.05 and P<0.01, respectively, Rep = replication, LSD (5%) = least significant different at 5% probability level and CV (%) =coefficient of variation in percent, Numbers in parenthesis stands for the degree of freedom.

In the present study, all the traits exhibited wide ranges of variation between the maximum and minimum genotype mean values (Table 3). For example, total tuber yield ranged from 48.3 t ha^{-1} to 18.34 t ha^{-1} with a mean of 33.52 t ha^{-1} whereas marketable tuber yield ranged from 44.72 t ha^{-1} 16.3 t ha^{-1} with a mean of 31.38 t ha^{-1}. In addition, large tuber weight ranged from 80.64% to 24.56% with a mean of 55.02% whereas medium tuber weight ranged from 48.74% to 14.93% with a mean of 30.34%. The sphericity of the tuber ranged from 92% to 70.81 % with a mean of 80.16 While, dry matter content ranged from 32.13% to 23.1 with a mean of 27.26%.

3.2. Estimates of Variance Components

According to this experiment result, Genotypic variance (σ^2g) values ranged from 0.45 for total soluble solid to 296.88 for average tuber weight while phenotypic variance (σ^2p) values ranged from 0.48 to 299.59 for total soluble solid and average tuber weight, respectively. The GCV values were ranged from 6.17% for dry matter content to 41.42% for large tuber number. Similarly, the PCV values ranged from 6.36% for Sphericity of the tuber to 41.48 % for large tuber number (Table 3). In the present study, the phenotypic variance was in general higher than the genotypic variance for all the characters (Table 3). Thus, it suggests the substantial influence of the environment besides the genetic variation for the expression of these traits. The same result was also reported by many authors [4, 34, 36, 37].

Traits with high estimates of GCV and PCV has a high potential for effective selection but, traits having low estimates

for both variability components is difficult or impractical for selection due to the masking effect of environment on the genotypic effect [8, 30]. According to Deshmukh *et al*. [11], PCV and GCV values greater than 20% are considered as high; values between 10% and 20% are medium; whereas values less than 10% are considered as low. In this study genotypic coefficient of variation estimates were high (>20%) for total tuber yield, marketable tuber yield, average tuber weight, large tuber weight, medium tuber weight, small tuber weight, large tuber number, and small tuber number. Accordingly, these traits practically provide high chance for effective selection. In contrast, starch content, marketable tuber number, and medium tuber number had moderate GCV values, those traits provide practically moderate chance for selection whereas, dry matter content, sphericity of the tuber, geometric mean diameter and total soluble solid had low GCV values, and hence these traits provide practically less chance for selection.

3.3. Estimation of Heritability in Broad Sense and Genetic Advance

Estimates of heritability in a broad sense ranged from 71.95 for dry matter content to 99.87 for large tuber number (Table 3). According to Singh [19], if the heritability of a character is very high, selection for such characters could be easy. This is because there would be a close correspondence between the genotype and the phenotype due to the relative small contribution of the environment to the phenotype. As a result of the environment's masking effect, selection may be extremely challenging or almost impossible for traits with low heritability. Considering this benchmark, the heritability estimate in this study was high for all the trait studied. Therefore, these characters are effective for selection to improve crop productivity.

According to the study result, genetic advance as percentage of mean ranged from 99.87% large tuber number to 71.95% dry matter content. High genetic advance as percentage of mean recorded for large tuber number (85.33%); average tuber weight (57.42%); small tuber number (67.15%); large tuber weight (58.07%); medium tuber weight (60.18); marketable tuber yield (50.97); and total tuber yield (47.77). whereas, low genetic advance as percentage of mean recorded for dry matter content (12.72%); Sphericity of the tuber (12.77%); total soluble solid (18.69%); geometric mean diameter (18.98mm); and marketable tuber number (20.59). According to Sing [30], high heritability estimates combined with high genetic advance are usually more useful than heritability estimates alone in forecasting gain under selection. Whereas, low heritability accompanied with genetic advance is due to non-additive gene effects for the particular character and would offer less scope for selection because of the influence of the environment. In the present study, high heritability coupled with high-expected genetic advance as percentage of mean was recorded for large tuber number, average tuber weight, small tuber number, large tuber weight, medium tuber weight, marketable tuber yield, and total tuber yield. As a result, these characteristics are critical for a breeder to consider while making a selection. Many researchers also reported high heritability estimates along with the high genetic advance for tuber yield, number of tubers and average tuber weight, and marketable tuber yield [4, 28, 34, 36, 38].

Table 3. *Genetic Variability of yield and Yield component Traits evaluated for 16 varieties and 2 local cultivar.*

Trait	Max	Min	Mean	σ2g	σ2p	GCV (%)	PCV (%)	Hb (%)	GA	GAM
Total tuber yield (t ha^{-1})	48.3	18.34	33.52	60.43	61.47	23.19	23.39	99.15	16.01	47.77
Marketable tuber yield (t ha^{-1})	44.72	16.3	31.38	60.28	60.65	24.74	24.82	99.69	15.99	50.97
Marketable tuber number (%)	95.82	66.13	79.36	62.92	64.50	10.00	10.12	98.77	16.34	20.59
Average tuber weight (gm)	105.24	35.98	61.81	296.88	299.59	27.88	28.00	99.55	35.49	57.42
Large tuber number (%)	52.76	7.79	31.07	165.64	166.06	41.42	41.48	99.87	26.51	85.33
Medium tuber number (%)	39.62	22.17	30.59	13.59	17.08	12.05	13.51	89.21	7.60	24.83
Small tuber number (%)	62.75	13.12	38.34	156.21	159.08	32.60	32.90	99.09	25.75	67.15
Large tuber weight (%)	80.64	24.56	55.02	240.55	241.65	28.19	28.25	99.77	31.95	58.07
Medium tuber weight (%)	48.74	14.93	30.34	78.56	79.07	29.21	29.31	99.68	18.26	60.18
Small tuber weight (%)	31.31	3.70	14.64	55.52	56.56	50.9	51.37	99.08	15.35	104.85
Geometric mean diameter (mm)	74.74	50.28	63.04	33.75	36.68	9.22	9.53	96.71	11.97	18.98
Sphericity of the tuber (%)	92.00	70.81	80.16	24.68	26.02	6.20	6.36	97.38	10.23	12.77
Dry Matter content (%)	32.13	23.1	27.26	2.83	5.47	6.17	8.58	71.95	3.47	12.72
Total Soluble Solid (^{0}Brix)	8.40	5.93	7.42	0.45	0.48	9.07	9.37	96.85	1.39	18.69
Starch Content (%)	16.63	8.80	14.30	5.04	5.31	15.70	16.11	97.42	4.62	32.34

where**,** Max = maximum value, Min= minimum value, σ^2g =genotypic variance, σ^2p =phenotypic variance, GCV=genotypic coefficient of variation in percent, PCV=phenotypic coefficient of variation in percent, H2=heritability in broad sense, GAM.= genetic advance as percent mean.

4. Conclusion and Recommendation

The results of this study revealed the existence of significant variation among tested potato varieties and local cultivars for all the examined traits. The significant variation and high range mean values indicates the presence of considerable variability in tested varieties and local cultivar for economic importance traits and the higher chance of selecting best genotypes with high yield to improve the crop productivity through selection. Seven characters viz., large tuber number, average tuber weight, small tuber number, large tuber weight, medium tuber weight, marketable tuber yield, and total tuber yield characters could be used as good criteria for selection in the potato improvement because, these characters had high genotypic coefficient of variation,

board sense heritability estimate and genetic advance as percent of the mean.

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