Genotype x Environment Interaction for Tuber Yield, Dry Matter Content and Specific Gravity in Elite Tetraploid Potato (*Solanum Tuberosum* L.) Genotypes

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Abstract: A study was conducted to determine stability of tuber yield, dry matter content and specific gravity, and the nature and magnitude of genotype x environment (G x E) interaction in elite tetraploid potato genotypes. Eleven potato genotypes including two standard checks were evaluated in the eastern part of Ethiopia at Haramaya, Langae, Kulubi, Hirna and Arberekete during 2008 and 2009 cropping seasons under rainfed condition. There were significant variations among genotypes with respect to tuber yield and dry matter content while the genotypes exhibited comparable tuber specific gravity values. Significant G x E interaction was observed for tuber yield and dry matter content and G x E mean square for tuber specific gravity was not significant indicating that G x E has negligible influence on the trait. Partitioning of the G x E interaction for both tuber yield and dry matter content indicated the presence of both linear and non-linear types of G x E interactions. None of the genotypes were found to be stable and ranked at the top for tuber yield, dry matter and specific gravity. The stability and responsiveness appeared to be specific for specific character within a single genotype. Genotype CIP-392640-528 is stable for specific gravity, average responsive for tuber dry matter content and above responsive for tuber yield. Highly significant positive correlation (r = 0.99) was obtained between specific gravity and dry matter content proving that specific gravity is a true indicator of tuber dry matter content. The observed significant G x E interaction for tuber yield and dry matter content suggests that potato breeders should give special emphasis for G x E interaction while developing stable and high yielding genotypes in terms of tuber yield and dry matter content.

Keywords: Hararghe; Pooled Analysis; Pooled Deviation; Responsiveness; Stability

1. Introduction

Ethiopia has suitable edaphic and climatic conditions for the production of high quality ware and seed potatoes. About 70% of the available agricultural land is located at an altitude of 1800-2500 masl and receives an annual rainfall of more than 600 mm, which is suitable for potato production (Solomon, 1987). However, the total area under potato production is estimated at 36736 ha with an annual production of 385258 metric tons (FAOSTAT Data, 2004). The national average yield is approximately 10.5 tons ha^{-1}, which is very low compared to the world average of 16.4 tons ha^{-1}. A number of production problems that account for the small area cropped with potato and the low national yield have been identified. The major ones are unavailability and high cost of seed tubers, lack of well-adapted cultivars, sub-optimal agronomic practices, the prevalence of diseases and insect pests, and inadequate storage, transportation, and marketing facilities.

The entire variable encountered in producing a crop can be collectively called environment and every factor that is part of the environment has the potential to cause differential performance that is associated with G x E interaction in potatoes (Fehr, 1987). Potato is grown around the world in a wide array of environments and the crop is flexible to adapt to different growing conditions. Nevertheless, some of its traits such as tuber yield, specific gravity and dry mater contents are found to be influenced by environmental changes as shown by previous G x E studies (Tai and young, 1972; Tai, 1979, DeJong *et al.*, 1981, Yildirim and Caliskan, 1985, Stephen *and* Joseph 1991; Haynes *et al.*, 1995; Tekalign, 2003; Hassanpanah, 2010).

The dry matter content of tubers is an important measure of quality and it is used to assess suitability for the processing purpose as it influences process efficiency, product yield and oil absorption (Stevenson *et al.,* 1964). Specific gravity of raw potatoes is widely accepted by the potato processing industry as a measure of total solids, starch content and other qualities (Fitzpatrick *et al.,* 1964). High dry matter content and specific gravity in potato tubers are important to the grower and the processor.

A number of improved potato cultivars have been developed by different research institutions in Ethiopia and widely used for the preparation of traditional food types. In developing these varieties, however, much emphasis was given to productivity per unit area and late blight resistance or tolerance while less emphasis was given to processing quality. Currently, the demand for cultivars suitable for processing of potato crisps and French fries is increasing. To meet the demand, Potato Improvement Program of Haramaya University has revised its breeding strategy and working towards the development of late blight tolerant varieties with high tuber yield and dry matter content as well as specific gravity values. In addition, the suitability of the varieties for processing is being tested in a laboratory. As part of the breeding program, the study was undertaken to assess genetic variability for tuber yield, dry matter content and specific gravity in advanced breeding materials introduced from International Potato Center (CIP) and investigate the effect of different growing conditions on these characters; ultimately to identify stable genotypes with high tuber specific gravity and dry matter content for future improvement effort. This paper reports phenotypic stability of eleven elite tetraploid potato genotypes for

ISSN 1992-0407

tuber yield, dry matter content and specific gravity, and the nature and magnitude of G x E interaction in potato.

2. Materials and Methods

2.1. Description of the Study Areas

Eleven potato genotypes including two standard checks were grown at Haramaya, Langae, Kulubi, Hirna and Arberekete during the 2008 and 2009 cropping seasons under rainfed condition. The locations represent the major potato growing areas of eastern Ethiopia since they are diverse in climate and soil type and have been used as testing sites for Potato Improvement Program of Haramaya University (Table 1).

Table 1. Description of the experimental sites.

Location	Altitude (masl)	Soil type	Annual rainfall (mm)	Mean annual Max./Min. T^o (^{o}C)
Haramaya	1980	Alluvial soil	780	23.4/8.5
Langaie	2025	Vertisol	810	22.5/9.4
Kulubi	2330	Leptosol	862	19.5/7.3
Hirna	1845	Vertisol	847	21.8/8.6
Arberekete	1850	Verti-cambisol	890	21.5/10.3

2.2. Experimental Procedures

At all locations, the experimental plots were arranged in a randomized complete block design with three replications. Plots were arranged continuously and end plots were bordered by two rows of potato plants. Five rows of ten hills were planted at a spacing of 75 cm between rows and 30 cm between plants. Spacing between plots and replications were 1 m and 1.5 m, respectively. At each site, plots were fertilized with 150 kg phosphorus ha^{-1} in the form of diammonium phosphate and 100 kg nitrogen ha^{-1} in the form of urea. The entire rate of phosphorus and the half rate of the nitrogen fertilizer were applied at the time of planting. The remaining half of the nitrogen was applied at flowering. Cultural practices such as weeding, cultivation and ridging were practiced as per the regional recommendation (Teriessa, 1997).

2.3. Data Collection

Fresh tuber yield of 20 hills harvested from the central rows was used as a base to determine total tuber yield per ha. Tuber specific gravity was measured using the weight in air and weight in water method (Murphy and Goven, 1959). To determine dry matter content of tubers, ten tubers were taken at random from the harvested plot, washed, chopped and mixed. Two sub-samples 200 g each were taken and pre-dried at a temperature of 60°C for 15 h and further dried for 3 h at 105°C in a drying oven. Dry matter content was calculated as the ratio between dry and fresh mass expressed as a percentage.

2.4. Data Analysis

Data were subjected to combined analysis of variance after doing Barlett's test of homogeneity to obtain estimates of environmental, genotypic, and genotype x environment interaction source of variation. The following linear model developed by Eberhart and Russell (1966) was used..

$$Y_{ij} = \mu_i + \beta_i I_i + \delta_{ij}$$

where Y_{ij} = mean performance of the ith variety at the jth environment; μ_i = Mean of the ith variety over all the environments; β_i = Regression coefficient ; I_i = Environnemental index ; δ_{ij} = Deviation from regression of the ith variety at jth environment.

Computation of stability parameters for each genotypes and partitioning of G x E interaction into linear and non-linear components were done using the procedure developed by Elberhart and Russell (1966). The regression coefficient (β_i) and the mean square deviation (S^2d_i) were used as measures of responsiveness and stability, respectively, according to Elberhart and Russell (1966) and Finlay and Wilkinson (1963). The analysis of variance and the linear regression were performed using STATISTICA computer software (Statsoft, 1999). Simple linear correlations between parameters were computed when applicable.

3. Results and Discussion

According to Bartlett's homogeneity test, the observed chi-square (χ^2) is less than the table value (P< 0.01) indicating that error variances of the ten environments are homogeneous and hence pooled analysis was done.

The combined analysis of variance for G x E interaction is presented in Table 2. Mean squares for genotypes were highly significant for tuber yield and dry matter content signifying the existence of considerable variation among the genotypes. Various researchers reported the existence of significant variability among genotypes for tuber yield (Tai and young, 1972; DeJong *et al.*, 1981; Haynes *et al.*, 1995; Tekalign, 2003; Hassanpanah, 2010). Greater variation for dry matter and glucose contents were demonstrated in a pre-breeding population of diploid species than in the more advanced tetraploid breeding population (Amoros *et al.*, 1999-2000). On the contrary, mean square for specific gravity found to be non significant indicating that there is no significant variability among the genotypes for this specific trait. This may be attributed to the advancement of these genotypes from 150 initial breeding clones based on tuber specific gravity and dry matter content. Haynes *et al.* (1995) evaluated 72 diploid hybrid clones grown at two sites for three consecutive years for specific gravity and reported a significant variation among them.

Table 2. Analysis of variance for stability of potato tuber yield, dry matter and specific gravity.

		Mean squares		
Source	df	Tuber yield	Dry matter	Specific gravity
Genotype	10	125.19**	5.54**	0.00014^{ns}
Environment + (G x E)	99	55.55	3.85	0.00008
Environment (linear)	1	3309.58	290.47	0.00610
G X E (linear)	10	$11.58^{**(NS)}$	$0.60^{**(NS)}$	$0.000019^{ns(NS)}$
Pooled Deviation	88	23.57**	0.96**	0.00021^{ns}
Pooled Error	200	0.012	0.125	0.00033

*^{ns}, ** = Not significant at 5% and significant at 1% difference probability level, respectively, when tested against pooled error; $^{(NS)}$ = Not significant at 5% probability level when tested against pooled deviation.*

The mean squares for G x E were highly significant for tuber yield and dry matter content indicating that the genotypes showed a differential response to the characters in the different environments. The existences of significant G x E interaction in potato for tuber yield (Tai and young, 1972; Tai, 1979; DeJong *et al.*, 1981; Yildirim and Caliskan, 1985; Hassanpanah, 2010) and dry matter content (Tai and young, 1972) have been reported based on the findings of previous similar investigations. The G x E mean square for tuber specific gravity was not significant indicating that G x E has negligible influence on the trait. Stephen and Joseph (1991) found no relationship between mean specific gravity of clones and their stability across different environment. Similarly, Haynes *et al.* (1995) observed no correlation between average specific gravity during three years and stability variance statistics.

Partitioning of the G x E interaction for both tuber yield and dry matter content using Eberhart and Rusell (1966) model proved that mean squares due to G x E (linear) and the pooled deviation were significant indicating the presence of both linear and non-linear types of G x E interactions. G x E (linear) found to be non significant when tested against pooled deviation indicating the predominance of non-linear type of G x E interaction although appreciable linear type of interaction was noticed. Significant high pooled deviation suggests that deviations of all of the genotypes (from their expected performances) are not similar in magnitude and unpredictable causes of variation are responsible for the observed G x E interactions. Hence, it is difficult to predict the performance of the genotypes across the environments for tuber yield and dry matter content.

Table 3. Estimates of stability parameters for tuber yield, tuber dry matter and specific gravity of eleven potato genotypes.

	Tuber yield (ton ha^{-1})			Dry matter (%)			Specific gravity (g cm^{-3})		
Genotype	Mean	β_i	S^2d_i	Mean	β_i	S^2d_i	Mean	β_i	S^2d_i
1. AL-268	25.50 (9)	0.92**	17.81^{++}	23.76 (3)	1.05**	0.14^{NS}	1.0971 (3)	1.07**	-0.00032^{NS}
2. CIP-384321-3	32.11 (1)	1.06^{ns}	45.95^{++}	22.50 (11)	0.81**	0.78^{++}	1.0907 (11)	0.79**	-0.00031^{NS}
3. CIP-386423-13	30.49 (2)	1.28**	21.23^{++}	23.52 (4)	1.02**	0.01^{NS}	1.0958 (4)	0.99**	-0.00033^{NS}
4. CIP-387224-25	27.47 (6)	0.98**	18.31^{++}	22.88 (7)	0.66^{ns}	2.86^{++}	1.0930 (6)	1.31**	-0.00032^{NS}
5. CIP-391058-506	21.50 (10)	0.64^{ns}	44.90^{++}	23.29 (5)	1.28**	-0.19^{NS}	1.0948 (5)	1.26**	-0.00033^{NS}
6. CIP-391058-560	20.59 (11)	0.80^{ns}	59.09^{++}	22.90 (6)	0.83**	-0.37^{NS}	1.0928 (7)	0.73**	-0.00033^{NS}
7. CIP-392640-525	27.50 (5)	1.28**	8.29^{++}	24.15 (2)	0.89**	1.74^{++}	1.0990 (2)	0.97**	-0.00030^{NS}
8. CIP-392640-528	26.91 (8)	1.19**	4.60^{++}	24.87 (1)	0.85^{ns}	3.51^{++}	1.1027 (1)	0.94^{ns}	-0.00025^{NS}
9. CIP-392650-517	29.00 (4)	0.96**	17.50^{++}	22.86 (8)	1.42**	-1.35^{++}	1.0927 (8)	1.23**	-0.00031^{NS}
10. Gabissa	27.02 (7)	0.93**	4.60^{++}	22.70 (9)	0.90**	0.85^{++}	1.0921 (9)	0.96**	-0.00032^{NS}
11. Harchassa	29.99 (3)	0.96**	15.66^{++}	22.55 (10)	0.79**	0.64^{++}	1.0910 (10)	0.72**	-0.00031^{NS}
Mean	27.10			23.27			1.0947		

*^{ns}, ** = Not significantly different from unity at 5% and significantly different from unity at 1% probability level, respectively; ^{NS}, $^{++}$ = Not significantly different from zero at 5% and significantly different from zero at 1% probability level, respectively; Figures in parenthesis are ranks of genotypes.*

According to Perkins and Jinks (1968) a genotype having a mean higher than the overall mean, a regression coefficient (β_i) close to unity and deviation from regression coefficient (S^2d_i) equaling zero is considered to be superior for the character considered. The genotypes used in this study did not exhibit uniform stability and responsiveness pattern for the three traits (Table 3). None of the genotypes found to be stable and ranked at the top for tuber yield, dry matter and specific gravity. The stability and responsiveness appeared to be specific for specific character within a single genotype. For instance, genotype CIP-392640-528 is stable for specific gravity, average responsive for tuber dry matter content and above responsive for tuber yield. CIP-384321-3 was average responsive to changing environment for tuber yield, low responsive for tuber dry matter content and specific gravity. Genotypes CIP-386423-13 and CIP-392640-525 exhibited higher mean tuber yield and β_i value significantly higher than unity indicating that they are sensitive to environmental changes and responsive to high yielding environments. On the other hand, *Gabissa* and AL-268 had lower mean tuber yield along with β_i value significantly lower than unity indicating that the genotypes are least responsive to changing environments and can be considered as better adapted to poor environments.

From the study, it was observed that the best performing genotypes for tuber yield (CIP-384321-3 and CIP-386423-13), and dry matter content and specific gravity (CIP-392640-528 and CIP-392640-525) exhibited low stability, indicating that mean performance and stability are two different components probably genetically controlled in different manners. Similar findings were reported by Bucio-Alanis *et al.* (1969), Verma *et al.* (1978), Singh and Gupta (1984) and Singh (1988). In general, the highest specific gravity value corresponded with the higher percent dry matter content of the clones. Moreover, highly significant positive correlation (r = 0.99**) was observed between specific gravity and dry matter content, thus indicating that specific gravity was a true indicator of the amount of tuber dry matter. In agreement with the present study, Tsegaw and Zelleke (2002), Baye *et al.* (2005) and Tekalign and Hammes (2005) reported significant positive association between specific gravity and dry matter content at phenotypic level.

4. Conclusion

The study confirmed that the existence of considerable variation among the genotypes with respect to tuber yield and dry matter content but not for tuber specific gravity. The genotypes showed a differential response to tuber yield and dry matter content in the different environments. On the contrary, G x E has negligible influence on tuber specific gravity. The observed significant G x E interaction for tuber yield and dry matter content suggests that potato breeders should give special emphasis for G x E interaction while developing stable genotypes characterized by high tuber yield and dry mater content.

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