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Evaluation of Specific Gravity of Potato Varieties in Ethiopia as a Criterion for Determining Processing Quality

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ABSTARCT

Specific gravity (SG) is the measure of choice for estimating dry matter (DMC) and starch content (SC) and ultimately for determining the processing quality of potato varieties. Evaluation of the SG of 25 potato varieties was carried out at three distinct locations in the Amhara region of Ethiopia with the main objectives of determining their culinary quality and most suitable areas of production. The varieties were planted in a 5 × 5 balanced lattice design of six replications during the 2011 rainy season. The results of the data analysis showed highly significant ($P < 0.01$) genotypic and location differences and significant ($P < 0.05$) genotype × environment interactions. The pooled SG values ranged from 1.058 to 1.102. The SG of tubers of the improved variety Belete was the highest while that of Menagesha was the lowest. Furthermore, the SG values for varieties grown at Debretabor were higher than those for the corresponding varieties grown at Adet and Merawi. The DMC and SC were computed based on the SG and showed significant ($P < 0.01$) genotypic variability. The highest DMC and SC were also obtained at Debretabor; thus, it is an ideal location to grow potatoes for high DMC and starch accumulation. Additive main effects and multiplicative interaction analysis identified CIP-392640.524, Zengena, Jalenie and Belete as stable genotypes with SG values above average.

Keywords: specific-gravity, variability, potato varieties, processing quality, additive main effects and multiplicative interaction analysis

INTRODUCTION

Potato (*Solanum tuberosum* L.) is a staple food crop for rural people in the cool highland parts of Ethiopia where the environment precludes the production of common cereals but does support hardy crops such as barley and cool season food legumes. Potato provides food, employment and income as a cash crop for over 2.3 million households dwelling in this part of the country (Central Agricultural Census Commission, 2003). In recent years, potato production has dramatically increased by about 64%, from 349,000 t in 1993 to 572,332 t in 2010 (FAO, 2011). Potatoes are mostly consumed after boiling and in a sauce where potatoes are incorporated as an ingredient (Tesfaye *et al*., 2010). Nevertheless, there is an increasing demand for potato as an ingredient in other fast foods that entail salad and processed products such as French fries and crisps, as a result of dietary diversification among urban dwellers, emerging fast food restaurants and roadside small-scale fryers (Tesfaye *et al*., 2010). In addition, it is being used by starch manufacturing firms. The demand

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for starch is expected to increase in line with the ongoing establishment of textile, pharmaceutical and paper manufacturing industries in the country. To backstop this trend, research has involved multifaceted efforts and recommended over 30 improved potato varieties that can spearhead its productivity and profitability among growers (Ministry of Agriculture and Rural Development of Ethiopia, 2008). Nonetheless, very little attention has been paid (Asmamaw *et al*., 2010; Elfnesh *et al*., 2011) to study the post-harvest qualities of these varieties and hence information related to their culinary quality is scanty. This, in turn, has resulted in the non-selective use of potato varieties found in the market for either table or processing purposes which has resulted in the prevalence of French fries and crisps that are inferior in quality with poor color, texture and flavor and are saturated with oil (Tesfaye *et al*., 2010).

1. Quality is one of the most important characteristics of potato and its quality is dependent on external and internal aspects of the tuber. However, various workers have pointed out that the true quality of potato is directly linked with its dry matter content (Storey and Davies, 1992; Dale and Mackay, 1994); an important attribute to both the food and nonfood potato industries determining both the quality and yield of the processed product (Haase, 2004). Consequently, potato varieties with a dry matter content of 20% or higher, a starch content of 13% and above and/or a specific gravity of 1.08 or higher are the most preferred for processed products (Kirkman, 2007). Specific gravity has been used as a criterion of potato quality due to its positive correlation with the dry matter content of tubers and the rapidity with which it can be determined (Lulai and Orr, 1979). Generally, it has also been considered the most practical index of mealiness (Warren and Woodman, 1974). Thus, it is extensively used by processors to assess the suitability of tubers for the production of processed products (Murphy and Goven, 1959; Gray and Hughes, 1978). Like any other quality attribute, genotype has a decisive effect in determining the specific gravity of potato varieties (Rivero *et al*., 2009). However, its effect is modified by cultural and environmental factors during the growing season (Killick and Simmonds, 1974). Significant genotype × location (Love and Pavek, 1991; Asmamaw *et al*., 2010; Elfnesh *et al*., 2011), genotype × season (Abubaker *et al*., 2011) and genotype × year (Ekin, 2011) interactions have also been reported. This underscores the relevance of evaluating genotypes under varying sets of environmental conditions to determine the suitable environment in which varieties can manifest their maximum performance potential. Accordingly, 25 potato genotypes were evaluated in three distinct environments with the following objectives: to evaluate the specific gravity of 18 improved potato varieties, 3 elite clones and 4 widely grown farmer's cultivars; and to identify the appropriate production environments of table and processing type potatoes.

MATERIALS AND METHODS

Description of the experimental sites

The study was carried out in three distinct districts of the Amhara National Regional State of Ethiopia—Adet, Merawi and Debretabor (Figure 1). The Adet site was located at $11^0 16'32''$ N and $37^0 29'30''$ E at an elevation of 2,240 m above sea level. Its soil type was a red brown Nitosol. Likewise, the Merawi site was located at an altitude of 1,960 m above sea level at $11^0 30'0''$ N and $37^0 0'0''$ E and had a heavy, clayey, textured, red Nitosol. The Debretabor site was situated in the cool highland part of this region at an elevation of 2,706 m above sea level and had a soil type classified as Luvisol. This site was located at $11^0 51'0''$ N and $38^0 1'0''$ E. The rainy season over the sites extends from May through October and is sufficient for crops with a maturity period of 120–150 d. Details of the soil pH, cation exchange capacity, organic matter content, available N, P, K, texture, precipitation, sunshine hours, altitude, rainfall and temperature of these sites are indicated in Tables 1 and 2.

Field experimentation

In this study, a total of 25 potato varieties of different maturity classes were used—namely, Menagesha, Challa, CIP-395096.2 (elite clone), Wochecha, Gorebella, Agere (farmer's cultivar), Belete, Ater Abeba (farmer's cultivar), Bulle, Tolcha, Aba Adamu (farmer's cultivar), Marachare, Jalene, Guasa and CIP-396004.337 (elite clone) with intermediate maturity and Gera, Zengena, Shenkolla and CIP-392640.524 (elite clone) with medium early maturity and

Table 1 Physicochemical properties of soils of the three experimental sites.

Experimental site	Altitude above sea level (m)	Soil physical and chemical properties						
		Soil pH	Total N (%)	Available P (ppm)	Available K (Cmol$^+$. kg^{-1})	CEC (Meq per100 g)	Organic matter (%)	Texture
Adet	2,240	5.20	0.44	7.17	0.781	30.62	1.69	Heavy clay
Merawi	1,960	5.00	0.19	8.70	0.768	26.00	2.75	Heavy clay
Debretabor	2,706	4.94	0.20	17.18	0.339	31.74	3.00	Clay

CEC = Cation exchange capacity.

Data analyzed by the Adet Agricultural Research Center Soil and Water Research Department, Ethiopia.

Table 2 Mean air temperature, rainfall, relative humidity and sunshine hours at the three experimental sites.

Experimental site	Cropping season months	Mean monthly rainfall (mm)	Mean air temperature (^{0}C)		Relative humidity (%)	Sunshine (hr)
			Minimum	Maximum		
Adet	May	161.6	18.1	27.9	54	8.3
	June	83.6	18.1	26.3	70	6.0
	July	338.7	14.6	25.2	79	4.6
	August	213.6	13.0	24.2	80	4.9
	September	155.0	11.7	24.2	72	6.1
	October	171.8	10.0	25.9	66	8.4
Merawi	May	172.4	15.0	28.7	68	11.0
	June	347.6	14.4	26.9	71	9.8
	July	399.9	13.6	24.8	74	8.4
	August	364.3	13.2	24.4	74	8.3
	September	203.9	12.9	25.1	72	8.6
	October	97.3	12.1	26.5	69	9.6
Debretabor	May	65.3	15.2	23.8	54	6.4
	June	151.2	11.8	21.6	71	5.5
	July	499.3	10.0	18.9	80	3.0
	August	527.9	9.3	19.2	83	2.9
	September	203.0	9.3	20.5	75	6.2
	October	41.4	9.0	21.9	60	7.8

Source: Ethiopian Meteorological Agency branch at Bair dar.

Figure 1 General location of the three experimental sites.

Awash, Hunde, Gabisa, Gudene, Sisay (farmer's cultivar) and Ararsa with early maturity. Sample plots of each species were planted in three distinct environments in the Amhara region of Ethiopia, at Adet, Merawi and Debretabor during the rainy season (May to October) of 2011. The 18 improved varieties (that is, neither the elite clones or farmer's cultivars) had passed through the rigorous stages of variety development to examine their wider adaptability, yield potential and disease resistance. In addition, nine of them (Tolcha, Wochecha, Zengena, Jalene, Guasa, Marachare, Gera, Gabisa and Challa) had also been previously evaluated for their processing quality using the parameters of DMC, SG, pH, reducing sugar, color, sourness, flavor and crisp-making potential in two separate experiments carried out in Ethiopia by Asmamaw *et al*. (2010) and Elfnesh *et al*. (2011). The three study sites have distinct cropping patterns due mainly to temperature, soil type and rainfall distribution differences. At all the experimental sites, the 25 varieties were planted in a complete 5 × 5 lattice design with six replications on a gross plot size of 9 m^2. Each plot had four rows of 3 m long that were 0.75 m apart and planted with a total of 40 tubers at a spacing of 0.3 m between plants in a row. The plots at Adet and Merawi received 81 $kg.ha^{-1}$ nitrogen and 69 $kg.ha^{-1}$ P_2O_5. At Debretabor, each plot was supplied with 108 $kg.ha^{-1}$ nitrogen and 69 $kg.ha^{-1}$ P_2O_5 according to site-specific recommendations. The mineral nutrients were supplied in the form of diammonium phosphate (DAP) and urea. The DAP was supplied at planting just below the seed tuber with light covering of soil to avoid direct contact with the seed tuber while the urea was side-dressed with half applied at two weeks after emergence and the remainder at flowering owing to the high mobility of urea in the soil complex. All other crop husbandry practices were done as needed. Fungicide mancozeb 65%WP was also sprayed twice to fully protect growing plants from damage by late blight of potato. At maturity, the tuber yield and related data of each variety were recorded from each replication.

Specific-gravity determination

In determining the SG of each variety evaluated across the three distinct environments, healthy and marketable size grade tubers were selected randomly from the central rows of two of the six replications. Then, tubers were cleaned and weighed in both air and water by the method of Murphy and Goven (1959). Finally, the SG value was computed using Equation 1:

$$\text{SG} = \text{Weight of tuber in air} / (\text{Weight of tuber in air} - \text{Weight of tuber in water}) \qquad (1)$$

Statistical analysis

To determine the effects of genotype on the SG value, the data from each site was subjected to simple analysis of variance (ANOVA). Concurrently, a combined ANOVA was carried out to see the effects of the genotype × environment interaction and to identify superior varieties with desirable quality attributes. All the statistical analyses were carried out using the SAS software package (SAS Institute Inc., USA, 2009) by the command PROC GLM (procedure of general linear model). Moreover, to convert tuber specific gravity (SG) to dry matter content and starch content percentage equivalents, the conversion equations of Von Schéele *et al.* (1937) and Kleinkopf *et al.* (1987), and Von Schéele *et al.* (1937) and the brine/salt solution-based conversion table, respectively, were compared. The results of both group analyses were highly significant (r = 0.99; $P < 0.001$). Consequently, the equation from Von Schéele *et al.* (1937) of starch (%) = 17.565 + 199.07 × (specific gravity – 1.0988) and the equation from Kleinkopf *et al.* (1987) of dry matter (%) = -214.9206 + 218.1852 × (specific gravity) were used to convert the SG value of varieties in this study to starch content and dry matter content, respectively. Finally, additive main effects and multiplicative interaction analysis was carried using the Agrobase 20 for Windows package (Agromix Software, Inc. 2000) to identify stable varieties.

RESULTS

The specific gravity (SG) results of the simple ANOVA at each location among the tubers of the 25 varieties were highly significant ($P < 0.01$). The specific gravity was also influenced by location (Table 3). Accordingly, the specific gravity of tubers grown at Debretabor was higher than that of corresponding varieties grown at both Adet and Merawi. The highest SG value (1.119) at Debretabor was obtained from the improved variety Belete. At Merawi and Adet, the highest SG values were 1.103 and 1.092, respectively. These values were obtained from the elite clone CIP-396004.337 and the widely cultivated farmer's cultivar Ater Abeba, respectively (Table 3). Perversely, the lowest SG value in all three trials was recorded from the improved variety Menagesha (Table 3). Moreover, the differences in SG values of the same genotype across locations were as high as the differences observed between the different genotypes tested in one location (Table 3). This in turn has resulted in a ranking order shift among genotypes across the tested environments.

The presence of such statistically significant genotype × environment interactions usually impedes the selection process owing to the considerable impact of the environment on the overall observed variances. Therefore, further combined ANOVA analysis across the trial locations was carried out in order to be able to distinctly sort out those varieties with minimum fluctuations with the change in environment.

The combined ANOVA results revealed a statistically significant ($P < 0.05$) genotype × environment interaction (Table 4). This caused a ranking order shift of genotypes across locations and as such, genotypes which had the highest rank in one location did not maintain the same rank in the other locations. Accordingly, the highest combined SG value of 1.102 was recorded from the improved variety Belete. This variety ranked second both at Adet and Merawi. The elite clone CIP-3396004.337 was ranked second and the farmer's cultivar Ater Abeba and the improved variety Challa were ranked third with SG values of 1.098 and 1.097 and 1.097, respectively. Though its SG values met the cut-off point demanded by the processing industries, the second-ranked genotype in the combined analysis was tenth and fifth at Adet and Debretabor, respectively (Table 3).

The dry-matter content and starch content equivalents of tuber SG values showed highly significant ($P < 0.01$) differences between treatments tested at a site and across locations (Table 4).

The dry matter content at Adet, Merawi and Debretabor ranged from 13.96 to 23.45%, 15.24 to 25.84% and 18.88 to 29.25%, respectively (Table 4). At all three sites, the lowest value was recorded from the variety Menagesha while the highest was obtained from Ater Abeba, CIP-396004.337 and Belete, for Adet, Merawi and Debretabor, respectively (Table 4). Likewise, the starch content for Adet, Merawi and Debretabor ranged from 7.63 to 16.29, 8.81 to 18.47, and 12.13 to 21.59, respectively. The lowest and highest valued varieties were those that had the lowest and highest dry matter content (Table 4).

Additive main effects and multiplicative interactions (AMMI) analysis of SG across the three environments clearly showed a genotypic response to changing environmental variables across locations (Figure 2). Accordingly, CIP-392640.524, Zengena and Jalene were found to have similar SG values across locations. Similarly, Belete, Challa, Ater Abeba, and Gorebella showed small interactions but with SG values far greater

Table 3 Mean of specific gravity of 25 potato varieties evaluated under three distinct environments in Amhara region of Ethiopia during 2011 rainy season.

Variety	Specific gravity (g.cm^{-3})				Marketable tuber yield (t.ha^{-1})
	Adet	Merawi	Debretabor	Grand mean	
^{a}Menagesha	1.050^{d}	1.055^{i}	1.072^{e}	1.058^{j}	25.38^{ij}
^{b}Gera	1.077^{bcd}	1.073^{defg}	1.095^{abcde}	1.081^{fghi}	30.45^{defg}
^{c}Challa	1.091^{ab}	1.087^{bcde}	1.112^{abc}	1.097^{abc}	34.06^{cd}
^{d}CIP-395096.2	1.076^{abc}	1.060^{gh}	1.087^{cde}	1.074^{i}	29.10^{efghi}
^{e}Wochecha	1.072^{c}	1.071^{efg}	1.081^{de}	1.075^{hi}	19.41^{k}
^{f}Awash	1.068^{c}	1.068^{fgh}	1.082^{de}	1.075^{ghi}	17.22^{k}
^{g}Gorebella	1.088^{abc}	1.081^{bcdef}	1.113^{abc}	1.094^{abcde}	38.05^{ab}
^{h}Zengena	1.089^{abc}	1.085^{bcde}	1.100^{abcd}	1.091^{abcdef}	29.31^{efghi}
^{i}Hunde	1.091^{abcd}	1.076^{defg}	1.110^{abc}	1.092^{abcdef}	31.87^{def}
^{j}Agere	1.088^{abc}	1.089^{abcd}	1.109^{abc}	1.095^{abcd}	24.80^{j}
^{k}Shenkolla	1.082^{abc}	1.073^{defg}	1.103^{abcd}	1.086^{cdefgh}	29.93^{defghh}
^{l}Belete	1.092^{ab}	1.095^{ab}	1.119^{a}	1.102^{a}	40.51^{a}
^{m}Ater Abeba	1.093^{a}	1.088^{abcd}	1.111^{abc}	1.097^{abc}	30.46^{defg}
^{n}CIP-392640.524	1.083^{abc}	1.083^{cdef}	1.092^{bcde}	1.084^{defghi}	25.75^{hij}
^{o}Gudene	1.091^{ab}	1.074^{efg}	1.103^{abcd}	1.089^{bcdef}	26.69^{ghij}
^{p}Bulle	1.072^{abc}	1.072^{efg}	1.104^{abcd}	1.084^{defghi}	23.85^{j}
^{q}Gabisa	1.077^{abc}	1.074^{defg}	1.091^{bcde}	1.082^{efghi}	30.51^{defg}
^{r}Tolcha	1.074^{bc}	1.071^{efg}	1.103^{abcd}	1.082^{efghi}	18.54^{k}
^{s}Aba Adamu	1.089^{abc}	1.093^{abc}	1.102^{abcd}	1.094^{abcd}	27.96^{fghi}
^{t}Marachare	1.077^{abc}	1.088^{abcd}	1.094^{abcde}	1.086^{cdefg}	33.94^{cd}
^{u}Sisay	1.081^{abc}	1.080^{bcdef}	1.098^{abcd}	1.086^{cdefg}	27.52^{ghij}
^{v}Ararsa	1.073^{c}	1.088^{abcd}	1.093^{bcde}	1.084^{defghi}	27.18^{ghij}
^{w}Jalene	1.084^{abc}	1.086^{bcde}	1.113^{ab}	1.094^{abcde}	36.24^{bc}
^{x}Guasa	1.080^{abc}	1.089^{abcd}	1.113^{ab}	1.094^{abcde}	38.96^{ab}
^{y}CIP-396004.337	1.081^{abc}	1.103^{a}	1.111^{abc}	1.098^{ab}	32.99^{cde}
Grand mean	1.081	1.080	1.101	1.087	29.22
CV%	0.50	0.47	0.71	0.60	8.14
SEM (t.ha^{-1})	±0.02	±0.015	±0.024	±0.019	7.13

Mean separation using Duncan's multiple range test at $P < 0.01$ level of probability.

Means in the same columns followed by the same letter(s) are not significantly different.

CV% = Coefficient of variation, SEM = Standard error of the mean.

The superscript preceding each variety name in the first column is an identifier of the variety in the biplot in Figure 2.

than the overall mean value. A high SG value is normally associated with greater product yield compared with those varieties having lower SG values. In addition, the marketable yield level of these varieties is an essential yardstick in identifying varieties with cumulative high products during processing. Contrarily, Wochecha, Awash and Menagesha were positioned in the lower SG range with lower interaction values.

DISCUSSION

The differences in the specific gravity of tubers of potato varieties reported in this study

Table 4 Mean dry matter and starch content of the 25 potato varieties under three distinct environments in Amhara region of Ethiopia during 2011 rainy season.

Variety	Dry matter content (%)			Starch content (%)		
	Adet	Merawi	Debretabor	Adet	Merawi	Debretabor
Menagesha	13.96^{d}	15.24^{i}	18.88^{e}	7.63^{d}	8.81^{h}	12.13^{e}
Gera	20.00^{abc}	19.08^{defgh}	23.98^{abcde}	13.15^{abc}	12.31^{defg}	16.78^{abcde}
Challa	23.20^{ab}	22.25^{bcdef}	27.71^{abc}	16.07^{ab}	15.20^{bcde}	20.18^{abc}
CIP-395096.2	19.74^{abc}	16.36^{hi}	22.22^{cde}	12.91^{abc}	9.83^{gh}	15.17^{cde}
Wochecha	18.97^{c}	18.67^{fgh}	20.99^{de}	12.21^{c}	11.94^{efg}	14.05^{de}
Awash	19.85^{abc}	17.99^{ghi}	21.20^{de}	13.01^{abc}	11.32^{fgh}	14.24^{de}
Gorebella	22.45^{abc}	20.93^{bcdefg}	27.87^{abc}	15.39^{abc}	14.00^{bcdef}	20.33^{abc}
Zengena	22.72^{abc}	21.81^{bcdef}	25.06^{abcd}	15.63^{abc}	14.80^{bcde}	17.76^{abcd}
Hunde	23.11^{ab}	19.74^{defgh}	27.24^{abc}	15.99^{ab}	12.91^{defg}	19.75^{abc}
Agere	22.47^{abc}	22.71^{abcd}	27.09^{abc}	15.40^{abc}	15.62^{abcd}	19.62^{abc}
Shenkolla	21.13^{abc}	19.08^{defgh}	25.84^{abcd}	14.18^{abc}	12.31^{defg}	18.47^{abcd}
Belete	23.34^{ab}	23.91^{ab}	29.25^{a}	16.19^{ab}	16.72^{ab}	21.59^{a}
Ater Abeba	23.45^{a}	22.47^{abcde}	27.53^{abc}	16.29^{a}	15.40^{abcd}	20.02^{abc}
CIP-392640.524	21.35^{abc}	20.17^{cdefg}	23.40^{bcde}	14.38^{abc}	13.31^{cdef}	16.25^{bcde}
Gudene	23.15^{ab}	19.41^{defgh}	25.83^{abcd}	16.02^{ab}	12.61^{defg}	18.47^{abcd}
Bulle	19.96^{abc}	18.87^{efgh}	26.04^{abcd}	13.11^{abc}	12.11^{efg}	18.65^{abcd}
Gabisa	21.35^{abc}	19.30^{defgh}	23.13^{bcde}	14.38^{abc}	12.51^{defg}	16.00^{bcde}
Tolcha	19.41^{bc}	18.65^{fgh}	25.66^{abcd}	12.61^{bc}	11.91^{efg}	18.31^{abcd}
Aba Adamu	22.57^{abc}	23.52^{abc}	25.54^{abcd}	15.50^{abc}	16.36^{abc}	18.20^{abcd}
Marachare	20.07^{abc}	22.50^{abcd}	23.85^{abcde}	13.21^{abc}	15.43^{abcd}	16.61^{abcde}
Sisay	20.83^{abc}	20.69^{bcdefg}	24.73^{abcd}	13.90^{abc}	13.78^{bcdef}	17.46^{abcd}
Ararsa	19.08^{c}	22.52^{abcd}	23.52^{bcde}	12.31^{c}	15.45^{abcd}	16.36^{bcde}
Jalene	21.48^{abc}	21.91^{bcdef}	27.95^{ab}	14.50^{abc}	14.93^{bcde}	20.40^{ab}
Guasa	20.72^{abc}	22.62^{abcd}	28.03^{ab}	13.80^{abc}	15.54^{abcd}	20.47^{ab}
CIP-396004.337	20.94^{abc}	25.84^{a}	27.38^{abc}	14.00^{abc}	18.47^{a}	19.88^{abc}
Mean	21.01	20.65	24.19	14.07	13.74	17.89
CV%	5.64	5.35	6.79	7.68	7.32	8.72
SEM	3.55	3.17	5.13	3.24	3.02	4.68

Mean separation using Duncan's multiple range test at $P < 0.01$ level of probability.

Means in the same columns followed by the same letter(s) are not significantly different.

CV% = Coefficient of variation. SEM = Standard error of the mean.

generally agreed with earlier research reports (Asmamaw *et al.*, 2010; Ekin, 2011; Elfnesh *et al.*, 2011). Asmamaw *et al.* (2010) and Elfnesh *et al.* (2011) reported a specific gravity range of 1.064 to 1.094 and 1.078 to 1.10, respectively. Likewise, Ekin (2011) reported SG values ranging from 1.065 to 1.077 from a study of eight varieties over two consecutive years. Despite the divergent environmental conditions under which Elfnesh *et al.* (2011) and the current studies were carried out, the SG values reported for the two common varieties of Gabisa (1.086–1.103) and Challa (1.086–1.110) were similar to the SG values obtained in the current study of 1.074 to 1.091 for Gabisa and 1.087 to 1.112 for Challa. Equally, the SG values of Gera, Tolcha, Wochecha, Marachare, Zengena, Guasa and Jalene reported in Asmamaw *et al.* (2010) agreed with the trend recorded in the current study. The small differences observed between the results from these two studies presumably emanated from the varying temperature, soil type and rainfall

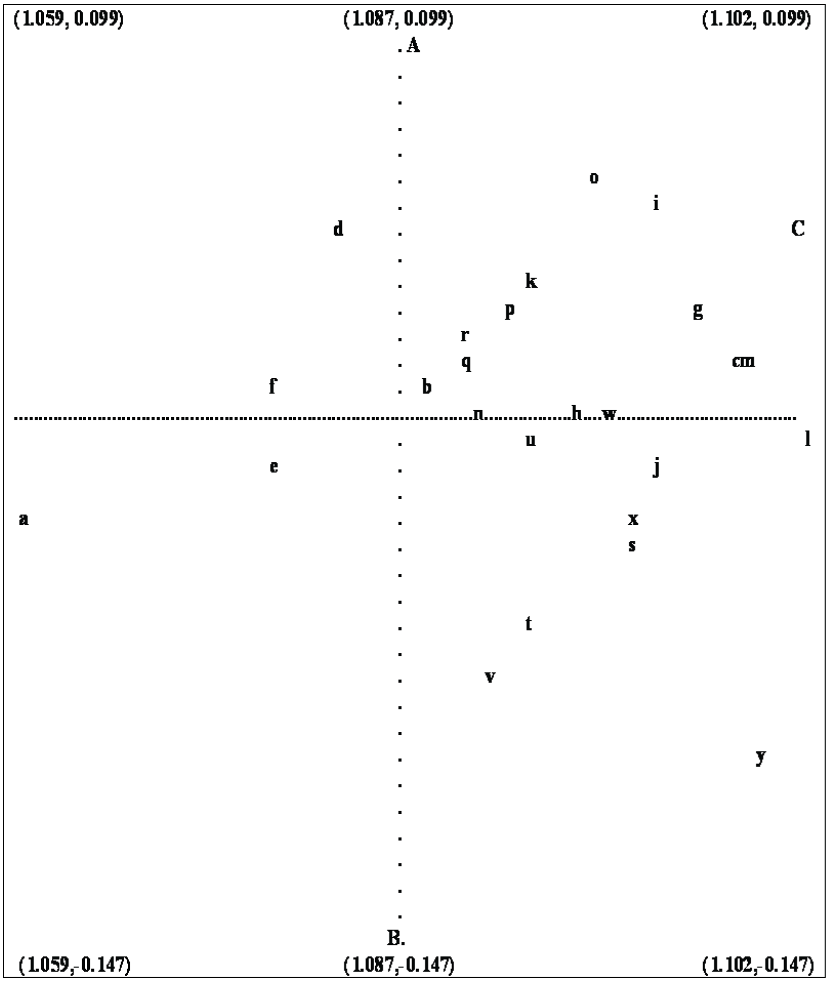

Figure 2 Biplot with abscissa plotting genotypic means as a,b,c,..., from 1.059 to 1.102 and ordinate plotting of interaction principal component axis 1 from -0.147 to 0.099. Environments are plotted as A (Adet), B (Merawi and C (Debretabor). The lowercase letters refer to the varieties listed in Table 3.

recorded at the different sites and the varying conditions in different years at the same site. The different crop protection measures during these experiments might have also contributed to the observed differences as improper control of late blight leaf disease of potato (a serious potato disease worldwide) can have a substantial effect on the photosynthetic efficiency of the growing crop and starch deposition in the tuber that in turn can result in either low or high SG values (Hide and Lapwood, 1978). In general, the agreement among these research results clearly indicates that specific gravity is of value as a measure of potato processing quality.

The significant effects of location on the tuber SG of varieties have also been reported by different workers (Killick and Simmonds, 1974; Asmamaw *et al.*, 2010; Elfnesh *et al.*, 2011). Clearly, the effect of location on the SG of varieties originates from the differential climatic variables that prevail in each environment during crop growth. According to Govindakrishan and Haverkort (2006), the ideal average daily temperature for better yield and quality potato production should be below 21 ^{0}C and above 5 ^{0}C. Similarly, Struik (2007) reported day and night temperatures of 20 ^{0}C and 16 ^{0}C as optimal for total and tuber dry matter production and dry matter apportioning to the tuber. Moreover, it has been reported that tubers produced at high temperatures will have a very low dry matter concentration and a low starch content associated with it (Struik, 2007). The high SG values, dry matter concentration and starch content obtained at Debretabor as contrasted to those of Adet and Merawi presumably resulted from the optimal temperature ranges that favored better photosynthesis, high dry matter production and partitioning to the tubers as clearly noted from the climatic data table of the study period. Moreover, the high organic matter content and high cation exchange capacity soils at Debretabor with sufficient adsorption sites for mineral nutrients could substantially contribute to better moisture retention and essential minerals availability for better crop performance. Contrarily, the temperature ranges at Adet and Merawi were higher than the optimal ceiling that facilitated senescence and poor source-sink relations at these sites. Ekin (2011) has also reported results of a similar kind from a study carried out for two consecutive seasons with marked differences in temperature and moisture during the two years. The high starch content and dry matter content at Debretabor compared to Adet and Merawi presumably could be attributed to the ideal cool conditions that did not interfere with source-to-sink strength or the assimilate allocation. Additionally, the short photoperiod that limits giberellic acid levels in the leaves and the high light intensity that facilitate both early tuber initiation and tuber bulking possibly contributed to the observed differences (Moorby, 1978).

The significant effect of location on genotype for tuber SG was clearly reflected through the inconsistent performance of the genotypes across the study sites and their subsequent ranking order shift. A significant genotype × environment interaction is a common feature of traits conditioned by multiple genes. This has been reported in earlier studies (Killick and Simmonds, 1974; Asmamaw *et al.*, 2010; Abubaker *et al.*, 2011; Ekin, 2011; Elfnesh *et al.*, 2011). A consideration of the sensitivity of genotypes to environmental change has led to predictions about the consequences of selecting genotypes in different environments. Accordingly, in the AMMI analysis in which the nature of interactions can be visualized in a biplot (Kempton, 1984), upward selection in above-average environments and downward selection in below-average environments results in genotypes with a high sensitivity, whereas upward selection in below-average environments and downward selection in above-average environments would result in ones with a low sensitivity. In this study, the CIP-392640.524, Zengena, Jalene and Belete, genotypes, with 0 to -1 interaction principal component axis scores and above average SG values, were found to be highly stable varieties across the study sites in the increasing order of mean SG values being plotted on the x-axis and in the downward quadrant for an above-average environment. Challa, Ater Abeba and Gorebella followed with higher mean SG values and a slightly higher interaction value than all the above varieties. Under such situations, any recommendation ought to take into account the cumulative role of each genotype's SG value, interaction value and ultimately marketable yield for profitable potato production by growers. Thus, Belete, Challa, Grebella, Jalene and Ater Abeba were recommended for processing purposes based on their SG values, performance stability and tuber yield. Similarly, the Debretabor site was found to be the ideal environment for processing potato production. Moreover, Belete, Challa and Gorebella were found apt for French fries owing to their tuber shape with a long axis relative to their transverse axis. Equally, the round-shaped Ater Abeba was apposite for crisp manufacturing purposes. Yet, this does not rule out use of other varieties provided they fulfill the global quality standards mentioned earlier of a dry matter content of 20% or higher, a starch content of 13% and above and/or a specific gravity of 1.08 or higher, as these criteria enable potato growers to earn maximum profit.

CONCLUSION

This study confirmed the presence of significant genetic variability in the SG of tubers of potato varieties in Ethiopia. In addition, the environment had a marked influence on value of tuber SG of varieties. A significant genotype × location interaction was also observed owing to site differences in climatic factors (temperature and photoperiod) and the soil physical and chemical properties that affected the photosynthetic efficiency of varieties and assimilate partitioning among various plant parts. This study showed the importance of SG in estimating the DMC and SC of potato indirectly and determining the processing quality of varieties in Ethiopia, as clearly observed from their SG values that agreed with similar studies reported earlier by different authors. Nevertheless, since potato quality is affected by soil and climatic conditions, the results strongly suggest the continuation of this study in various parts of the country to develop national recommendations.

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