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Genetic Variation among Drought Tolerant Potato (*Solanum tuberosum* L.) Genotypes for Tuber Yield and Related Traits in North western Ethiopia

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Abstract

Estimation of variability is the first step in the process of variety development. The research was conducted at Simada research site of Adet Agricultural Research Center a satellite site for drought experiments in 2016 main rain season to estimate genetic variability among 105 potato genotypes that included five checks. The experiment was laid out in Augmented design and data were collected for 20 traits. The analysis of variance revealed the presence of highly significant (P<0.01) differences among genotypes for all traits considered except plant height, small and medium size tubers percentage. Total tuber yield ranged from 13.92 to 41.79 ton ha^{-1}. Three new entries (20SET4.2, 20SET4.1 and 16SET5.5) had total tuber yield advantage of 35 to 51% over the best yielding check (Belete).). Phenotypic (PCV) and genotypic (GCV) coefficient of variation values ranged from 1.86 to 32.8 and 1.3 to 25.5%, respectively, while heritability and genetic advance as percent of mean estimates ranged from 45.95 to 89.15 and 3.33 to 40.89%, respectively. Moderate to high GCV, PCV, H^2 and GAM were estimated for majority of the traits. suggesting selection breeding is effective to improve these traits. The result revealed exploitable variations among the tested drought tolerant potato genotypes in which appropriate breeding method is possible to improve potato productivity in the terminal moisture stress area.

Keywords: Augmented design, Drought and Variability.

Introduction

Potato (*Solanum tuberosum* L.) is one of the staple food crops in most parts of the world. It is the most consumed food crop world-wide next to wheat and rice (Birch *et al.*, 2012; Hancock *et al.*, 2014) and plays an increasingly essential role in ensuring food security (Vreugdenhil, 2007). Potato production provides food, employment, and income as a cash crop (Scott *et al.*, 2000) and helps in increasing food availability while contributing to a better land use ratio by raising the aggregate efficiency of agricultural production systems (Gastelo *et al.*, 2014).

The production of potato is expanding at a faster rate than other food crops in Ethiopia and other developing countries. It is possible to produce potato in

Ethiopia on about 70% of the arable land (Medhin *et al.*, 2000). In 2015/16 cropping season, a sum of over 3.66 million Mt of potato was produced from an area of over 296,578 hectares of land (CSA, 2016). The national average yield is very low (12.66 t ha^{-1}) as compared to the potential yield (40 t ha^{-1}) obtained under research conditions (Getachew and Mela, 2000). Moisture stress due to recurrent drought has been found one of the contributors to the low yield of potato in most areas of the country.

Environmental stresses represent the most limiting factors for agricultural productivity, have detrimental effects on plant growth and yield and are serious threats to agriculture (Wang et al. 2003). Among the environmental stresses, drought stress is one of the most adverse factors to plant growth and productivity (Shao *et al.*, 2008). The eastern part of South Gondar such as Simada Woreda is characterized by erratic rainfall pattern with short duration and high intensity (late onset and early offset of rain) this implies that besides the amount, distribution of rainfall plays a lot to drought. The global climate change is aggravated this problem from time to time. The production of potato in Simada Woreda was limited and unsatisfactory contribution to food and nutrition security. This is mainly due to the absence of drought tolerant potato varieties in the country. In many areas, potato regularly suffers transient water stress due to erratic rainfall or inadequate irrigation techniques (Thiele *et al.*, 2010). This potato production problem is encounters all drought prone areas of the country. Currently, the National Potato Project is focusing on the development of drought tolerant potato genotypes since absence of such varieties is becoming the major production constraint in the country.

Different studies have shown that the responses of potato to drought vary among varieties and some drought tolerant potato cultivars produce reasonable yields under conditions where grain crops fail, particularly when drought coincides with flowering and seed set (Iwama and Yamaguchi, 2006). It is also well established fact that the yield potential of crop genotypes vary due to genotypic differences, environmental influences and the interactions of the two (Becker and Leon, 1988). Therefore, evaluating of potato genotypes, assessing the genetic variability and estimation of heritability of traits are critical initial steps to develop potato varieties adaptable to semi-arid areas.

The development of drought tolerant potato varieties not only depend on the availability of genotypes but also on the knowledge of genetic variability of the populations. However, such genetic information is lacking, because no attempt has made to introduce drought tolerant potato genotypes in Simada Woreda in particular and in similar moisture stress areas of the country. Thus, this study was conducted with the objective of to estimate the extent of genetic variability in potato genotypes developed for moisture stress areas.

Materials and Methods

Description of the experimental site

The experiment was executed at Adet Agricultural Research Center, Simada experimental site during the main growing season of 2016. Simada is located in Amhara National Regional State South Gondar Administrative Zone, 770 km North of Addis Ababa and 105 km South East of Debrtabor. Simada is positioned at about $11^0$21'N latitude and $38^0$25'E longitude and at an altitude of 2407 m.a.s.l. It has annual mean temperature of 16.8°C. The area has minimum and maximum monthly mean temperature of 10.3- 23.3°C, respectively. The site receives mean annual rainfall of 838.7mm which is abundant but mal-distributed.

Treatment and experimental design

The experiment comprised 100 potato genotypes tailored for moisture stress (drought prone) areas of the world by International Potato Center (CIP). The genotypes were introduced by Adet Agricultural Research Center. Four released potato varieties (Belete, Gera, Shenkolla and Guassa) in the country and one farmer's cultivar commonly used in Simada district were included in the trail. The field trial was arranged in Augmented Block design with 5 blocks. Each block contained 20 genotypes and 5 checks randomized to each experimental plot separately in a block. The genotypes appeared once, while the checks were planted at each block. Each genotype was planted in a gross plot size of 2.25m^2 which accommodate 10 plants. The two most external plants at the beginning and end of each row were considered as boarder plant, this allowed eight middle harvestable plants. The distance between plots and blocks were maintained at1 and 1.5 m, respectively.

Experimental procedures and field management

Medium size (35-45 mm diameter) and well-sprouted potato tubers were planted at spacing of 75 and 30 cm between rows and plants, respectively, as per the national recommendation. Fertilizer was applied at the rate of 69 kg ha^{-1} P_2O_5 in the form of DAP (150kg ha^{-1} DAP) and 108 kg ha^{-1} N in the form of Urea (176kg Urea ha^{-1} + from 150kg ha^{-1} DAP) as per Adet Agricultural Research Center recommendation of the neighbouring zone Debrtabor. The whole rate of phosphorus was applied during planting while nitrogen fertilizer was applied in split application of 50% Urea (46% N) including nitrogen from DAP at the time of planting and the remaining 50% of the recommended rate was applied 30 days after planting. Weeding, cultivation and earthing-up were practiced at the appropriate time to facilitate root, stolon and tuber growth as per the national recommendation for the crop. Before two weeks of harvesting as the crop attained maturity (yellowing of stems and senescence of leaves) dehullming was done to thicken the tubers.

Table 1: List of potato genotypes used in the experiment

No.	Accession code	No.	Accession code	No.	Accession code	No.	Accession code
1	16SET5.1	26	11SET3.3	51	24SET5.9	76	F30.4
2	16SET5.2	27	11SET3.4	52	19SET7.1	77	F 16.1
3	16SET5.3	28	11SET3.5	53	19SET7.2	78	F16.2
4	16SET5.4	29	11SET3.6	54	19SET7.3	79	F16.3
5	16SET5.5	30	11SET3.7	55	19SET7.4	80	F26.1
6	16SET5.6	31	11SET3.8	56	5SET6.1	81	F26.2
7	16SET5.7	32	25SET6.1	57	5SET6.2	82	F29.1
8	16SET5.8	33	25SET6.2	58	5SET6.3	83	F29.2
9	16SET5.9	34	25SET6.3	59	5SET6.4	84	F29.3
10	16SET5.10	35	25SET6.4	60	5SET6.5	85	F10.1
11	16SET5.11	36	25SET6.5	61	2SET8.1	86	F10.2
12	16SET5.12	37	25SET6.6	62	2SET8.2	87	F14.1
13	20SET4.1	38	22SET7.1	63	2SET8.3	88	F14.2
14	20SET4.2	39	22SET7.2	64	3SET6.1	89	F14.3
15	20SET4.3	40	22SET7.3	65	3SET6.2	90	F22.1
16	20SET4.4	41	22SET7.4	66	23SET3.1	91	F22.2
17	20SET4.5	42	22SET7.5	67	23SET3.2	92	28SET6.1
18	20SET4.6	43	24SET5.1	68	4SET8.1	93	28SET6.2
19	20SET4.7	44	24SET5.2	69	4SET8.2	94	F18
20	20SET4.8	45	24SET5.3	70	4SET8.3	95	F20
21	20SET4.9	46	24SET5.4	71	27SET7.1	96	F28
22	20SET4.10	47	24SET5.5	72	27SET7.2	97	F23
23	20SET4.11	48	24SET5.6	73	F30.1	98	F24
24	11SET3.1	49	24SET5.7	74	F30.2	99	F15
25	11SET3.2	50	24SET5.8	75	F30.3	100	F21.1

Data collection

Data were collected on the basis of plot, net plot and sample plants from central plants in a row. Phenological parameters (days to emergence, flowering and maturity) were collected from the entire plots. Leaf area, plant height and stem number per plant were collected from five plants randomly taken from the central plants and the average value was considered per plant basis. Tuber size distribution (very small < 20gm, small 20 to < 39 gm, medium 39-75gm, and large >75 gm according to Lung'aho *et al.* (2007) and other yield and yield components were measured from the net plot.

Bulking rate (g day^{-1}) was calculated as total weight of tubers harvested from net plot divided by number of days taken from days to flowering to physiological maturity (CIP 2014).

Tuber dry matter content (%): Clean and unpeeled tubers were chopped into small 1-2 cm cubes and about 200g chopped samples were dried in an oven at a temperature of 80^{O}C for about 72 hours to a constant weight at regular intervals. The percent of dry matter was calculated according to CIP (2007) as:

$$\text{Dry matter (\%)} = \frac{\text{Weight of sample after drying (g)}}{\text{Initial weight of sample (g)}} \text{ x100\%.}$$

Specific gravity of tubers: Five kg of all size tubers randomly taken from tubers used to estimate total tuber yield. Specific gravity was determined by the weight in air and weight in water method. Tubers first weighted in air and then weighted submerged in water.

Where $\text{Specific Gravity} = \frac{\text{weight in air}}{\text{weight in air} - \text{weight in water}}$ (Kleinkopf *et al.*, 1987).

Total starch content (g/100g): Starch content in percent was estimated from specific gravity as established by Talburt and Smith (1959) as cited by Yildrim and Tokuşoğlu, (2005) as: Starch content (%) = 17.546 + 199.07 × (specific gravity-1.0988), where specific gravity was determined as indicated above by the weight in air and weight in water method.

Data analysis

Analysis of variance

Analysis of variance was computed by using the Statistical package for augmented design (SPAD) software (Abhishek *et al.*, 2010). Significantly different means were separated using critical difference in each category viz., among control, among tests and tests vs control. Correlation and genetic distance were computed using STATISTICA-7 basic statistical analysis software (U.S.A.)

Estimation of variability components

All traits were considered for further variability analysis for which mean squares of accessions are significant. The genetic advance that can be made was computed along with heritability, genotypic and phenotypic coefficients of variations were estimated. Estimation of genetic parameters was used to identify and determine the genetic variability among the genotypes. In addition, descriptive statistics (range and mean) was used to compare differences among different groups of accessions.

Phenotypic and genotypic variations

Phenotypic and genotypic variances and coefficient of variations were calculated by the methods suggested by Burton and de Vane (1953) as:

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

Phenotypic Variance $(\sigma^2 p) = \sigma^2 g + \sigma^2 e$

Where: Environmental variance $(\sigma^2 e)$ =Mean square of error, MSg = Mean square due to genotypes and r = the number of replications.

Phenotypic Coefficient of Variation (PCV) = $\frac{\sqrt{\sigma 2p}}{x} x100$ and Genotypic coefficient of variation (GVC) =$\frac{\sqrt{\sigma 2g}}{x} x100$. Where X = Mean value of the trait

Heritability and genetic advance

Heritability in broad sense for those traits for which accessions exhibited significant mean squares was computed by using the formula given by Falconer and Mackay (1996).

$H^2 = \frac{\sigma 2g}{\sigma 2p}\ x100$, Where: H^2 = heritability in broad sense, $\sigma^2 p$= phenotypic variance and $\sigma^2 g$ = *Genotypic variance.*

Genetic advances under selection (GA): Expected genetic Advances for each character at 5% selection intensity was calculated by the formula described by Johanson *et al.* (1955).

Genetic Advances (GA) = $K.\sigma\ p.H^2$, Where: K =constant (selection differential where K= 2.06 at 5% selection intensity, σp = Phenotypic standard deviation, H^2= heritability in broad sense.

Genetic advances as percent of mean was calculated to compare the extent of predicted advances of different traits under selection, using the formula.

GAM= $\frac{GA}{X} X100$ (Falconer and Mackay (1996). Where: GAM = genetic advances as percent of mean, GA= Genetic advances under selection and X = Mean of population in which selection will be employed.

Results

Analysis of variance

The analysis of variance showed the presence of highly significant ($P<0.01$) differences among genotypes for all traits except plant height, small and medium size tubers (Table 2). In separate comparison of tests vs controls the analysis of variance showed significant ($P<0.05$) differences for all the traits but not for unmarketable tuber yield and very small size tuber in percent. It was also revealed significant ($P<0.05$) differences among controls (check varieties) for all traits except for plant height, average tuber weight, small and large size tubers proportion in percent. It was also observed significant differences among tests (new entries) for all traits except for plant height, small and medium size tubers.

Mean performance of genotypes

Mean and range performance of tuber yield and yield related traits were given in table 2. Days to emergence, days to flower and days to physiological maturity ranged from 11.28 to 21.48, 39.68 to 64.08 and 74.04 to 106.64 days for 105 potato genotypes, respectively. The genotypes also varied for leaf area and stem number per plant ranged from 10.06 to 18.56 cm^2, and 1.67-9.23, respectively. Bulking rate of genotypes ranged from 49.58 to 260.63gm day^{-1} while tuber number per plant, tuber yield per plant and average tuber weight ranged from 7.05 to 38.97, 0.19 to 1.02 kg and 16.36 to 69.62g, respectively. Marketable, unmarketable and total tuber yield of genotypes ranged from 10.81 to 38.99, 0.65 to 9.01 and 13.92 to 41.79 ton ha^{-1}, respectively. Very small size tubers proportion in percent ranged from 9.76 to 60.54, while large size tubers were from 0.17 to 40.59%.

Table 2. Mean squares and their significance for 17 traits of 105 potato genotypes evaluated at Simada during 2016

		Mean squares					
	Block(4)	Treatment (104)	Among control(4)	Among tests(99)	Tests vs Control (1)	Error	CV (%)
Days to emergence	1.36	6.67**	17.96**	5.29**	98.57**	0.76	5.64
Days to flowering	1.76	21.2**	33.56**	19.99**	90.74**	1.51	2.19
Days maturity	51.24	44.62**	15.94*	41.25**	492.03**	3.49	2.02
Leaf area(cm^{2})	0.5	2.21**	2.69**	2.01*	19.11**	0.37	4.48
Stem number per plant	0.16	2.21**	1.86**	2.15**	9.21**	0.25	12.11
Tuber number per plant	1.28	24.86**	10.05**	42.57**	61.99**	0.59	4.92
Tuber yield per plant(kg)	0.002	0.04**	0.015**	0.037**	0.04*	0.003	9.02
Average tuber weight(g)	19.1	149.54**	24.53NS	152.46**	360.15**	12.75	9.18
Marketable tuber yield (t ha^{-1})	6.97	27.94**	11.47*	28.72**	16.83*	2.57	6.76
Unmarketable tuber yield(t ha^{-1})	0.04	1.9**	2.87**	1.86**	0.19NS	0.16	16.63
Total tuber yield(ton ha^{-1})	6.66	27.08**	17.07**	27.55**	20.66**	2.12	5.56
Bulking rate per plot (g/day),	1234.61	1264.29**	879.84**	1238.92**	5313.81**	107.91	7.79
Very small tuber percentage	74.51	137.5**	299.77**	132.06**	26.19NS	37.02	18.59
Large tuber percentage	5.65	77.47**	11.71NS	80.87**	3.23NS	8.95	20.6
Tuber dry matter (%)	0.41	8.68**	2.72*	7.96**	103.73**	0.81	3.47
Specific gravity	0.00007	0.00081**	0.0004*	0.00074**	0.01**	0.00008	0.83
Total starch content(g/100gm),	2.77	32.21**	14.04*	29.26**	396.61**	3.17	13.61

*and**=significant at P<0.05 and P<0.01, respectively, NS=Nonsignificant, CV (%) = coefficient of variation in percent.

Table 3. Mean and range values and estimates of variability components for 17 traits of 105 potato genotypes at Simada in 2016.

Traits	Range	Mean	σ^2g	σ^2e	σ^2p	GCV (%)	PCV (%)	H^2b	GA	GA%
Days to emergence	11.28-21.48	15.46	1.18	0.76	1.9	7	8.95	62.11	1.76	11.42
Days to flowering	39.68-64.08	55.97	3.94	1.51	5.45	3.54	4.17	72.29	3.46	6.20
Days maturity	74.04-106.64	92.27	8.23	3.49	11.72	3.1	3.7	70.22	4.94	5.34
Leaf area(cm^2)	10.04-18.56	13.55	0.34	0.37	0.74	4.28	6.35	45.95	0.81	5.99
Stem number per plant	1.67-9.23	4.18	0.39	0.25	0.64	14.8	19.1	60.94	1	23.98
Tuber number per plant	7.05-38.97	15.67	4.85	0.59	5.44	14.00	14.9	89.15	4.27	27.24
Tuber yield per plant(kg)	0.19-1.02	0.6	0.007	0.003	0.01	13.3	16.7	70.00	0.14	23.99
Average tuber weight(g)	16.36-69.62	38.9	27.36	12.75	40.1	13.4	16.3	68.23	8.88	22.83
Marketable tuber yield (t ha^{-1})	10.81-38.99	23.7	5.07	2.57	7.64	10.6	11.7	66.36	3.77	15.98
Unmarketable tuber yield(t ha-	0.65-9.41	2.45	0.35	0.16	0.51	24.1	29	68.63	1	40.89
Total tuber yield(ton ha^{-1})	13.92-41.79	26.16	4.99	2.12	7.11	8.57	10.2	70.18	3.84	14.75
Bulking rate per plot (g/day),	49.58-260.63	133.26	231.27	107.91	339.18	11.41	13.82	68.18	25.75	19.32
Very small tuber percentage	9.76-60.54	32.73	20.09	37.02	57.12	13.7	23.1	35.17	5.47	16.7
Large tuber percentage	0.17-40.59	14.52	13.7	8.95	22.65	25.5	32.8	60.49	5.92	40.77
Tuber dry matter (%)	18.62-31.28	26.05	1.6	0.81	2.38	4.6	5.62	67.23	2.13	7.77
Specific gravity	1.02-1.15	1.07	0.0002	0.00008	0.00023	1.3	1.86	86.96	0.04	3.33
Total starch content(g/100gm),	1.14-27.19	13.09	5.8	3.17	8.98	19.2	23.8	64.59	3.97	31.59

Key: σ^2g, σ^2e, σ^2p= genotypic, error and phenotypic variances and GCV, PCV=genotypic and phenotypic coefficient of variation, H^2b, GA, GA%= Broad sense heritability, genetic advance and genetic advance as percent of mean respectively.

Estimates of variability components

Phenotypic and genotypic coefficient of variations, heritability and genetic advance

Analysis of genetic variability components like genotypic and phenotypic variance, genotypic and phenotypic coefficient of variability, heritability in broad sense and genetic advance as percentage of mean for 17 traits are presented in table 3. Genotypic and phenotypic coefficient of variation ranged from 1.3-25.5 and 1.86-32.8%, respectively. Unmarketable tuber yield and large size tubers as percentage were the highest for both GCV and PCV values. In addition, very small size tubers distribution as percentage (23.1%) and starch content in percent (23.8%) were also high in phenotypic coefficient of variation. Specific gravity was the lowest for both genotypic and phenotypic coefficient of variation.

The estimated heritability in broad sense ranged from 35.17 (very small tuber size percentage) to 89.15 (tuber number per plant) while genetic advance as percent of mean was ranged from 3.33 (specific gravity) to 40.89% (unmarketable tuber yield). For the other traits heritability was estimated in the range between 60.94 to 74.09% for days to emergence, days to flowering, days to maturity , stem number per plant, tuber yield per plant, average tuber weight, marketable tuber yield, unmarketable tuber yield, total tuber yield, bulking rate per plot, large tuber percentage, dry matter and total starch content in percent. The lowest heritability was obtained from leaf area (45.95) and very small tubers proportion in percent (35.17). Genetic advance as percent of mean (GAM) was ranged from 3.33 to 40.89%. The maximum genetic advance as percent of the mean was obtained from unmarketable tuber yield (40.89%), while the lowest was from specific gravity (3.33%).

Discussion

The analysis of variance observed significant variation among genotypes, even in separate comparison of tests and control alone and tests vs control tell the presence of adequate variations that allow applying selection breeding to obtain high yielding variety which combine other desirable traits to improve the yield of potato in the study area and similar agro ecologies. Similar finding reported by Addisu *et al*. (2013) the presence of significant differences among nine regional and national released varieties for days to emergence, days to flowering, and days to maturity, number of stem per plant, tuber number per plant, tuber yield and big tubers proportion as percentage. Abraham *et al*. (2014) found highly significant difference for all pheonological traits, stem per plant, tuber yield, tuber per plant, and big tubers proportion as percentage. Wassu and Simret (2015) evaluated 26 potato genotypes at Dire Dawa tolerant to heat stress and reported significant differences among genotypes for tuber yield, yield related traits and tuber dry matter content. Habtamu *et al.* (2016) reported the existence of significant differences among evaluated 16 improved varieties and two farmers' cultivars for tuber yield and yield related traits as evaluated at three locations of eastern Ethiopia.

A wide range of variation was noticed in all the traits among the genotypes which indicated that diverse genotypes were included in the study. This may provide sufficient scope for further selection and improvement on these traits. A total of 5, 71 and 77 new entries (genotypes) showed early emergence, flowering and maturity than the recent released variety (Belete), respectively. The three new entries viz. 20SET4.2, 20SET4.1, and 16SET5.5 which were introduced as drought tolerant genotypes had total tuber yield advantage of 51%, 41%, and 35 % respectively, over the best check (Belete). The genotypes also had wide range of variation for very small and large tubers size proportion. Similar findings were reported by, Addisu *et al.* (2013) who observed wide range of variations among potato genotypes for tuber number per plant, big size tubers proportion as percentage, days to flowering, days to 90% maturity, number of stems per plant, and tuber yield per plant. Wassu and Simret (2015) reported wide range of variations among 26 potato genotypes for total tuber yield, marketable and unmarketable tuber yield, tuber dry matter and starch content evaluated at lowland area. Habtamu *et al.* (2016) reported variations among 18 potato cultivars for total tuber yield, marketable tuber yield, unmarketable tuber yield, average tuber weight and large tuber number as percent at three locations of eastern Ethiopia

According to Deshmukh *et al.* (1986) phenotypic and genotypic coefficient of variation values greater than 20% are regarded as high, whereas values less than 10% are considered to be low and values between 10% and 20% to be moderate. Based on this demarcation, unmarketable tuber yield and large size tubers as percentage had high genotypic and phenotypic coefficient of variation, while very small size tubers distribution as percentage and starch content in percent exhibited high phenotypic coefficient of variation. Moderate GCV and PCV were found for stem number per plant, tuber number per plant, tuber yield per plant, average tuber weight, marketable tuber yield, and tuber bulking rate. In addition, very small size tubers percentage and total starch content in percent had moderate genotypic coefficient of variation, hence this result may allow implementing selection breeding to improve these traits. In agreement with this study, Addisu *et al.* (2013) reported moderate genotypic and phenotypic coefficients of variation for tuber yield and number of stems per plant.

All phenological traits, leaf area and specific gravity had low GCV and PCV values. This suggested selection based on phenotype expression of genotypes might not possible due to the highest masking of environmental factors on the expression of these traits. Addisu, *et al.*, (2013) also found low phenotypic and genotypic coefficients of variation for days to maturity.

In the present study phenotypic coefficient variation was generally higher than genotypic coefficient variation values in all traits, implies influence of environmental factors on the expression of traits. This result was similar with the results reported by Sattar *et al.* (2007). Addisu, *et al.* (2013) also stated phenotypic coefficients of variation were found to be higher than genotypic coefficients of variation for all traits. Singh *et al.* (2013) observed sufficient variability in potato genotypes and overall values of PCV were greater than those of GCV. Relatively low difference between GCV and PCV were observed for days to maturity, tuber number per plant and specific gravity, this indicated less environmental influence in the trait. This is in accordance with Tekalign (2009) recorded the lowest GCV and PCV for specific gravity.

Estimates of heritability in broad sense were considered according to Pramoda and Gangaprasad (2007) as heritability estimates low (<40), medium (40-59), moderately high (60-79) and very high (≥ 80%). Based on this category very high heritability estimates were computed for tuber number per plant (89.15%) and specific gravity (86.96%), suggested the selection of genotypes with high mean values of these traits may lead to the improvement of the mean values in the selected genotypes for traits. The estimated heritability in broad sense could be categorized as moderately high heritable for days to emergence, days to flowering, days to maturity , stem number per plant, tuber yield per plant, average tuber weight, marketable tuber yield, unmarketable tuber yield, total tuber yield, bulking rate per plot, large tuber percentage, dry matter and total starch content in percent. Getachew *et al.* (2016) reported high heritability (> 60%) for marketable tuber yield, total tuber yield, average tuber weight, and tuber dry matter. Abraham *et al.* (2014) found high heritability estimates for days to emergence, days to flowering, and days to maturity, tuber number per plant, tuber yield per plant, and stem number per plant. Regassa and Basavaraja (2005) also reported moderate heritability for total weight of tuber per plant, total tuber yield, and tuber dry matter content. According to Singh (2001) if heritability of a trait is very high (≥ 80%), selection for such traits could be fairly easy, since there would be close correspondence between the genotype and the phenotype due to the relative small contribution of the environment to the phenotype.

Medium heritability value was calculated for leaf area while low heritability value obtained for very small tubers proportion in percent. This showed that the environmental effect constitute a major portion of the total phenotypic variation. Singh (2001) also stated for traits with low heritability (≤ 40%) selection may be greatly difficult due to the masking effect of the environment.

In the current study, the extent of heritability for most of the traits was moderate to very high, which may be attributed due to uniform environment where the genotypes grown. In general, the high and moderate heritability estimates for most of the characters suggested the higher chance of improving these traits through Selection.

Genetic advance as percent mean (GAM) was categorized into low (≤ 10%) moderate (10-20%) and high (≥ 20%) as established by Johnson *et al.* (1955). Therefore, stem number per plant, tuber number per plant, tuber yield per plant, average tuber weight, unmarketable tuber yield, large size tubers proportion and total starch content had high GAM. This suggested to the improvement of these traits in genotypic value for the new population compared with the base population under one cycle of selection is rewarding. Genetic advance under selection (GA) refers the improvement of traits in genotypic value for the new population compared with the base population under one cycle of selection at a given selection intensity (Singh, 2001). Similar findings by Tripura *et al.* (2016) reported high GAM for number of tuber per plant, weight of tuber per plant, and single tuber weight during evaluation of 23 potato genotypes.

Days to flowering, days to maturity, leaf area, dry matter and specific gravity showed low GAM. This suggested that the improvement of these traits in genotypic value for the new population compared with the base population under one cycle of selection is not rewarding. Addisu, *et al.* (2013)) reported low genetic advance as percent of mean for days to flowering and days to maturity while Sattar *et al.* (2007) found low GAM for tuber dry matter.

The present study revealed that relatively high heritability coupled with high expected genetic advance as percent of mean for tuber number per plant, tuber yield per plant, stem number per plant, average tuber weight, large tuber percentage, and total starch content. Therefore, these traits could be improved more easily than other traits by the selection of genotypes with high mean values. On the other hand, high heritability associated with medium predicted genetic advance were obtained for days to emergence, marketable tuber yield, bulking rate and total tuber yield. This indicated that these traits were highly heritable and selection of high performing genotypes is possible to the improvement of the traits. Most likely the heritability of these traits is due to additive gene effects and selection may be effective for these traits in early generations. Synonymous findings by Regassa and Basavaraja (2005) reported higher heritability estimates were coupled with high genetic advance as percent of the mean for number of main stem per plant, number of large sized tuber, total weight of tuber per plant, marketable and total tuber weight. Getachew *et al.* (2016) also reported high heritability coupled with high genetic advance as percent of mean for total tuber yield, marketable tuber yield and average tuber weight. Singh (2008) found high heritability and genetic advance for marketable tuber yield, total tuber yield, weight of tubers per plant. High heritability estimates along with high genetic advance as percentage of mean are more useful in predicting yield under phenotypic selection than heritability alone (Mondal,2003). Memon *et al.* (2005) stated as high heritability and high genetic advance associated with quantitative traits have great importance in selection of genotype in early generations. Effective selection may be done for the traits having high heritability accompanied by high genetic advance which is due to the additive gene effect Panse (1957). Moderately to high or low heritability coupled with low expected genetic advance as percent of the mean were found in days to maturity, days to flowering leaf area, and specific gravity. The traits that had low heritability coupled with GAM values suggested the scope of improvement using selection is low due to the high influence of environment that limit the improvement to be made based on phenotypic expression of genotypes. The association of high heritability with low predicted genetic advance was reported to be attributed by predominant effects of non-additive gene (Ahmed *et al.*, 2007. Panse (1957) also reported that low heritability accompanied with genetic advance is due to non-additive gene effects for the particular trait and would provide less scope for selection because of the influence of environment.

In conclusion, the significant differences among genotypes for almost all traits implies the presence of adequate variations among genotypes that allow appropriate breeding methods to develop varieties that combine high yield with desirable traits. Moreover estimates of variability components also exhibited moderate to high for most of the traits. This also suggested that selection breeding is applicable to improve these traits which might provide the higher chance of increasing the mean values of generations. Therefore, the current study results showed that the presence of exploitable variations among the introduced drought tolerant potato genotypes in which selection breeding is possible for the study area and similar areas with similar potato production constraints.

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Response of Improved and Local Potato (*Solanum tuberosum* L.) Cultivars to Different Levels Nitrogen Fertilizer application at Haramaya, Eastern Ethiopia

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Abstract

A field experiment was conducted on a research field of Haramaya University during the 2012 main cropping season to determine the relative agronomic and tuber quality performances of potato varieties in response to nitrogen (N) application. The treatments consisted of four N rates (0, 55, 110 and 165 kg N ha^{-1}), and two improved (Bubu and Zemen) and three local (Batte, Daddafa and Jarso) varieties. The experiment was laid out as RCBD with a factorial arrangement and replicated three times. Plot size was 4.5 m x 3.6 m (16.2 m^2) accommodating six rows of plants at the spacing of 75 cm between ridges and 30 cm between plants. Net plot area was 3 m x 3 m (9 m^2). The results revealed that increasing the rate of N from 0 to 55 kg N ha^{-1} significantly increased most of the measured parameters. However, increasing N beyond this level did not affect most of the parameters. Variety also significantly influenced many parameters within these N rates; the improved variety Bubu and local variety Daddafa showed relatively promising performance during the experiment. However, the yields obtained from these varieties were much less than the expected potential productivity common on research fields. In addition, the response of all varieties to the increased rates of nitrogen application was not also found to be robust. This could be due toan environmental stress observed as a main factor among others, namely frost, which occurred just before maturity may account for the underperformance and less response of the varieties. The interaction effects of N and variety were not significant on all parameters. Positively and highly significant associations were found for a number of the measured parameters. In conclusion, the results revealed that the optimum performances of all varieties occurred at the N rate of 55 kg N ha^{-1}. In addition, improved variety Bubu, followed by Zemen, was superior to the other varieties in terms of tuber productivity.

Keywords: Varieties, Yield, Nitrogen Level, Growth

Introduction

Research findings have indicated that potato could be one of the most important crops to be introduced in the area where the population experiences recurrent malnutrition due to heavy dependence on cereal crops and poor crop productivity provided that appropriate agronomic practices are applied (Zelalem*et al.*, 2009). Potato is regarded as a high-potential food-security crop because of its ability to provide a high yield of high-quality product per unit input with a shorter crop cycle (mostly < 120 days) than major cereal crops like maize (Hirpa*et al.*, 2010).It has been stated by John J. Burke (2017) that at least six major potato roles can be assigned to the potato tuber. These include hunger-relieving crop, food (either fresh, processed), animal food, propagule (from which to produce the next crop), feed stock in industry for starch and alcohol, an item of commerce, and a resource of biodiversity. He also detailed that potatoes are grown and eaten in more countries than any other crop; they are grown in all the continents except Antarctica. In the global economy they are the fourth most important crop in total production and the fourth largest contributor to human caloric consumption, after the three cereals, rice, wheat and maize.

About more than 1.13million farmers are potato growers in Ethiopia; and this crop added 29.84% of the area to the total root crop, and contributed 21.24% to the total root crop production (CSA, 2017/2018). Hirpa *et al.*(2010) indicated that potato is grown in four major areas in Ethiopia. These areas include the central, the eastern, the north-western and the southern regions (mainly located in the Southern Nations', Nationalities' and Peoples' Regional State and partly in the Oromia region).In this study they also stated that these areas together cover approximately 83% of the potato farmers.

Mulatu *et al.* (2008) pointed out that potato is the second most advantageous crop next to khat (*Chataedulis*) in supporting farmers' welfare with 759% increase in income over sorghum (*Sorghum bicolour* (L.) Moench) which is the main staple cereal crop grown in Hararghe. Compared to the other areas of potato production, this area is characterized by export market oriented production particularly to Djibouti and Somalia (Hirpa *et al.*, 2010). Similarly, Mulatu*et al.* (2005) stated that the development of potato culture in Hararghe, like other vegetables, is due to the presence of an export and cross-border market outlet to Djibouti and Somalia; it is also due to the presence of a domestic market in the major urban settlements of Hararghe, including Dire Dawa, Harar, Jigjiga, Chiro and several other towns. Most farmers grow local potato varieties namely, Batte, Jarso, Samune, Daddafa, Mashenadima, etc. throughout the year using irrigation and rainfalls (Anonymous, 2011). However, Mulatu *et al.* (2005) reported that some farmers targeted by research and extension as well as those involved in nongovernmental organization (NGO) seed programmes have access to improved varieties released by Haramaya University. Despite the use of local varieties, the productivity of potato in this area is equivalent to the productivity in the central area; this might be due to good farm management practices triggered by farmers' market orientation.

The optimal response to N fertilizer application differs by cultivar (Kleinkopf *et al.*,1981; Johnson *et al.*, 1995) and soil type. Similarly, the other finding indicated that nutrient elements efficiency is the relative yield of one genotype in a poor soil as compared to its yield in a favourite nutritional condition. Maximum efficiency of nutrient element use is obtained while its concentration is near to critical level, because without excessive amounts of element in plant tissues, the highest yield is gained. In view of that, the release of new potato cultivars requires additional revision to develop best management recommendations for N fertilization of potato and for optimization of tuber yield and quality (Saeidi *et al.*, 2009).

Nitrogen is the mineral nutrient most commonly deficient in agricultural soils. As a result, in developed countries, farmers apply relatively high rates of N fertilizers. Soil-plant system inefficiencies prevent complete utilization of the N, leaving residual N in the soil, which is a waste of natural resources and cause for environmental concern (Hopkins *et al.*, 2008). Worldwide, crops do not directly utilize about half of the applied N and the overall N use efficiency has declined with increasing N fertilizer use (Dobermann, 2005). On the other hand, as compared to the developed countries, in developing countries such as Ethiopia, Kenyaand Uganda, the amounts of fertilizers applied to the potato crop are very low. For example, in a study conducted by Gildemacher *et al.* (2009), the amounts of FYM, N, and phosphorus applied to potato crop were estimated to be only 4 t ha^{-1}, 43 kg N ha^{-1}, and 101 kg P ha^{-1} in Kenya, 3 t ha^{-1}, 30.6 kg N ha^{-1}, and 33.4 kg P ha^{-1} in Ethiopia, and 2.2 t ha^{-1}, 37.6 kg N ha^{-1}, and 46.9 kg P ha^{-1} in Uganda, respectively.

A blanket recommendation of 110 kg N ha^{-1} (165 kg urea ha^{-1}) and 90 kg P_2O_5 ha^{-1} (195 kg DAP ha^{-1}), has been promoted in Ethiopia for a long time, without any formulation of the amount of farmyard manure to be used for production of the crop (Institute of Agricultural Research, 2000).An experiment conducted at Haramaya on clay soil indicated that application of 87 kg N ha^{-1} and 46 kg $P_2O_5ha^{-1}$ is needed for optimum potato production(Getu, 1998). Hence, fertilizer requirement varies across locations due to reasons such as difference in soil types, nutrient availability of the soil, economic factors of the area, moisture supply and variety(Zelalem *et al.*, 2009). Although many potato varieties have been released in the country, there is lack of clear information regarding N fertilizer requirement, management of the individual cultivar for optimum tuber yield. This necessitates a continuous research towards the establishment of appropriate fertilizer rates for the newly released varieties for specific location. According to Atkinson *et al.* (2003), newer potato cultivars are becoming more widely grown because of improved characteristics such as earliness, yield, quality, and storability, and increased resistance to insects, pathogens, and other environmental stresses. Therefore, this experiment was carried out with the objective of evaluating the response of improved and local potato varieties to different rates of N fertilizer at Haramaya area.

Materials and Methods

Description of the study site

The experiment was conducted during the 2012 GC main growing season under rain-fed condition at research field on the main campus of Haramaya University. Haramaya is located at 9°26'N latitude, 42°30'E longitude and at an altitude of 1980 meters above sea level. The site received mean annual rainfall of 780 mm, with the mean minimum and maximum temperatures of 8.25°C and 24.4°C, respectively(Mohammed *et al.* 2013). The soil of the experimental site is a well drained deep alluvial with a sub-soil stratified with loam and sandy loam (Tamire, 1973). Analysis of the chemical and physical properties of the soil indicated that it has organic carbon content of 1.15%, total N content of 0.11%, available phosphorus content of 18.2 mg kg^{-1} soil, potassium content of 0.65 cmol kg^{-1}soil (255 mg K kg^{-1} soil), pH of 8.0, and percent sand, silt, and clay contents of 63, 20, and 17, respectively (Simrat, 2010). These results indicate that the soil is low in organic carbon and total N, high in exchangeable potassium, and medium in available phosphate (Landon, 1991; Ryan *et al*, 2001).

Description of experimental material

Two improved potato varieties (Zemen and Bubu) that were released by Haramaya University and three local varieties (Daddafa, Jarso and Batte)were used. Bubu was released in 2010 (Tekalign, 2011). Itis recommended for the highlands of eastern and western Hararghe zones with an altitude ranging from 1650-2330 meter above sea level. Zemen was released in 2001 (Ethiopian Agricultural Research Organization, 2004).It is adapted to east and west Hararghe with an altitude of 1700-2000 meter above sea level that receives an annual rainfall of 700-800 mm.

Field experiment set up

The experiment was laid out in randomized complete block design (RCBD) in a factorial arrangement with four treatments and three replications. Treatments were 0, 55, 110 and 165 kg N ha^{-1}, assigned to each plot randomly. The land was cultivated by a tractor and pulverized by human labour. The number of plots was 60, and the size of each plot was 4.5 x 3.6 m wide.

Soil sampling and analysis

Soil samples were taken randomly in a W-shaped pattern of the entire experimental field before planting. Five samples were taken using an augur from each arm of the W-shaped lines to the depth of about 0-30 cm from the top soil layer, and combined to a composite sample. This composite was air-dried, pounded and sieved through a 2 mm sieve. From this mixture, a sample weighing 1 kg was prepared, and finally analyzed. Soil pH was determined from the filtered suspension of 1:2.5 soils to water ratio using a glass electrode attached to a digital pH meter (Page, 1982). Soil texture was determined by modified Bouyoucos hydrometer method as described by Singh (1980).The sample was analyzed for total N, available phosphorus, potassium, and organic carbon contents. Organic carbon content of the soil was determined based on oxidation of organic carbon with acid dichromate medium following the Walkley and Black method as described by Dewis and Freitas (1970). Total N was determined using Kjeldhal method (Jackson, 1975). Available phosphorus was determined by extraction with 0.5 M $NaHCO_3$ according to the methods of Olsen *et al.* (1954), and potassium was determined with a flame photometer after extracting exchangeable K from the soil with 0.5 N Ammonium-acetate at pH 7 (Hesse, 1971).

Planting and fertilizer application

Medium-sized and well sprouted potato tubers were planted on the ridges at a spacing of 30 cm between plants and 75 cm between rows. The tubers were planted at a depth of 10cm and covered with soil (Ngungi, 1982). One row consisted of 12 plants, and one plot consisted of 6 rows. The spacing between plots and blocks were 1 m and 1.5 m, respectively. Net plot area was 3 m x 3 m (9 m^2). The plants were fertilized equally with Urea (46% N) as source of Nitrogen and triple superphosphate (46% P_2O_5) as source of phosphorus for all the plots. Nitrogen (110 kg N ha^{-1}) in the form urea, was applied at the specified rates in three splits (one fourth at plant emergence; half of it two weeks after emergence; and one fourth at the initiation of tubers/start of flowering) as topdressing. However, triple super phospate (46% P_2O_5) was applied as basal fertilizer at the rate of 90 kg P_2O_5 ha^{-1}at planting.

Other cultural activities such as weed control, earthing-up and fungicide application were equally applied for the whole experimental area. Controlling of weeds was performed by hoeing and by hand pulling/uprooting. Earthing-up was done to prevent exposure of tubers to direct sunlight, for promoting tuber bulking and for easily harvesting. Fungicide, Ridomil MZ 65% WP at a rate of 1.5 kg/ha which is diluted at a rate of 40 g per 20 litre water, was sprayed once a week for the control of potato late blight (*Phytophthora infestans*). It was sprayed two times during wet season when the plants were at vegetative growing stage. Fungicide, Ridomil MZ 65% WP (1.5 $kgha^{-1}$which is diluted at a rate of 40 g per 20 litre water) was sprayed two times once a week to control potato late blight (*Phytophthora infestans*).

Data collection

All data for growth parameters were taken up on randomly selecting 5 plants from central rows in each plot. Days to flowering was recorded at about 50 percent flowering of plant population in each plot. Days to maturity was recorded when 50 percent of the plants of different treatments were ready for harvest as indicated by senescence of the haulms. Plant height was determined by measuring the height from the base to the apex of plants. To determine leaf area, plants were selected at 50 percent flowering; then leaf area index was estimated from individual leaf length via the formula developed by Firman and Allen (1989).

$\log_{10}$ (leaf area in cm^2) = 2.06 x $\log_{10}$ (leaf length in cm) – 0.458.Leaf area index was obtained by dividing the value of leaf area by the area of land occupied by the plant using the formula:Leaf area index (LAI) = LA_mx N /A. Where: LA_m=mean leaf area; A=area (cm^2) occupied by one plant in the cropping area; N=number of leaves on the plant

Number of main stems per hill was taken (when plants about to initiate flower bud) by counting the number of stems emerging from each tuber (per hill) from below the soil. The weight of fresh aboveground biomass was measured just at flower initiation before tuber set. Then, oven-dried at about 65^0C until constant weight was obtained, and dry weight was determined. Underground fresh and dry biomass was determined just before senescence by weighing both fresh and dry weight (oven-drying similar to aboveground biomass). Finally, total fresh and dry biomass was calculated from the sum of shoot and underground biomasses.

Marketable tuber yield was calculated by taking the average weight of tubers (at harvest) from plants in the central rows of each plot. To do this, stand count per plot was also taken to enable us calculating yields per hectare. Tubers free from diseases, insect pests, and greater than or equal to 25 g in weight were considered as marketable, while diseased and small-sized (< 25 g) tubers were considered as unmarketable. Unmarketable tuber yield was recorded at the same time. Afterwards, the total tuber yield per plot was recorded by adding up the weights of marketable and unmarketable tubers. Similarly, both marketable tuber number and unmarketable tuber number were taken at harvest by counting, and then total tuber number was obtained by adding up the number of marketable and unmarketable tubers. At the same time, mean tuber weight was determined at harvest by dividing the weight of all tubers by the total number of tubers. Finally, the proportional weight of tubers sizes were categorized into small (25-39 g); medium (40-75 g), and large (>75 g) according to Lung'aho *et al.* (2007). Then each of these categories was counted, and the proportion of the weight of each tuber category was expressed as a percentage. Harvest index was determined from 5 randomly taken plants in the central rows of each plot just at physiological maturity, washed with water, and sliced into thin (about 3 mm) pieces.

The sliced tubers were pre-dried in the sun by thinly spreading in an open air to dissipate excess moisture, and the partially dried tubers were wrapped up in paper and dried overnight in an oven at about 65^oC until constant weight was obtained.

Haulms, leaves, and all other plant parts were also dried in the same way. Then, harvest index was computed by dividing the dry weight of the tubers by the dry weight of the total biomass. In other ways it is the ratio of economic yield to biological yield which characterizes the movement of dry matter to the economic part of the plant. Tubers specific gravity was determined by the weight in air/weight in water method. Five kg tubers of all shapes and sizes were randomly taken from each plot. The selected tubers were washed with water, first weighed in air and re-weighed by suspending in water. Finally, specific gravity was calculated via the formula (Kleinkopf*et al.*, 1987):

$$\text{Specific gravity} = \frac{\text{Weight in air}}{(\text{Weight in air} - \text{Weight in water})}$$

Tuber dry matter content was determined based on five medium-sized fresh tubers which wererandomly taken at harvest from each plot. The tubers were weighed, sliced and dried overnight in an oven at about 65°C until a constant weight was obtained. Finally, the dry matter percentwas calculated according to Williams and Woodbury(1968) as follows.

$$\text{Dry matter (\%)} = \frac{\text{Wight of sample after drying (g)}}{\text{Initial weight of sample (g)}} \times 100\%$$

Plant tissue analysis was done by taking leaf samples from plants just before the start of tuber initiation (when plants about to initiate flower bud). Sixty fully grown mature leaves with petioles were randomly taken from the fourth nodal insertion from top of the plant (middle of stem) from each plot. The leaf samples were dried at about 65°C to constant weight, ground, and analyzed for total N by the modified Kjeldhal method as described by Jackson (1975).

Data analysis

Datawere subjected to analysis of variance (ANOVA) using the Generalized Linear Model of the SAS statistical package (SAS, 2002) version 9.1. All significant pairs of treatment means were compared using Least Significant Difference (LSD) test at 5% level of significance. Correlation analysis was done to detect linear relationship between parameters where needed.

Results and Discussion

Effects of N and variety on growth parameters

Effect of N and its interaction effect with each variety did not significantly influence days to flowering and days to physiological maturity. However, the main effects of variety highly significantly influenced days to flowering and days to physiological maturity. The results revealed that prolonged days to flowering (about 51 days) and days to maturity (about 109 days) were observed for Batte (local variety). However, earlier dates of flowering and maturity were observed for the improved varieties (Bubu and Zemen) as well as the local varieties Daddafa and Jarso compared to the local variety Batte (Table 1).The observed differences in days to flowering and days to physiological maturity of these cultivars may be due to their inherent genetic characteristics. This difference could be due to certain factors (Shunka *et al.*, 2016), some of which genetic, agro-ecological variation, soil fertility status, etc.

A positive and highly significant association between days to flowering and days to physiological maturity was observed. In line with this study, Birhuman and Kang (1993) reported a medium association between days to flowering and days to physiological maturity.

Plant height as well as leaf area index were significantly and highly significantly affected respectively, by the main effects of N and variety. However, there was no significant effect regarding the interaction of the two factors on the above parameters. As shown in Table 1 increasing the rate of N application from 0 to 55 kgha,$^{-1}$ increased plant height by 15% and leaf area index by 29%. However, increasing the rate of N supply beyond this level did not change the magnitude of both parameters. On the contrary, Anabausi *et al.* (1997) reported that application of N increment (0, 125, 250, or 350 kg Nha^{-1}) on potato resulted in a significantly increase in plant height. Also, Jatav*et al.* (2017) stating that application of N showed significant effect on all the growth parameters up to 150 kg ha^{-1}.Bubu and Daddafa produced significantly taller plants than the other three varieties. Batte, Bubu, and Daddafa had significantly higher leaf area index than Jarso and zemen.

Kleinkopf *et al.* (1981) and Dwelle *et al.* (1981) reported that a high N supply is important for rapid leaf expansion and for obtaining a LAI between 4 and 6, a value considered necessary for high tuber yields of potato.However, in this study leaf area index of 4.00 or above was attained by neither of the varieties. Consistent with this proposition, Marschner (1995) stated that, as a rule, the crop yield increases until an optimal value in the range of 3-6 is reached, the exact value depending on plant species, light intensity, leaf shape, leaf angle and other factors. The author further explains that, at a high LAI, mutual shading usually becomes the main limiting factor, and when the water supply is limited, however, drought stress and corresponding negative effects, particularly at the sink sites, can decrease the optimal LAI to values far below those resulting from mutual shading. Batte, Bubu and Daddafahad significantly higher leaf area index than Jarso and Zemen. In this study, plant height positively and highly significantly correlated with leaf area index. Consequently, increase in these parameters may result in increased yield (Tables 1&3).

This reveals that plants manufacture their food on the canopy and later be translocated to the other parts of the plant to be utilized or stored. According to Lalonde *et al.* (2004), Sugars and amino acids are generated in plants by assimilation from inorganic forms; and these assimilated forms cross multiple membranes on their way from production sites to storage or use locations.Hence, both the above parameters contributed to the yield increment. The effect of N as well as the interaction effect of variety with N supply did not significantly affect the number of main stems produced per hill which is contrary to Kołodziejczyk (2014). However, highly significant differences were observed among the varieties. Related to the present study, the absence of N effect could be due to the case that the trait responsible for stem number was not influenced much by mineral nutrition. Becausestem number is the indication of storage condition, physiological age of the seed variety and tuber size(Assefa, 2005).The highest number of main stems per hill was achieved by Bubu (improved variety) whereas the lowest was attained by Jarso (local variety) as in Table 1.Thus, number of main stem of Bubu exceeded that of Jarso by about 100%.

Consistent with the results of Morena*et al.* (1994), the number of stems per hill was influenced by variety. Association of stem number with marketable tuber yield and total tuber yield was positive and highly significant. In agreement with the result of this study, Allen (1978) stated that an increase in stem number per hill resulted in increased total and graded tuber yields. On the other hand, Yibekal (1998) reported that there was weak association between stem number and tuber yield. Moreover, Goodwin *et al.* (1969) reported absence of relationships between yield and the number of main stems for the same above ground density; which implies that tubers with many main stems and those with single/or few main stems have produced similar yields.

Table 1.The main effects of N and variety on days to flowering and physiological maturity, plant height (cm), leaf area index, and number of main stems per hill.

Treatment	Parameters				
Nitrogen($kgha^{-1}$)	days to flowering	days to physiological maturity	plant height	leaf area index	number of main stems per hill
0	48.67	106.67	54.80^{b}	2.17^{b}	5.85
55	46.53	104.53	62.92^{a}	2.79^{a}	6.63
110	46.80	104.80	60.99^{a}	2.89^{a}	6.04
165	46.27	104.27	61.52^{a}	2.97^{a}	6.35
Significance Level	ns	ns	*	*	ns
LSD (5%)	--	--	5.51	0.57	--
Variety					
Batte	51.08^{a}	109.08^{a}	57.35^{b}	2.89^{a}	6.47^{b}
Bubu	45.00^{c}	103.00^{c}	65.02^{a}	3.40^{a}	8.38^{a}
Daddafa	46.58^{bc}	104.58^{bc}	65.33^{a}	2.94^{a}	6.00^{b}
Jarso	47.67^{b}	105.67^{b}	54.13^{b}	2.11^{b}	4.10^{c}
Zemen	45.00^{c}	103.00^{c}	58.45^{b}	2.19^{b}	6.13^{b}
Significance Level	***	***	**	***	***
LSD (5%)	2.31	2.31	6.16	0.64	1.36
CV (%)	5.9	2.7	12.4	28.5	26.5

NB: Means within a column followed by the same letter are not significantly different at 5% level of significance; ns=non-significant; *=significant at 5%; **=significant at 1%; ***=significant at 0.1% probability levels.

Fresh biomass was not significantly affected by the effect of N. Similarly, the interaction effect of N and variety did not significantly affect all of the components of the shoot and underground biomass. But, shoot dry biomass was significantly affected by the main effect of N while the rest of all components of the biomass were highly significantly affected by the main effects of N and variety. In agreement with this result, Assefa (2005) revealed that increasing N application from 0 to 55 $kgha^{-1}$ increased underground fresh and dry biomass yield, total fresh biomass, and shoot dry biomass. However, increasing the N supply beyond this level did not influence any of the biomass components produced by the potato crop. Besides, Millard and Marshall (1986) and Saluzzo *et al.* (1999) reported that N fertilization increased dry matter accumulation in canopy, underground biomass, and total dry biomass, respectively, from 656.7 to 880.0 g/hill, 919 to 1226 g/hill, 51.89 to 65.11 g/hill, 164.1 to 218.6 g/hill, 216.0 to 283.6 g/hill. In line with this result, the finding of Blumenthal *et al.* (2008) showed that N is often the most limiting factor in crop production; hence, application of Nfertilizer results in higher biomass yields and protein yield and concentration in plant tissues. In addition, Barakat *et al.* (1991) noticed that potato shoots fresh weight was increased with each N dose increment.The highest shoot fresh biomass yield was produced by Bubu and Daddafa, followed by Batte and Zemen while the lowest was produced by Jarso. Thus, the shoot fresh biomass produced by the improved variety Bubu exceeded that of Jarso, Batte and Zemen, by 122, 50, and 43%, in the order listed here. Similarly, the highest underground fresh biomass yield was produced by Bubu, followed by Daddafa and Zemen.

The lowest underground fresh biomass yield was produced by Batte and Jarso. Thus, Bubu produced 59, 43, and 42% more underground fresh biomass than Jarso, Zemen, and Batte, respectively.Bubu and Daddafa produced the highest total fresh biomass yield, followed by Zemen and Batte. However, Jarso produced the lowest total fresh biomass yield. Total fresh biomass yield produced by Bubu exceeded that produced by Jarso, Batte, and Zemen by 73, 44, and 25%, respectively (Table 2).However, in terms of dry biomass production, Bubu exceeded all varieties. Thus, the shoot dry matter produced by Bubu was the highest, followed by that produced by Daddafa and Batte. Jarso and Zemen had the lowest shoot dry biomass production. The shoot dry matter produced by Bubu exceeded that produced by Jarso, Zemen, Batte, and Daddafa by 131, 79, 42, and 26%, in the order listed here. Similarly, the underground dry biomass yield produced by Bubu was superior to the underground dry biomass yields produced by all other varieties, and its underground dry biomass yield exceeded the underground dry biomass yields produced by Jarso, Batte, Daddafa, and Zemen by 127, 67, 53, 40%, in the order listed here. The varieties also differed significantly in total dry biomass yield produced per hill. The highest total dry biomass yield was produced by Bubu, closely followed by Batte, Daddafa and Zemen. The lowest total dry biomass yield was produced by the local variety Jarso. Thus, total dry biomass yield produced by Bubu exceeded those produced by Jarso, Batte, Zemen, Daddafaby 128, 61, 48, 46%, respectively (Table 2). This indicates that Bubu has the best performing potential at the study area condition.

Table 2.The main effects of N and variety on shoot and underground fresh biomass(g/hill), and shoot and underground dry biomass(g/hill).

Treatment	Parameters					
	Fresh biomass			Dry biomass		
Nitrogen($kgha^{-1}$)	shoot fresh biomass	underground fresh biomass	total fresh biomass	shoot dry biomass	underground dry biomass	total dry biomass
0	262	656.7^{b}	919^{b}	51.9^{b}	164.1^{b}	216.0^{b}
55	315	848.0^{a}	1163^{a}	60.9^{ab}	215.2^{a}	276.1^{a}
110	319	928.7^{a}	1248^{a}	65.2^{a}	236.0^{a}	301.2^{a}
165	346	880.0^{a}	1226^{a}	65.1^{a}	218.6^{a}	283.6^{a}
Significance Level	ns	***	***	*	***	***
LSD (5%)		98.8	146.4	10.3	23.3	30.3
Variety						
Batte	273.0^{b}	713.3^{c}	986^{b}	61.5^{b}	183.1^{c}	244.5^{b}
Bubu	409.0^{a}	1015.0^{a}	1424^{a}	87.1^{a}	306.2^{a}	393.3^{a}
Daddafa	400.0^{a}	924.2^{ab}	1324^{a}	68.9^{b}	200.4^{bc}	269.4^{b}
Jarso	183.9^{c}	638.3^{c}	822^{c}	37.7^{c}	134.6^{d}	172.3^{c}
Zemen	286.9^{b}	850.8^{b}	1138^{b}	48.5^{c}	218.1^{b}	266.6^{b}
Significance Level	***	***	***	***	***	***
LSD (5%)	74.2	110.5	163.7	11.5	26.1	33.8
CV (%)	28.9	16.1	17.4	22.9	15.1	15.2

NB: Means within a column followed by the same letter are not significantly different at 5% level of significance; ns=non significant; *=significant at 5%; ***=significant at 0.1% probability levels.

Effects of N and variety on yield components and yield

The effect of N was highly significant on all parameters of tuber number while the effect of variety was highly significant on marketable as well as unmarketable tuber numbers. But, the interaction effect of the two factors on all the components of tuber number was not significant; also, the main effect of variety was not significant on total tuber number.The results showed that increasing N application from 0 to 55 kgha^{-1} increased marketable tuber number produced per hillby 33%, unmarketable tuber number by 58%, and total tuber number by 40%. However, increasing the application of N from 55 to 110 and 165 kgha^{-1} did not affect all tuber number parameters. In line with the results of this study, significant increases in tuber number in response to increased application of N was reported by Lynch and Rowberry (1997)and Sparrow *et al.* (1992). However, it was observed by Morena*et al.* (1994), and Sharma and Arora (1987) that there was no strong relationship between N application rates and tuber number. On the other hand Kołodziejczyk (2014) found that the share of the number of stems per 1 m^2 as well as the number of tubers per stem showed significant contribution in the yield increment within the rate of N application.

The varieties Bubu and Zemen produced the highest marketable tuber numbers. However, Bubu also produced the lowest unmarketable tuber number per hill. This was followed by the tuber numbers produced by Batte and Zemen. These varieties produced also the highest number of unmarketable tubers. The lowest marketable tuber number was produced by Jarso and Daddafa. These two varieties also produced the highest unmarketable tuber numbers (Table 3). Thus, Bubu produced 23, 19, and 17% more marketable tuber number than Jarso, Daddafa, and Batte, respectively.

Marketable, unmarketable and total tuber yields were highly significant influenced by the effects of N and variety. However, there was no significant effect with regard to the interaction effect of the two factors on tuber yield. An increase N application from 0 to 55 kgha^{-1} increased marketable tuber yield by 25%, total tuber yield by 27%, unmarketable tuber yield by 53%. However, increasing the rate of N from 55 to 110 and 165 kg Nha^{-1} did not affect marketable and total tuber yields as well as unmarketable tuber yield (Table 3).

The highest marketable and total tuber yields were obtained from the improved Bubu variety whereas the lowest marketable and total tuber yields were obtained from the local Jarso variety. The varieties Zemen, Daddafa and Batte lay in the intermediate range in terms of marketable and total tuber productivity. Thus, Bubu produced 54, 25, 22, and 14% more marketable fresh tuber yield than Jarso, Daddafa, Batte, and Zemen, respectively. In terms of production of total tuber yield, Bubu was superior to all other varieties except Zemen, which produced total tuber yield that was in statistical parity with the former. The lowest total tuber yield was produced by Jarso. The total tuber yield of Bubu exceeded that of Jarso, Daddafa and Batte by additional increments of 43, 19, and 16%, in the order listed here. The least unmarketable tuber yield was produced also by Bubu (Table 3).Berga*et al.* (1994) reported that unmarketable tuber yield might be controlled more importantly by manipulating other factors such as disease incidence, harvesting practice, etc. rather than mineral nutrition.

The differences in yield among these varieties could be related to their genetic makeup in the efficient utilization of inputs like nutrients; it is one of the four major categories of factors affecting yield (soil, genetic, climatic and management practices) as reported by (Downs and Hellmers, 1975; Tisdale *et al.*,1995). Hence, as reported by Hammes and De Jager (1990) and Gawronska *et al.* (1990), variation in tuber yield of these varieties may be due to differences in the rate of photosynthesis and dry matter production. In this study, there was strong positive association of plant height with marketable and total tuber yield. This means, the higher the height the higher the yield with an increase in N rate. Also, there was an increase in leaf area index which could indicate the responsibility of leaf for the subsequent yield increment (Tables 1& 3). Parallel to this, Singh and Singh (1987) found that the correlation between plant height and tuber yield was positive and strong. In contrast, as reported by Sidhu *et al.* (1980), plant height was slightly important for tuber yield; however, Gopal (2001) found the absence of significant association between plant height and tuber yield.

Table 3.The main effects of N and variety on marketable and unmarketable tuber number (count/hill) and marketable and unmarketable tuber yield(tonnes/ha).

Treatment	Parameters					
	Tuber number			Tuber yield		
Nitrogen($kgha^{-1}$)	marketable tuber number	unmarketable tuber number	total tuber number	marketable tuber yield	unmarketable tuber yield	total tuber yield
0	6.46^{b}	2.36^{b}	8.81^{b}	18.13^{b}	1.645^{b}	19.76^{b}
55	8.60^{a}	3.71^{a}	12.32^{a}	22.58^{a}	2.520^{a}	25.10^{a}
110	8.37^{a}	3.24^{a}	11.61^{a}	22.45^{a}	2.298^{a}	24.75^{a}
165	8.35^{a}	3.89^{a}	12.24^{a}	21.87^{a}	2.626^{a}	24.49^{a}
Significance Level	***	***	***	***	**	***
LSD (5%)	0.81	0.72	1.21	2.17	0.52	2.32
Variety						
Batte	7.65^{bc}	3.59^{a}	11.24	21.07^{b}	2.37^{a}	23.44^{b}
Bubu	8.93^{a}	2.23^{b}	11.16	25.63^{a}	1.56^{b}	27.19^{a}
Daddafa	7.52^{c}	3.49^{a}	11.01	20.45^{b}	2.46^{a}	22.90^{b}
Jarso	7.22^{c}	3.59^{a}	10.81	16.60^{c}	2.42^{a}	19.00^{c}
Zemen	8.42^{ab}	3.59^{a}	12.01	22.54^{b}	2.559^{a}	25.10^{ab}
Significance Level	**	**	ns	***	**	***
LSD (5%)	0.91	0.80	--	2.42	0.58	2.59
CV (%)	13.8	29.4	14.6	13.8	31.1	13.3

NB: Means within a column followed by the same letter are not significantly different at 5% level of significance; ns=non-significant; **=significant at 1%; ***=significant at 0.1% probability levels.

Tuber size was not significantly influenced by the interaction effect of N and variety. Similarly, the main effect of N was not significant on small-sized tuber though it was significant on medium-sized tuber and highly significant on large-sized tuber. Highly significant influence of the main effect of variety on tuber sizes was also observed. Based on the result, as N application increased from 0 to 165 kgha^{-1}medium-sized tuber showed about 45 to 50%increase but large-sized tuber significantly decreased from 40 to 33% as compared to the control (Table 4).According to Assefa (2005), increased application of N increased the yield of medium-sized and large-sized tubers; however, the increase in N application was not significant with respect to small-sized tuber category. The author elucidated that the increase was significant at all levels of N application in the medium -sized and large-sized tuber yields, which indicates the positive effect of N in dry matter partitioning to tubers. The increase in the medium-sized tuber at the expense of larger-sized tuber is an accepted value since medium-sized tuber is more preferred.On small-sized tuber, the highest value was obtained for Jarso (about 22%) while the lowest was obtained for Bubu (about 9%) variety. On large-sized tuber, the lowest value was obtained for Jarso (about 24%) and the highest for Bubu (about 45%) which was statistically similar to Batte. On medium-sized tuber, the highest value was obtained for Jarso (54.05%) and Zemen (51.9%) while the lowest was obtained for Batte (about 45.2%) though statistically not different fromBubu and Daddafaas shown in Table 4.

Mean tuber weight was not significantly influenced by the effect of N and its interaction with variety butthere was highly significant influence of the main effect of variety. Contrary to this study, Harris(1978),Giardini (1992) and Morena *et al.*(1994) reported that yield increment due to mineral nutrition was attributed to its effect on average tuber weight; Peter and Hruska (1988) also reported that the increased size and duration of the haulm stemming from improved supply of nutrients favored the tuber weight. Similarly, Patricia and Bansal (1999) reported the increase in average tuber weight of tubers with the supply of fertilizer nutrients could be due to more luxuriant growth, more foliage and leaf area and higher supply of photosynthates which helped in producing bigger tubers, hence resulting in higher yields. In addition, Balenger *et al.* (2002), Barakat *et al.* (1991), and Gaber and Sarg (1998) reported that potato average tuber weight increased with N increasing. Similar result also found by Kołodziejczyk M. (2014) that is each application of N rate within the range to 180 kg Nha^{-1} caused a noticeable increase in an average tuber weight.

The result revealed that the highest and the lowest, respectively, mean tuber weights were observed for Bubu(about 55%) and Jarso (about 40%)relatively (Table 4).The result revealed that a positive and highly significant association was observed between marketable tuber number and marketable tuber yield, marketable tuber number and total tuber yield, mean tuber weight and marketable tuber yield, and mean tuber weight and total tuber yield. In line with this, the finding of Maris (1969) revealed that tuber number and average tuber weight are important components determining tuber yield. The finding of Berga and Caesar (1990) also agrees with this statement in that tuber number is more important than average tuber weight in determining tuber yield.

Harvest index was highly significantly influenced by the main effect of N. Similarly, the main effect of variety was highly significant on the above parameter. However, the interaction effect of the two factors was not significant. According to Wien (1997), the consequent prolonged shoot growth and the increased duration of a canopy for light interception usually produces a much higher final of tubers than in plots that receive no N fertilizer; this is in spite of the fact that the unfertilized plants have a much higher harvest index. This idea is contradicted with the result of the present study in which an increase of harvest index with an increase of N application from 0 to 165 $kgha^{-1}$ was observed (Table 4). This may indicate that the optimal yield was not obtained due to factors such as environmental condition (e.g. frost), disease (potato late blight), etc. otherwise the harvest index would have been decreased.It was indicated in a study by Beukema and Van der Zaag (1990) that in temperate zone harvest indices of 0.75-0.85 are quite common but in warmer climates, the harvest index tend to be lower and often a wider variation is also observed between cultivars or growing conditions. In the present study, the highest value was recorded on Zemen (0.78) while the lowest was obtained by Batte (0.702). However, Zemen was statistically not different from Bubu; similarly, Batte was not statistically different from Daddafa and Jarso. In general, improved varieties (Bubu and Zemen) obtained better values as compared to the local varieties namely, Batte, Daddafa and Jarso (Table 4).

Table 4. The main effects of N and variety on tuber size distribution (%) in weight, mean tuber weight (g) and harvest index.

Treatment	Parameters				
	Tuber size distribution			mean tuber weight	harvest index
Nitrogen(kgha⁻¹)	Small-sized	medium-sized	large-sized		
0	13.69	45.59^{b}	40.72^{a}	49.89	0.71^{b}
55	16.05	51.48^{a}	32.47^{b}	46.17	0.74^{a}
110	15.30	48.50^{ab}	36.20^{ab}	47.78	0.74^{a}
165	16.06	50.27^{a}	33.67^{b}	45.26	0.74^{a}
Significance Level	Ns	*	**	ns	**
LSD (5%)	--	3.659	4.743	--	0.02371
Variety					
Batte	14.76^{b}	45.20^{b}	40.04^{ab}	47.42^{b}	0.70^{b}
Bubu	9.22^{c}	45.94^{b}	44.84^{a}	55.46^{a}	0.75^{a}
Daddafa	15.07^{b}	47.64^{b}	37.28^{bc}	46.64^{b}	0.71^{b}
Jarso	22.17^{a}	54.05^{a}	23.77^{d}	39.88^{c}	0.72^{b}
Zemen	15.15^{b}	51.97^{a}	32.88^{c}	46.97^{b}	0.78^{a}
Significance Level	***	***	***	***	***
LSD (5%)	3.11	4.09	5.30	3.92	0.02
CV (%)	24.7	10.1	17.9	10.0	4.4

NB: Means within a column followed by the same letter are not significantly different at 5% level of significance; ns=non-significant; *=significant at 5%; **=significant at 1%; ***=significant at 0.1% probability levels.

Effects of N and variety on quality parameters

Tuber dry matter was highly significantly affected by the main effect of N. Similarly, the main effect of variety on tuber dry matter as well as on specific gravity was highly significant. However, the main effect of N on specific gravity was not significant which is in agreement to the reports of Roberts and Cheng (1988) as well as Joern and Vitosh(1995).Likewise, the interaction effect of N and Variety was not significant on both the attributes of quality parameters.

The result showed that increasing N application from 0 to 55kgha^{-1}decreased tuber dry matter by about 5%. However, beyond this level of N supply, tuber dry matter yield was unaffected. The highest value of tuber dry matter was obtained for Bubu (about 28.5%) while the lowest was obtained for Jarso (about 19.7%). According to the finding of Beukema and Van der Zaag (1979), dry matter content is influenced by a large number of factors; most importantly, cultivar, maturity, growth pattern as influenced by N fertilizer application, and climate and soil. Related to the present result, different scholars (Westermann *et al.*, 1994b; Kanzikwera*et al.*, 2001) reported a significant reduction in percent dry matter content due to increase in N application; this could be attributed to the fact that high rates of N stimulate more top growth than tuber growth thereby delaying tuber formation and maturity; thus, tubers tend to be harvested immature with low dry matter percentages. Similar results were found in a study by Assefa (2005) and Anabausi *et al.* (1997).On the other hand, Balenger *et al.* (2002), Barakat *et al.* (1991), and Gaber and Sarg (1998) reported that potato tuber dry matter % increased with N increasing.

Although statistically not different from Bubu, the highest value for specific gravity (about 1.08) was obtained for Zemen; the lowest result was obtained for Jarso (about 1.054) though not statistically different from Daddafa as shown in Table 5. In general, improved varieties (Zemen and Bubu) had higher values of specific gravity than the local ones (Batte, Daddafa and Jarso). Specific gravity was positively and strongly correlated (0.44***)to tuber dry matter, which is in agreement with the report of (Blumenthal *et al.*, 2008) stating that since specific gravity has a near-linear relation with dry matter and starch content in tubers, it is the common way for measuring these quality characters.Similarly, there is a very high correlation between the specific gravity of the tuber and the starch content and also the percentage of dry matter or total solids (Tony, 2010).

Nitrogen content of the leaf tissue was highly significantly influenced by the effect of N. It also observed that the effect of variety was significant. Nevertheless, there was no significant effect regarding the interaction of the two factors. As shown on the result, increasing N application from 0 to 165 $kgha^{-1}$ increased the availability of N concentration in leaf tissue from about 4.64 to 5.14%. Results of the present study agreed with that of Anabausi *et al.* (1997), Maier *et al.* (1994) and Rykbost *et al.* (1993) who reported increase in leaf N concentrations in response to increasing the rates of N application. The highest and the lowest values of N content in their tissue were recorded by Batte, local variety (about 5.16%) and Zemen, improved variety (about 4.71%), respectively (Table 5).

It was reported on nutrient sufficiency and toxicity thresholds for potato leaf(early bloom:3.5-4.5, toxic >6.5; late: 3.0-4.0), petiole(early bloom:>1.5 (nitrate-N)), and tuber (maturity: 1.2-1.8) tissues for N (%) content in this crop (Carl *et al.*, 2004). In accord to this, the result of the present study revealed that N content of the varieties in their leaf tissue, ranging from 4.7 to 5.1 %, were sufficient.

Table 5. The main effects of N and variety on tuber dry matter (%), specific gravity (g/cm3), and leaf tissue analysis (total N in %).

Treatment	Parameters		
Nitrogen($kgha^{-1}$)	tuber dry matter	specific gravity	leaf tissue analysis
0	25.20^{a}	1.0632	4.64^{b}
55	23.96^{b}	1.0639	5.08^{a}
110	23.47^{b}	1.0706	4.98^{a}
165	23.87^{b}	1.0696	5.14^{a}
Significance Level	***	ns	**
LSD (5%)	0.71	–	0.26
Variety			
Batte	23.40^{c}	1.0652^{b}	5.16^{a}
Bubu	28.52^{a}	1.0768^{a}	4.84^{bc}
Daddafa	23.12^{c}	1.0598^{bc}	5.03^{ab}
Jarso	19.86^{d}	1.0543^{c}	5.05^{ab}
Zemen	25.74^{b}	1.0782^{a}	4.71^{c}
Significance Level	***	***	*
LSD (5%)	0.79	0.011	0.29
CV (%)	4.0	1.2	7.1

NB: Means within a column followed by the same letter are not significantly different at 5% level of significance; ns=non-significant; *=significant at 5%; **=significant at 1%; ***=significant at 0.1% probability levels.

Conclusions

The results showed that increasing the rate of N fertilizer from 0 to 55 kg Nha^{-1} increased most of the measured parameters. However, beyond the supply of 55 kg Nha^{-1},there was no change in most of the parameters. Within these N rates, the improved variety Bubu and local variety Daddafa showed promising performance during the experiment. However, the yields obtained from these varieties were much less than the expected potential productivity common on research fields. In addition, the response of all varieties to the increased rates of N application was not also found to be robust. An environmental stress that occurred just before maturity, namely, frost, may account for the underperformance and less response of the improved varieties in particular to the increased rates of N. In addition, the local varieties suffered most from attack by late blight disease during growth in the wet season. Therefore, to reach a conclusive recommendation on the response of N fertilizer and tuber productivity of the varieties, further multi-location studies should be conducted under both irrigated and rain-fed conditions.

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Effect of Varieties and Growing Environments on Tuber Yield, Nutritional and Process Quality of Potato Grown In Bale Highlands, South Eastern Ethiopia

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Abstract

The highland of Bale is known with potato production, but post harvest quality of the crop is not emphasized yet. Therefore, this study was conducted to evaluate six potato varieties with the objective of assessing the effect of varieties and growing environment on tuber yield, nutritional and process quality of potato grown in Sinana and Dinsho highlands of Bale. The experiment was laid out in randomized complete block design with three replications. The varieties showed highly significant ($P \leq 0.05$) differences for all the parameters studied across the locations. The highest specific gravity, dry matter content and starch content (1.107, 26.61 and 19.19), respectively, were recorded from Dinsho location for Guddene variety and the highest total tuber yield was recorded from the same location for Durame followed by Ararsa while the lowest specific gravity, dry matter content and starch content(1.084, 19.41 and 14.61) respectively, were recorded from Sinana location for Ararsa variety and the lowest total tuber yield was also recorded for Milki at the same location. Most of the varieties were recorded as the highest values of specific gravity, dry matter content, starch content and total tuber yield at Dinsho indicating that it is an ideal location for potato production to be used for processing while Sinana is suitable for the production for home consumption. However, it is necessary to evaluate these varieties for a number of seasons and locations to recommend with high post harvest quality parameters required by the processors.

Keywords: Potato, Specific gravity, dry matter and starch content

Introduction

Potato (*Solanum tuberosum L.*) is an annual herbaceous, self-pollinated species. Potato belongs to family solanaceae and the genus Solanum with a basic set of 12 chromosomes (x = 12). Potato is one of the most important tuber crops, is used worldwide for human and animal consumption, and as raw material for starch and alcohol production. It is also one of the world's major staple crops, which produces more dry mater and protein per hectare than the major cereal crops (Storey *et al.*, 2007).

The history of potato is the testimony of the fact that whenever there has been scarcity of food grains, potato has become the food security of people. Potato, because of its great utility, occupies a pre-eminent place amongst the crops and a Acknowledged as the "king of vegetables" (Smita Bala Barik *et al.*, 2009). More than a billion people eat potatoes, and the total global potato production exceeds

374 million metric tons per year (André *et al.*, 2014). Potato has been highly recommended by the Food and Agriculture Organization (FAO) as a food security crop. It is the third most important food crop in the world after rice and wheat in terms of human consumption (FAO, 2014).

The development of potato varieties with improved post harvest quality and a wide adaptability is important to all segments of potato industry. Processors and other users of potatoes would benefit from a more uniform product if varieties produce the same specific gravity when grown in differing environments (Kabira, J. and L. Berga, 2003). Consumption of potato chips is not common in the country except in the big hotels and restaurants. Recently, however, small scale potato chips processors are flourishing in cities and big towns in developing varieties, much emphasis was given to productivity per unit area and late blight reaction while less emphasis was given to processing quality and studies regarding effect of storage on process and nutritional quality are less probable to get in the country (Asefa *et al*, 2016). To meet the demand for varieties suitable for processing industry and storable for longer periods and to keep market with minimum weight and nutritional loss is a very important to evaluate the fitness of the released varieties for processing and to incorporate processing quality as a yardstick in varietal development procedure. Hence, this study was initiated with objectives to study the effect of environments and varieties on total tuber yield, nutritional and process quality of potato.

Materials and Methods

This experiment was conducted in Southeastern Ethiopia, Bale Zone, at Sinana Agricultural Research Center and Dinsho during "Gena" cropping season of 2016. The areas possess a bimodal rainfall type. This bimodal rainfall system has created favorable condition to produce crops twice annually or double crop production season. Average annual maximum and minimum temperatures are 21 and 9°C, respectively. The dominant soil type is pellic vertisol and slightly acidic (Nefo *et al.*, 2008).

Hundee, Ararsa and Milki were released from Sinana Agricultural Research Center While Gudene and Jalene were released from Holleta Agricultural Research Center and Durame from southern part of Ethiopia were used for the study. The tubers were planted at each location in a Randomized Complete Block Design (RCBD) with three replications. Well-sprouted tubers of each variety were planted in six rows and ten hills per row at spacing of 75 and 30 cm between rows and plants, respectively. The gross plot size was 4.5 m x 3 m, and the distance between blocks and plots was 1.5m and 1m respectively. Fertilizer application was made as per the national recommendation made for the crop which is 92 kg P_2O_5

ha^{-1} in the form of Diammonium Phosphate (200 kg ha^{-1}) and the whole rate was applied at planting. Nitrogen fertilizer was applied at the rate of 75 kg ha^{-1} in the form of Urea in two splits, half rate after full emergence (two weeks after planting) and half rate at the initiation of tubers (at the start of flowering). Moreover, other agronomic managements rather than varietal differences, like weeding, earthining up, were uniformly applied to all experimental plots.

Collected data

Specific gravity of tubers (SG): This was determined by the weight in air and in water method. Five kilograms of tubers of all shapes and sizes were randomly taken from each plot. The tubers were washed with water. Then after the sample was first weighed in air and then re-weighed suspended in water. Specific gravity was calculated according to Kleinkopf *et al.*, (1987) formula.

$$\text{Specific gravity} = \frac{\text{Weight in air}}{\text{Weight in air} - \text{Weight in Water}}$$

To convert specific gravity value to dry mater and starch content, the equation from Kleinkopf *et al.* (1987) of dry matter (%) = -214.9206 + 218.1852 × (specific gravity) and Von Schéele *et al.* (1937) of starch (%) = 17.565 + 199.07 × (specific gravity) – 1.0988) were used.

Total tuber yield (TTY) (t/ha): This was determined as the sum of the weights of marketable and unmarketable tubers from the net plot area and converted to tons per hectare

Data analysis

Collected data was subjected to analysis of variance (ANOVA) for RCBD Using Genstat 15th edition computer software. Means that are significantly different were compared using Least Significant Difference (LSD) of probability at 5% level of significance.

Result and Discussions

Analysis of variance indicated the presence of significant ($P \leq 0.05$) differences among varieties for specific gravity. The specific gravity (SG) was influenced by location. Accordingly, the specific gravity of tubers grown at Dinsho was higher than that of corresponding varieties grown at Sinana except milki (Table 1). The highest SG value (1.107 and 1.106) in Dinsho was recorded from the improved variety of Gudanne and Jallene, respectively while the highest SG value at Sinana was recorded from Milki variety. Contrary, the lowest specific gravity (1.094 and 1.086) was obtained from Ararsa at Dinsho and Sinana, respectively. This is in line with Tesfaye *et al.*, (2012) who indicated the difference of specific gravity of potato varieties within three distinct environments ranged (1.119 to 1.050 for improved varieties of Belete and Menagesha). High specific gravity is an indication that the raw potatoes will produce high chips volume due to high dry matter content of tubers. Fitzpatrick *et al.* (1964) categorized tuber specific gravity values as low if less than 1.077, intermediate if between 1.077 and 1.086 and high if more than 1.086. Accordingly, all released varieties under the two locations, except Ararsa at Sinana, of the study were categorized under high specific gravity indicating that they are fit for processing.

Dry matter content of tuber was significantly ($p < 0.05$) influenced by varieties and growing environment. The mean dry matter content ranged between 26.61 to 23.77 and 26.39 to 19.41 at Dinsho and Sinana, respectively. At both locations, the lowest dry matter content was recorded from the improved variety called Ararsa. But, the varieties containing the highest dry matter content differed across the sites. The maximum dry matter content was recorded from Gudanne and Jalanne at Dinsho while the maximum dry matter content was recorded for Milki at Sinana. The difference of dry matter content at both locations may be due to environmental factors contributing to this crop quality parameter. Many attempts have been reported to correlate variations found in specific gravity of tubers with cultural practices and environmental conditions. The result of correlation analysis revealed that more dry matter accumulation was observed in Dinsho as the function of increasing specific gravity than at Sinana (Figure 1). Tesfaye *et al.*, (2012) and Elfnesh *et al.*, (2011) also reported that different dry matter content were observed within the same varieties at different locations.

Like dry matter content and specific gravity, starch content of the varieties was also different with different locations. The highest starch content was obtained from Gudanne (19.19%) and Jalanne (18.99%) at Dinsho while the highest (18.99%) at Sinana was recorded from Milki variety. However, the lowest starch content from Ararsa variety was 16.6% and 14.61 at Dinsho and Sinana, respectively. The result from study revealed that, for both locations there were significant difference for tuber dry matter content, starch content and specific gravity indicating that the varieties showed a differential response to the characters in the different environments. Similar findings were reported previously by Tekalign, (2015), Tesfaye *et al.*, (2012) and Kabira and Berga (2003).
The mean total tuber yield is ranged from 36 to 29 t ha^{-1} for Durame and Milki at Dinsho location while, 32 to 27 t ha^{-1} for the same varieties at Sinana location. High total tuber yield was recorded from all varieties at Dinsho than Sinana. This indicated the presence of variation in varieties and environments under study that can influenced total tuber yield as well as quality parameters.

Table 1. Mean of specific gravity, dry matter, starch content and total tuber yield of six potato varieties evaluated under two environments in Bale high lands

Locations	Varieties	Specific gravity(gcm^{-3})	Drymater content (%)	Starch content (%)	Total tuber yield($t\ ha^{-1}$)
	Gudanne	1.107	26.61	19.19	32.35
	Jalanne	1.106	26.39	18.99	30.5
	Milki	1.101	25.3	17.96	29
Dinsho	Ararsa	1.094	23.77	16.6	35.25
	Hunde	1.101	25.3	17.96	31
	Durame	1.106	26.39	17.96	36
	Gudanne	1.101	25.3	17.96	29
	Jalanne	1.101	25.3	17.96	28.67
Sinana	Milki	1.106	26.39	18.99	27
	Ararsa	1.084	19.41	14.61	31
	Hunde	1.099	24.86	17.6	29
	Durame	1.101	25.3	18.99	32
	CV	0.622	6.86	7.35	19.56
	LSD(0.05)	0.004	0.91	0.91	2.21

CV=coefficient of variation, LSD=least significant different

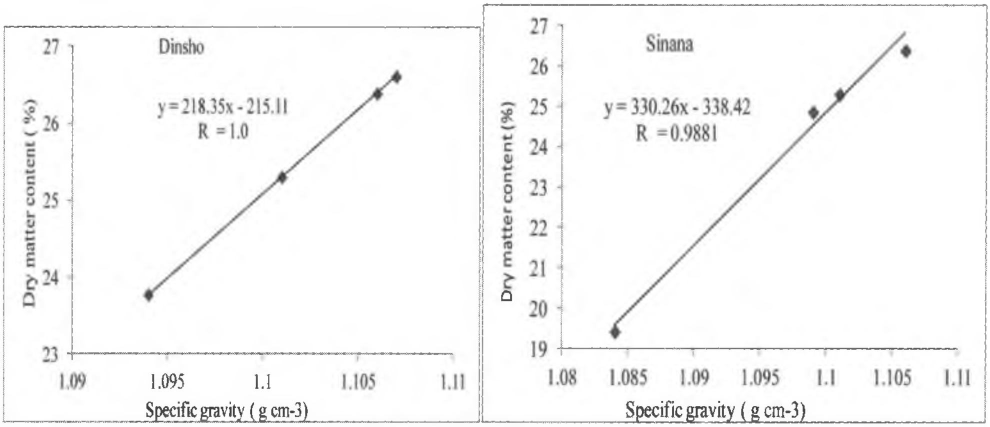

Figure 1: The relation of specific gravity to dry matter content for sex varieties of Potatoes at Dinsho and Sinana areas of Bale highland

Conclusion and Recommendation

The study confirmed that there were existences of considerable variations among the varieties in terms of specific gravity, dry matter, starch contents and total tuber yield indifferent environments. This indicated us quality characters of potato are governed by both varieties and environments. Most of the varieties under the study were recorded having the highest values of specific gravity, dry matter and starch content at Dinsho indicating that it is an ideal location for production of potato to be used for processing while Sinana is suitable to produce for table type potato production.

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