Kasetsart J. (Nat. Sci.) 46 : 671 - 683 (2012)

Dry Matter Content, Starch Content and Starch Yield Variability and Stability of Potato Varieties in Amhara Region of Ethiopia

Tesfaye Abebe[1], Shermarl Wongchaochant[2,*], Thunya Taychasinpitak[2] and Oranuch Leelapon[3]

ABSTRACT

Evaluation of dry matter content (DMC), starch content (SC) and starch yield (SY) of 25 potato varieties was carried out at three distinct locations in the Amhara region of Ethiopia during the 2011 cropping season. The main objectives were to examine the variability and stability of these traits and determine the proper production environments. The 25 varieties were examined in a complete 5 × 5 lattice design with six replications. Statistical analyses of the DMC, SC and SY of these varieties revealed significant ($P < 0.01$) genotypic and location variation and genotype × environment interactions. Consequently, their DMC and SC ranged from 17.82 to 26.70 and 9.75 to 17.85%, respectively, while SY ranged from 2.21 to 6.91 t.ha^{-1}. Correlation analysis revealed a strong linkage ($P < 0.01$) among these characters. Additive main effects and multiplicative interactions analysis for DMC and SC stability identified Gorebella, Ater Abeba, Challa, Belete and CIP-396004.337 as relatively stable for processing while Menagesha, Bulle, Ararsa were suitable for table purposes. Furthermore, Debretabor followed by Adet were found suitable for producing processing types while Merawi was suitable for table types. Thus, this study distinctly separated varieties and environments on the one hand and the available genetic resources for a breeding program aimed at improving DMC and SY of potato in Ethiopia on the other.

Keywords: starch content, dry matter content, potato, variability, stability

INTRODUCTION

Dry matter content (DMC) and starch content (SC) are the two overriding factors governing the quality of potato varieties (Kirkam, 2007). They have a very close association with the culinary quality of potatoes (Cobb, 1935).

The DMC of potato varieties is affected to a high degree by the variety, cultural and environmental conditions during the growing season and storage, and by processing methods and techniques (Karenlampi and White, 2009). Considering the notion of people's preference of one variety over the other, Hardenburg (1933) claimed potato quality is more dependent on the soil, climate and maturity than the variety itself, since properly grown and matured varieties could have as high levels of DMC and SC as other ones. In contrast, Stevenson and Whiteman (1935), Haddock and Blood (1939), Akeley and Stevenson (1944) and Mondal and Hosain (2006) claimed a larger effect was due to the genetic makeup and

[1] Amhara Agricultural Research Institute, Adet Agricultural Research Center, P.O.Box-08, Bahir Dar, Ethiopia.
[2] Department of Horticulture, Faculty of Agriculture, Kasetsart University, Bangkok 10900, Thailand.
[3] National Center for Genetic Engineering and Biotechnology, Pathum Thani 12120, Thailand.
* Corresponding author, e-mail: agrsmw@ku.ac.th

Received date : 01/06/12 Accepted date : 15/09/12

inherent differences of varieties. In the same way, Squirrell and M'acLennan (1928) underscored the overriding influence of the variety on potato quality compared to any other factors. The DMC variability in both cultivated cultivars and wild species has also been reported by several authors (Haddock and Blood, 1939; Jansen *et al*., 2001; Elfnesh *et al*., 2011). Likewise, the SC variability of potato varieties was reported by Barios *et al. (*1963) and Rivero *et al.* (2009). Nevertheless, DMC and SC, like any genetic characters, are a function of hereditary factors and the environment working together (Kooman *et al*., 1996). As a result, a potentially high, dry, matter-producing genotype will not achieve its potential unless it is subjected to the right environment. This has been noted from the variability in the DMC of the same variety across different sites and/or seasons at the same site (Barrios *et al*., 1961; Elfnesh *et al*., 2011). This clearly shows the relevance of evaluating genotypes across locations and seasons. The potato has had a long period of cultivation in Ethiopia dating back to 1958. Presently, it is widely grown across different parts of the country and supports over 2.3 million households of highland inhabitants (CACC, 2003). Correspondingly, the research system has released over 30 varieties that have better yield potential, adaptability and resistance to diseases. However, efforts to study their post-harvest qualities have been very limited in scope and involved inconsistent effort, while starch has never been addressed at all. This sets limits to the current move to develop cottage-level processing in towns and pharmaceutical, textile and paper industries, among others that require starch as an input. Therefore, generating comprehensive information related to potato quality factors and appropriate production sites is a timely issue. The main objectives of this study were: 1) to evaluate the dry matter and starch content and starch yield variability and stability of improved potato varieties, elite clones and widely grown farmers' cultivars in Ethiopia, and 2) to determine environments suitable for the production of table and processing potatoes.

MATERIALS AND METHODS

Description of experimental sites

Adet is positioned at $11^0$16'32″N latitude and $37^0$29'30″ E longitude. It has a red brown Nitosol soil. The Merawi experimental site is located at $11^0$30'0 ″N latitude and $37^0$10'0″ E longitude. The soil is a heavy clay-textured red Nitosol. Debretabor is located at $11^0$51'0″N latitude and $38^0$1'0″ E longitude at a cool highland elevation and has a soil type classified as Luvisol. The rainy season over the three sites extends from May through October and does not limit crops with a growing period ranging from 120 to 150 days. Hence, crops grown in these areas complete their crop cycle without requiring any kind of moisture supplement. Details of the soil pH, cation exchange capacity (CEC), organic matter (OM) content, available N, P, K, texture, precipitation, sunshine hours, altitude, rainfall and temperatures of these sites are indicated in Tables 1 and 2 below.

Table 1 Physicochemical properties of soils of three experimental sites.

Experimental site	Altitude (m)	Soil physical and chemical properties Soil pH	Total N (%)	Available P (ppm)	Available K ($Cmol^+.kg^{-1}$)	CEC (Meq per 100 g)	Organic matter (%)	Texture
Adet	2,240	5.2	0.44	7.17	0.781	30.62	1.69	Heavy clay
Merawi	1,960	5.0	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

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

Table 2 Mean monthly air temperature, rainfall, relative humidity and sunshine hours at experimental sites during 2011.

Experimental site	Cropping season months	Mean monthly rainfall (mm)	Mean air temperature (°C)		Relative humidity (%)	Sunshine (hr)
			Min.	Max.		
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.

Field experimentation

A total of 25 potato genotypes containing 18 improved varieties, 3 elite clones and 4 widely cultivated farmers' cultivars were grown in three distinct environments in Northwestern Ethiopia (Adet, Merawi and Debretabor) during the rainy season of 2011. These varieties had passed through a rigorous evaluation of variety development to examine their adaptability to wider environments, yield potential and disease resistance. Eight of them had also been evaluated for their processing quality in a different set of experiments. They have contrasting maturity times, plant growth habits and storability. The trial sites have distinct cropping patterns owing to the different environmental variables such as temperature and soil type among others that prevail at each site. In all the experimental sites, these varieties were planted in a complete 5 × 5 lattice design with six replications on a gross plot size of 9 m^2. Each plot was planted with a total of 40 tubers spaced at 0.75 × 0.3 m inter- and intra-row spacing, respectively. The plots at Adet and Merawi were fertilized with 81 $kg.ha^{-1}$ nitrogen and 69 $kg.ha^{-1}$ phosphorus (P_2O_5). At Debretabor, each plot was supplied with 108 $kg.ha^{-1}$ nitrogen and 69 $kg.ha^{-1}$ P_2O_5 as per specific recommendations. The mineral nutrients were supplied in the form of di-ammonium phosphate (DAP) and urea. The complete amount of DAP was supplied at planting just below the seed tuber with a light soil covering to avoid direct contact with the seed tuber while the urea was side dressed in two equal applications at 2 wk after emergence and at flowering owing to its mobility characteristic in the soil complex. All other crop husbandry practices, such as cultivation, hilling and weeding were undertaken 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.

Dry matter content analysis

Ten to twelve randomly selected healthy and blameless tubers were selected and used for dry matter determination. The tuber dry matter determination procedure of Liu *et al*. (2002) was followed with a slight modification in the drying method. In the current study, the DMC was determined by the loss of weight method on unpeeled and oven dried chopped tubers. Finally, the DMC of each variety was computed as the ratio of dried weight to fresh weight expressed as a percentage. A duplicate run was carried out for all 25 varieties tested at each of the three sites.

Starch content determination

The procedure of Liu *et al.* (2003) was followed, with some modification, to determine the native starch content of each variety at each location. In the current study, only sodium bisulphate was employed to avoid browning of the starch. Filtration was also done using muslin cloth. The starch cake was dried at 40 °C for 48 hr using a hot air oven (not with ambient air as in the stated protocol). Finally the dried starch (with an average moisture content of 15%) was finely ground, sifted through a 125μm stainless steel sieve and kept packed in air-tight plastic bags for further analysis of the amylose/amylopectin content and pasting properties.

Statistical analysis

The DMC and SC data of each site was subjected to separate analysis of variance (ANOVA) for each location and combined ANOVA across locations using the SAS statistical analysis package by the command PROC GLM (*procedure of general linear model*) SAS (SAS Institute Inc. 2009, USA). Pearson correlation analysis was performed to determine the relationship between dry matter content, starch content and starch using the Statistical Analysis System (SAS version 9.2). Finally, the AGROBASE statistical package (AGROBASE20; Agromix Software, Inc.; Winnipeg, Manitoba, Canada) was employed for additive main effects and multiplicative interaction (AMMI) analysis of the stability of cultivars performance across the three sites/environments which was displayed graphically in a biplot.

RESULTS

One-way analysis of variance

A separate ANOVA was computed for both DMC and SC performance of the 25 varieties evaluated at each location. The results of this one way ANOVA of both DMC and SC at each location showed highly significant ($P < 0.01$) genotypic mean squares for both DMC and SC (Tables 3 and 4). The mean DMC at Adet ranged between 18.44 and 26.93%. At Merawi, the DMC of the 25 varieties fell between 17.45 and 25.85%. Likewise, at Debretabor, these same varieties had a DMC value between 17.05 and 29.88%. At all the experimental sites, the lowest DMC was invariably recorded from the improved variety Menagesha (Table 3). Nevertheless, the varieties containing the highest DMC differed across the three sites. At Adet, the maximum DMC value was recorded for Ater Abeba while at Merawi and Debretabor the maximum DMC value was for Guasa and Agere/Guasa, respectively (Table 3). Another interesting observation in this study was the surfacing of certain group of varieties at the top rank at varying magnitudes across all the sites. This condition plainly depicts the fact that a potentially high yielding variety from the hereditary point of view will yield to its capacity provided the environment is suitable. Hence, the manifestation of the inherent productive potential of varieties follows its placement in the right niche. Overall, almost all varieties produced their maximum DMC at Debretabor (Table 3). As a result (except for the variety Menagesha which showed a consistently low DMC at all sites), the remaining varieties had a DMC value that made them ideal for processing. This clearly revealed the contribution of the environment in enabling cultivars to express their built-in hereditary potential.

In the same way, the SC of varieties showed significant differences within and across sites (Table 4). Accordingly, at Adet, the lowest starch content of 10.44% was obtained from the improved variety Menagesha. Conversely, the improved variety Hunde had the highest SC of 18.51% followed by Belete (17.98%) and Gabisa (17.96%). At Merawi, the lowest SC was recorded for the variety Menagesha, which also gave the lowest SC at Adet. However, the highest SC was recorded from the improved variety Belete (16.66%), which produced the second highest

Table 3 Mean dry matter content of the 25 varieties at three sites in Ethiopia during 2011.

Variety	Location		
	Adet	Merawi	Debretabor
[a]Menagesha	18.44^{k}	17.45^{l}	17.05^{l}
[b]Gera	22.06^{ghi}	19.98^{ghijk}	23.80^{ijk}
[c]Challa	26.59^{ab}	23.25^{cd}	27.83^{bc}
[d]CIP-395096.2	21.82^{ghi}	20.85^{fgh}	24.58^{hij}
[e]Wochecha	23.73^{cdefg}	18.65^{kl}	26.55^{cdefg}
[f]Awash	19.99^{ijk}	18.83^{jkl}	22.43^{k}
[g]Gorebella	25.09^{abcde}	22.33^{def}	29.18^{ab}
[h]Zengena	23.64^{cdefg}	18.50^{kl}	23.25^{jk}
[i]Hunde	19.95^{ijk}	18.35^{kl}	23.75^{ijk}
[j]Agere	24.24^{cdef}	20.70^{ghi}	29.98^{a}
[k]Shenkolla	22.82^{fgh}	21.43^{efg}	26.10^{defghi}
[l]Belete	24.60^{bcdef}	23.05^{cd}	29.00^{ab}
[m]Ater Abeba	26.93^{a}	25.50^{ab}	27.68^{bcd}
[n]CIP-392640.524	21.76^{ghi}	19.73^{hijk}	26.00^{defgh}
[o]Gudene	24.49^{cdef}	23.43^{cd}	26.75^{cdef}
[p]Bulle	21.01^{hij}	20.88^{fgh}	27.33^{cde}
[q]Gabisa	23.60^{cdefg}	19.10^{ijk}	23.65^{ijk}
[r]Tolcha	25.70^{abc}	20.30^{ghij}	24.93^{ghi}
[s]Aba Adamu	25.42^{abcd}	19.75^{hijk}	25.88^{efgh}
[t]Marachare	21.19^{hij}	22.58^{cde}	25.10^{fghi}
[u]Sisay	21.76^{ghi}	21.15^{efgh}	26.15^{defgh}
[v]Ararsa	19.59^{jk}	20.53^{ghi}	24.25^{ij}
[w]Jalene	21.97^{ghi}	24.18^{bc}	26.68^{cdef}
[x]Guasa	23.09^{efgh}	25.85^{a}	29.95^{a}
[y]CIP-396004.337	23.35^{defg}	23.28^{cd}	25.95^{efgh}
Mean	22.91	21.18	25.75
CV (%)	2.92	3.92	3.31
SEM at 1%	±2.01	±2.49	±2.55

CV = Coefficient of variance; SEM = Standard error of mean.

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

Mean values in the same column that are followed by the same letter/s are not significantly different.

yield at Adet. This was followed by the farmer's cultivar Ater Abeba (15.92%) and the elite cultivar CIP-396004.337 (15.18%).

Similar to the Adet and Merawi results, at the Debretabor site, the variety Menagesha produced the lowest SC (10.76%). On the other hand, the highest SC was recorded from the improved variety Gorebella (20.23%) followed by the elite cultivar CIP-396004.337 (18.63%) and farmer's cultivar Ater Abeba (18.42%). These clearly portrayed the different performances of varieties across sites.

Genotypic variation was also observed among the 25 varieties in their starch yield performance (Table 4). At Adet, Guasa gave the highest starch yield of 6.60 $t.ha^{-1}$, followed by Gorebella and Belete with 6.47 and 5.79 $t.ha^{-1}$, respectively, while Awash (2.03 $t.ha^{-1}$), Wochecha

Table 4 Mean starch content and starch yield of the 25 varieties in Ethiopia during 2011.

Variety	Starch content (%)			Starch yield ($t.ha^{-1}$)		
	Adet	Merawi	Debretabor	Adet	Merawi	Debretabor
^{a}Menagesha	10.44^{o}	8.04^{w}	10.76^{r}	2.56^{jk}	2.13^{kl}	2.76^{ghi}
^{b}Gera	13.64^{j}	13.84^{h}	17.71^{e}	3.78^{fghij}	4.43^{cdefg}	5.61^{bcd}
^{c}Challa	17.25^{c}	13.44^{j}	18.05^{d}	5.60^{abcd}	5.10^{bcde}	5.74^{bcd}
^{d}CIP-395096.2	11.60^{n}	14.44^{f}	17.38^{f}	3.26^{ghijk}	4.06^{defgh}	5.36^{bcd}
^{e}Wochecha	12.05^{m}	12.68^{p}	11.58^{q}	2.45^{jk}	2.59^{ijkl}	2.03^{i}
^{f}Awash	12.03^{m}	13.21^{l}	13.14^{p}	2.03^{k}	2.27^{jkl}	2.33^{hi}
^{g}Gorebella	18.39^{a}	14.97^{e}	20.12^{a}	5.79^{abc}	6.40^{b}	8.04^{a}
^{h}Zengena	12.40^{l}	9.87^{v}	15.22^{k}	3.30^{ghijk}	2.95^{hijk}	4.85^{cde}
^{i}Hunde	18.51^{a}	11.44^{t}	11.67^{q}	4.79^{cdef}	4.52^{cdefg}	3.53^{efgh}
^{j}Agere	16.98^{de}	13.48^{i}	14.30^{o}	3.82^{efghij}	3.37^{ghijk}	3.86^{efg}
^{k}Shenkolla	13.77^{j}	13.12^{m}	14.76^{m}	3.73^{fghij}	4.02^{defgh}	4.73^{cde}
^{l}Belete	17.98^{b}	16.66^{a}	16.68^{h}	6.47^{ab}	8.01^{a}	6.26^{b}
^{m}Ater Abeba	16.07^{h}	15.92^{b}	18.42^{c}	4.35^{defgh}	5.34^{bcd}	5.67^{bcd}
^{n}CIP-392640.524	16.27^{h}	13.44^{j}	14.44^{n}	4.23^{defghi}	3.76^{efghi}	3.37^{fgh}
^{o}Gudene	16.82^{ef}	14.14^{g}	16.83^{g}	4.43^{cdefg}	3.76^{efghi}	4.58^{def}
^{p}Bulle	12.73^{k}	12.17^{r}	16.31^{i}	2.89^{ijk}	2.99^{hijk}	3.96^{efg}
^{q}Gabisa	17.96^{b}	11.72^{s}	17.92^{d}	4.53^{cdefg}	3.71^{fghi}	6.20^{b}
^{r}Tolcha	17.82^{b}	10.89^{u}	15.27^{k}	3.68^{fghij}	1.62^{l}	3.08^{ghi}
^{s}Aba Adamu	16.93^{def}	12.74^{o}	14.92^{l}	4.71^{cdef}	3.72^{fghi}	4.03^{efg}
^{t}Marachare	15.49^{i}	13.24^{k}	13.19^{p}	5.03^{cdef}	5.10^{bcde}	4.08^{efg}
^{u}Sisay	16.58^{g}	13.13^{m}	14.94^{l}	4.35^{defgh}	3.36^{ghijk}	4.60^{def}
^{v}Ararsa	11.64^{n}	12.29^{q}	13.22^{p}	3.00^{hijk}	3.56^{ghij}	3.56^{efgh}
^{w}Jalene	16.73^{gf}	15.04^{d}	16.17^{j}	5.21^{bcde}	5.74^{bc}	5.95^{bc}
^{x}Guasa	17.12^{cd}	12.81^{n}	18.06^{d}	6.60^{a}	5.55^{bc}	6.34^{b}
^{y}CIP-396004.337	17.31^{c}	15.18^{c}	18.63^{b}	5.50^{abcd}	4.97^{cdef}	6.42^{b}
Mean	15.38	13.11	15.58	4.24	4.12	4.68
CV%	0.65	0.07	0.32	10.19	10.33	8.81
S.E.M. at 1%	±0.30	±0.03	±0.15	±1.30	±1.28	±1.24

CV = Coefficient of variance; SEM = Standard error of mean.

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

Mean values in the same column that are followed by the same letter/s are not significantly different.

(2.45 t.ha^{-1}) and Menagesha (2.56 t.ha^{-1}) produced the three lowest starch yields. At Merawi, the maximum starch yield of 8.01 t.ha^{-1} was obtained from Belete followed by Gorebella (6.40 t.ha^{-1}), Jalene (5.74 t.ha^{-1}) and Guasa (5.55 t.ha^{-1}). The lowest starch yield was recorded from Tolcha, (1.62 t.ha^{-1}) followed by Awash, Wochecha and Menagesha with values of 2.27, 2.45 and 2.56 t.ha^{-1}, respectively. At the Debretabor site, Gorebella produced the highest starch yield of 8.04 t.ha^{-1} followed by CIP-396004.337, Guasa, Belete and Gabisa with values of 6.42, 6.34, 6.26 and 6.20 t.ha^{-1}, respectively (Table 4). As before for SC, it is interesting to note the consistent prominence of certain cultivars with the highest and lowest scores across all locations with little irregularity. This indicates the overriding effects of heritable factors over environmental factors since similar varieties were positioned at the highest ranking with some order shift. Yet the inherent quality differences of varieties were very pronounced when grown under similar conditions. Thus, a combined ANOVA across sites was carried out to determine the magnitude of the genotype × environment interaction and identify those genotypes with better DMC, SC and starch yield.

Factorial analysis of variance

The results of the combined ANOVA indicated and highly significant ($P < 0.01$) genotype, location and genotype × location mean square for DMC, SC and starch yield (Table 5).

Consequently, the highest mean DMC was recorded from Ater Abeba (26.70%) followed by Guasa (26.30%), Challa (25.89%), Belete (25.55%) and Gorebella (25.53%). The lowest DMC was recorded from Menagesha (17.65%), Awash (20.41%) and Hunde (20.68%). High SC was recorded from Gorebella (17.82%), closely followed by Belete and CIP-396004.337 with values of 17.10 and 17.04%, respectively. The three lowest SC values were recorded from Menagesha (9.75%), Wochecha (12.10%) and Awash (12.49%). Belete had the highest overall mean starch yield of 6.91 t.ha^{-1} followed by Gorebella (6.74 t.ha^{-1}) and Guasa (6.16 t.ha^{-1}). The three lowest average starch yields of 2.21, 2.35 and 2.48 t.ha^{-1} were recorded from Awash, Wochecha and Menagesha, respectively (Table 5). Considering all three sites, Debretabor showed a pronounced effect for varieties to manifest their inherent quality differences. Accordingly, the highest overall values of DMC (25.75%), SC (15.58%) and starch yield (4.68 t.ha^{-1}) were recorded at this site. Adet and Merawi closely followed with overall mean values of DMC of 22.91% and 21.18%, of SC of 15.38% and 13.11% and of starch yield of 4.24 and 4.12 t.ha^{-1}, respectively. The significant genotype × environment interaction was observed to be qualitative in its nature as manifested by the inconsistent ranking of varieties across sites. Hence, varieties that have the least interaction with environment gave higher above average values of DMC, SC and starch yield are imperative. To test this effect, an AMMI was carried to identify the genotypes that were relatively stable in their performance.

Correlation analysis

Pearson correlation analysis among the quality governing factors was carried out (Table 6). The results of this analysis revealed the presence of a strong, positive association between DMC and SC (r = 0.81; $P < 0.01$), DMC and SY (r = 0.67; $P < 0.01$) and SC and SY (r = 0.82; $P < 0.01$) as shown in Table 6.

Hence, simultaneous improvement of these quality governing factors is possible as they are controlled by the same genetic factors.

AMMI Analysis

AMMI analysis of the DMC and SC of the 25 varieties across the three varying environments distinctly sorted out varieties with the minimal or smallest interaction with environments and identified those environments with better DMC and SC performance and subsequently high starch yield (Figures 1 and 2). As a result, Gorebella,

Table 5 Mean results of combined analysis of variance of dry matter content, starch content, starch yield and maturity date of 25 potato varieties in Ethiopia during 2011.

Variety	Dry matter content (%)	Starch content (%)	Starch yield ($t.ha^{-1}$)	Maturity date (days)
[a]Menagesha	17.65^{m}	9.75^{q}	2.48^{j}	108^{a}
[b]Gera	21.95^{jk}	15.86^{g}	4.60^{def}	97^{bcdef}
[c]Challa	25.89^{b}	16.25^{d}	5.48^{c}	102^{abcde}
[d]CIP-395096.2	22.41^{ij}	14.47^{j}	4.21^{efg}	103^{abcde}
[e]Wochecha	22.98^{hi}	12.10^{p}	2.35^{j}	105^{ab}
[f]Awash	20.41^{l}	12.49^{m}	2.21^{j}	89^{g}
[g]Gorebella	25.53^{bc}	17.82^{a}	6.74^{a}	102^{abcde}
[h]Zengena	21.80^{jk}	12.79^{n}	3.68^{gh}	100^{abcdef}
[i]Hunde	20.68^{l}	13.87^{k}	4.28^{efg}	103^{abcd}
[j]Agere	24.97^{cd}	14.92^{h}	3.68^{gh}	108^{a}
[k]Shenkolla	23.45^{gh}	13.88^{k}	4.16^{fg}	98^{bcdef}
[l]Belete	25.55^{bc}	17.10^{b}	6.91^{a}	105^{ab}
[m]Ater Abeba	26.70^{a}	16.80^{c}	5.12^{cd}	104^{ab}
[n]CIP-392640.524	22.50^{ij}	14.72^{i}	3.79^{gh}	100^{abcde}
[o]Gudene	24.89^{cde}	15.93^{ef}	4.25^{efg}	94^{fg}
[p]Bulle	23.07^{hi}	13.73^{l}	3.28^{hi}	102^{abcd}
[q]Gabisa	22.12^{jk}	15.93^{f}	4.81^{de}	95^{defg}
[r]Tolcha	23.64^{fgh}	14.66^{i}	2.79^{ij}	105^{ab}
[s]Aba Adamu	23.68^{fgh}	14.86^{h}	4.15^{fg}	102^{abcde}
[t]Marachare	22.95^{hi}	13.97^{k}	4.73^{def}	103^{abcd}
[u]Sisay	23.02^{hi}	14.88^{h}	4.10^{fg}	92^{fg}
[v]Ararsa	21.46^{k}	12.38^{o}	3.37^{h}	95^{cdefg}
[w]Jalene	24.27^{def}	15.98^{e}	5.63^{bc}	106^{ab}
[x]Guasa	26.30^{ab}	15.99^{e}	6.16^{b}	106^{ab}
[y]CIP-396004.337	24.19^{efg}	17.04^{b}	5.63^{bc}	104^{ab}
Mean	23.28	14.69	4.34	101
CV%	3.11	0.44	8.23	6.05
S.E.M. at 1%	±2.17	±0.19	±1.07	±2.47

CV = Coefficient of variance; SEM = Standard error of mean.
Mean values are separated using Duncan's multiple range test at $P < 0.01$ level of probability.
Mean values in the same column that are followed by the same letter/s are not significantly different.

Table 6 Correlation among dry matter content, starch content and starch yield of 25 potato varieties in Ethiopia during 2011.

Characteristic	DMC	SC	SY
DMC	1.00	0.81**	0.67**
SC		1.00	0.82**
SY			1.00

DMC = Dry matter content; SC = Starch content; SY= Starch yield.
** = Highly significant ($P < 0.01$).

Agere, Ater Abeba, Gudene and Belet were identified as stable for the DMC. Interaction - principal component axis (IPCA) 1 accounted for about 60% of the explained genotype by environment interaction (G × E) value.

The IPCA scores of these varieties were very small ranging from -0.19 for Belete to 0.15 for Ater Abeba. Gorebella and Agere had IPCA scores of 0.06 and 0.02, respectively indicating their close proximity to the x axis. In the same manner Gorebella, Belet, CIP-396004.337, Challa and Guasa were identified as stable varieties for SC across location. Here, IPCA1 explained 65% of the G × E value. Accordingly, the IPCA scores of these varieties were between -0.14 for Belete and 0.19 for CIP-396004.337. Hence, values close to the x axis indicate minimum interaction with the environment. The improved variety Menagesha invariably had the lowest DMC and SC across all locations (Figures 1 and 2). This variety also had the lowest IPCA score of 0.01. Stability analysis of starch yield (not presented) identified Jalene, Challa, Guasa, CIP-396004.337, Ater Abeba. Gorebella and Belete, which produced the highest starch yields, showed specific adaptation to Debretabor and Merawi, where they produced the maximum yield of both tuber and starch content. Overall, the Debretabor site was identified as the most suitable site with better DMC, SC and high starch yield production and was followed by the Adet site. Merawi was also found to be an appropriate site for table-type potato production.

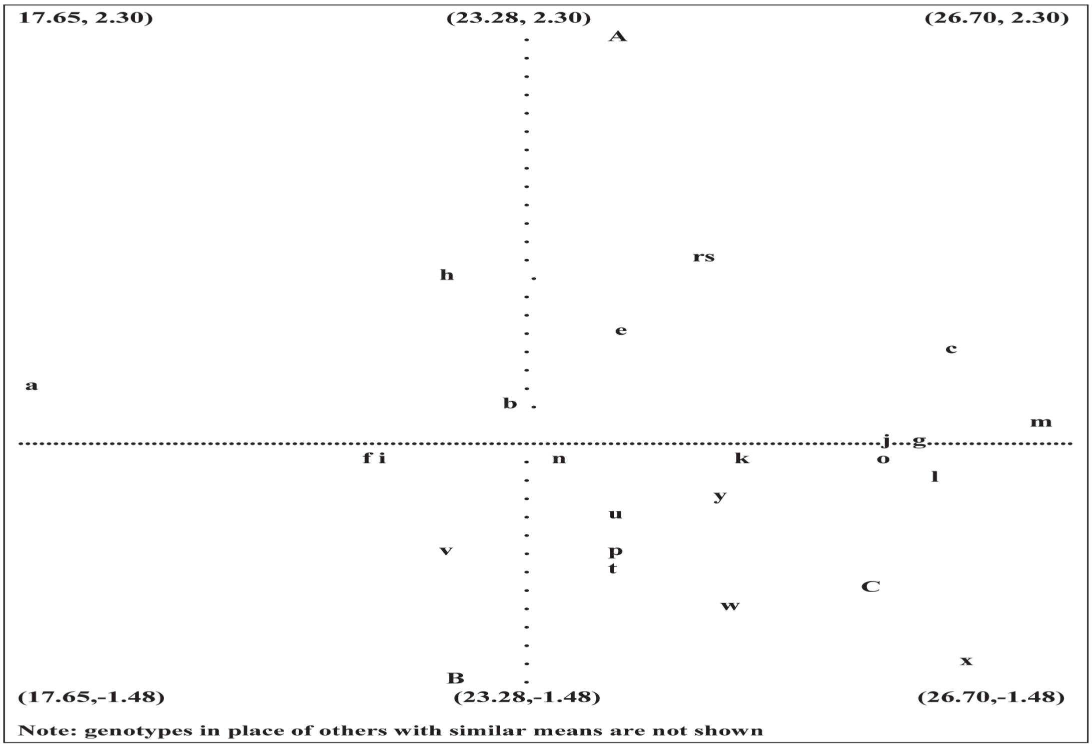

Figure 1 Biplot with x-axis plotting means of dry matter content and y-axis plotting interaction principal component axis 1. Genotypes are plotted as a,b,c,... and environments as A (Adet), B (Merawi), C (Debretabor).

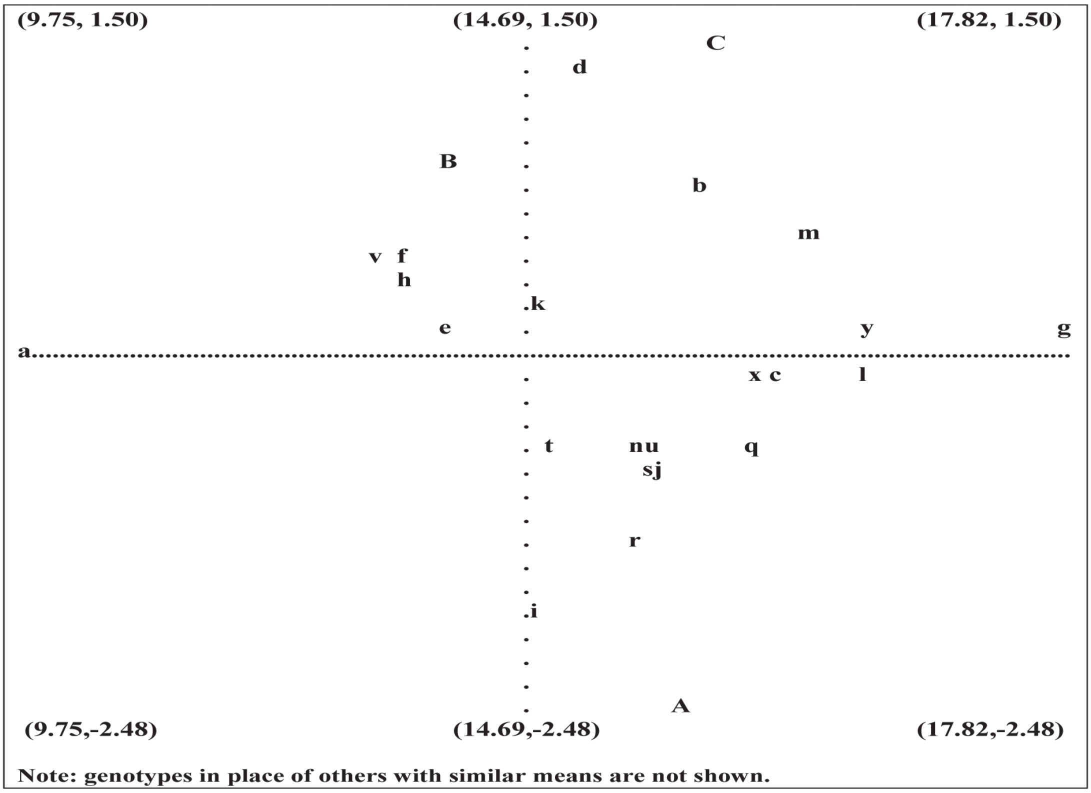

Figure 2 Biplot with x-axis plotting means of starch content and y-axis plotting interaction principal component axis 1 from genotypes plotted as a,b,c, ... and environments as A (Adet), B (Merawi), C (Debretabor).

DISCUSSION

The significant ($P < 0.01$) genotypic variation observed among the varieties evaluated in this study in dry matter and starch content agreed with earlier reports (Benesi *et al.*, 2004; Rivero *et al.,* 2009; Ekin, 2011; Elfnesh *et al.,* 2011). The sources of this variation, presumably attributed to heritable factors contributing to this crop yield and quality. Houghland *et al*. (1961), Cole (1980) and Munzert (1987), illustrated the positive correlation between late maturity, tuber size, plant growth habit and leaf angle orientation and that of dry matter and starch content. Such fundamental differences among varieties regarding these characteristics could account for the observed DMC and SC differences among the studied varieties. Gray and Hughes (1978) also reported that tubers from late-maturing potato varieties usually have higher DMC than tubers of early-maturing varieties. The results of the current study were in agreement with this established fact as all the varieties that had high DMC value—Ater Abeba (26.70%), Guasa (26.30%), Challa (25.89%), Belete (25.53%) and Gorebella (25.53%)—are characterized by a relatively long maturity cycle ranging from 102 to 106 days. Also, Belete, Challa, Gorebella and Ater Abebea have an upright and open-type vine growth in which their leaves are held at an acute angle that enables them to trap the maximum radiant energy to produce food energy. The significant role of such plant morphology for increased efficiency of light utilization in contrast to varieties having an umbrella type of vine growth with leaves nearly held perpendicular to sunlight that results in them shading each other is well described by Houghland *et al*. (1961). This was corroborated by the varieties that had lower DMC, SC and SY performance, such as Awash, as they too had an umbrella type of vine. The tuber size grade distributions of the varieties Ater Abeba, Challa, Guasa, Belete and Gorebella (56–112 g) were the larger ones which would have contributed to the high DMC as well as the high SC. Generally, all the above results of the current research clearly corroborate the results of earlier studies.

Likewise, the significant variation in yield parameters among the experimental sites was attributed to the prevailing differences in environmental variables such as temperature, relative humidity and sunshine hours and the soil physicochemical properties of these sites as seen in Tables 1 and 2. Burton (1966) reported prolonged and greater top growth of both early and late varieties under long-day compared to short-day conditions. The observed mean plant height of varieties at the Adet (61cm) and Merawi (55cm) sites that have comparatively longer day lengths than that at Debretabor (44cm) was in agreement with the above report. Burton (1966) cited Okazaw (1959, 1960) in support of his statement that haulm elongation is lower in plants grown under short compared to long days owing to the lowered gibberllin concentration under the short day conditions. Yet the degree of reduction varied with variety. Similarly, low temperature influenced the vegetative growth and rates of both photosynthesis and respiration with a net effect on dry matter yield. The available evidence suggests an optimum temperature for tuber formation and growth, in most varieties, is about 15–20 ^{0}C. Burton (1966) also cited Bushnell (1925) who reported that leaf and tuber size reduced as the temperature rises over the range of 20–29 ^{0}C, with no tubers forming at the upper temperature. The high DMC, SC and SY obtained at the Debretabor site as contrasted to that of Adet and Merawi clearly agrees with this report. Similarly, the relatively low DMC, SC and SY at Merawi were partly attributed to the high temperature during the latter crop stage that might have contributed to high respiration and reduced assimilate deposition. The high organic matter (OM) content of the soil at Debretabor in association with the low air temperature also contributed to low evapotranspiration and the subsequent retention of soil moisture for mineral transportation by the root system. The high OM content will also present sufficient adsorption surface area and improve the cation exchange capacity of the soil, for the supply of mineral nutrients needed by the crop.

Gray and Hughes (1978) reported that starch constitutes 65–80% of the dry matter content of the potato tuber. The positive, strong linkage observed in the current study between DMC and SC endorses this concept. The same explanation holds true for the strong link observed between SC and SY as the starch yield is a function of the starch content and tuber yield.

CONCLUSION

The genotypic variability observed in this study of the DMC, SC and SY agreed with earlier reports using a similar research procedure, as do the results of the influence of environment on the performance of genotypes owing to the prevailing set of environmental variables that influence growth and development of this crop plant. The strong, positive association observed among the three quality governing factors presents a valuable opportunity for improving them simultaneously as they are controlled by the same genetic factors. In general, the current study highlighted the on-hand resource that can be exploited in the breeding program for improved DMC, SC and SY in Ethiopia. Furthermore, environments suitable for production of the desired types of potatoes were clearly identified. Accordingly, Gorebella, Belete, Guasa, Challa, CIP-396004.337 and Ater Abeba were found ideal for processing, especially for high starch production while Menagesha, Awash, Ararsa, and Bulle were found to be most suitable for home consumption or for use as a table-type potato. Likewise, while the Debretabor site produced high values of DMC, SC and SY, Merawi was invariably suitable for table-type potato production owing to its climatic conditions. The superiority of the Debretabor site in dry matter accumulation and other quality factors is attributed to the temperature regime that is ideal for good potato production, dry matter accumulation and high SC and SY in contrast to high temperature that leads to competition among plant parts. The soil temperature and physicochemical properties also made a contribution. Yet, as these quality factors considerably vary across seasons and years, it is strongly recommended that the current research be continued for several years on a greater number of sites to allow firm recommendations to be made at the national level.

ACKNOWLEDGEMENT

The authors acknowledge the Ministry of Agriculture of Ethiopia for financially supporting the study and are also grateful to the Sustainable Water Harvesting and Institutional Strengthening in Amhara (SWHISA) project for its generous financial support for both field and laboratory work.

LITERATURE CITED

Agrobase. 2000. **Agrobase 20 for Windows.** Agromix Software, Inc. Winnipeg, Manitoba, Canada.

Akeley, R.V. and F.J. Stevenson. 1944. The inheritance of dry-matter content in potatoes. **Am. Potato. J.** 21: 83–89.

Barrios, E.P., D.W. Newsom and J.C. Miller. 1963. Some factors influencing the culinary quality of Irish potatoes. II. Physical characteristics. **Am. Potato J.** 40: 200–208.

Benesi, I.R.M., M.T. Labuschage, A.D.G. Dixon and N.M. Mahungu. 2004. Genotype × environment interaction effects on native cassava starch quality and potential for starch in the commercial sector. **Afr. Crop Sci. J.** 12(3): 205–216.

Burton, N.G. 1966. A survey of its history and factors influencing its yield, nutritive value, quality and storage. pp. 51–139. *In* N.G. Burton (ed.). **The Potato.** H. Veenman and N.V. Zonen (eds.). Wageningen, Holland.

Central Agricultural Census Commission (CACC). 2003. **Ethiopian Agricultural Sample Enumeration 2001/2002. Statistical Report on Farm Management Practices. Livestock and Farm Implements. Part II.** Addis Ababa, Ethiopia. 350 pp.

Cobb, J.S. 1935. A study of culinary quality in white potatoes. **Am. Potato J.** 12: 335–347.

Cole, C.S. 1980. Breeders' problems. **Annuals of Applied Biology** 96: 354–357.

Ekin, Z. 2011. Some analytical quality characteristics for evaluating the utilization and consumption of potato (*Solanum tuberosum* L.) tubers. **Afr. J. Biotechnol.** 10(32): 6001–6010.

Elfnesh, F., T. Tekalign and W. Solomon. 2011. Processing quality of improved potato (*Solanum tuberosum L.*) cultivars as influenced by growing environment and blanching. **Afr. J. Food Sc.** 5(6): 324–332.

Gray, D. and J.C. Hughes. 1978. Tuber quality. pp. 504–544. *In* P.M. Harris (ed.). **The Potato Crop: The Scientific Basis of Improvement.** Chapman and Hall. London, UK.

Haddock, J. L. and P.T. Blood. 1939. Variations in cooking quality of potatoes as influenced by varieties. **Am. Potato J.** 16: 126–133.

Hardenburg, E.V. 1933. Some false notions about potato varieties. **Am. Potato J.** 10: 201–204.

Houghland, G.V. C., R.V. Akeley and A. E. Kehr. 1961. A program for breeding industrial potato varieties. **Am. Potato. J.** 38: 419–422.

Jansen, G., W. Flamme, K. Schüler and M. Vandrey. 2001. Tuber and starch quality species and cultivars of wild and cultivated potato. **Potato Research** 44: 137–146.

Karenlampi, S.O. and P.J. White. 2009. Potato proteins, lipids, and minerals. pp. 99–125. *In* J. Singh and L. Kaur (ed.). **Advances in Potato Biochemistry.** Elsevier Academic Publishers. Maryland, USA.

Kirkman, M.A. 2007. Global markets for processed potato products. pp. 27–44. *In* D. Vreugdenhil, (ed.). **Potato Biology and Biotechnology Advances and Perspectives.** Elsevier. Oxford, UK.

Kooman, P.L., M. Fahem, P. Tegera and A.J. Haverkort. 1996. Effects of climate on different potato genotypes 2. Dry-matter allocation and duration of the growth cycle. **Eur. J. Agron.** 5: 207–217.

Liu, Q., E. Weber, V. Currie and R.Yada. 2003. Physicochemical properties of starches during potato growth. **Carbohydr. Polym.** 51: 213–221.

Liu, Q., R. Yada and J. Arul. 2002. Characterization of thermal properties of potato dry matter–water system. **J. Food Sci.** 67: 560–566.

Mondal, M.A.A. and M.M. Hossain. 2006. Combining ability in potato (*Solanum tuberosum* L.). **Bangladesh J. Bot.** 35(2): 125–131.

Munzert, M.1987. Potato breeding strategy in Federal Republic of Germany. pp.38–44. *In* G.J. Ellis and D.E. Richardson (eds.). **The Production of New Potato Varieties.** Cambridge University Press. Cambridge. UK.

Rivero, C.R., S.P.L. Hernández, R.E.M. Rodriguez and D. C. Romero. 2009. Chemical composition of eight cultivars of potatoes. Application of multivariate analysis. **Acta Alimentaria** 38 (4): 405–414.

SAS Institute Inc. 2009. **SAS System.** Cary, NC, USA.

Squirrell, W.J. and A.H. M'acLennan. 1928. Potatoes. **Ontario Bull.** 339: 2.

Stevenson, F.J. and F. Whitman. 1935. Cooking quality of certain potato varieties as influenced by environment. **Am. Potato J.** 12: 41–48.