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Variation in Chemical Composition and Pasting Properties of Starches of Different Potato Varieties Grown at Different Locations in Amhara Region, Ethiopia

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ABSTRACT

Potato starches isolated from 25 different varieties grown at three different locations in the Amhara region of Ethiopia in 2011 were studied to determine their variation based on amylose content (AMC) and amylopectin content (APC), and pasting properties by iodine colorimetry and Rapid Visco Analyzer procedures, respectively. The results revealed highly significant ($P < 0.01$) differences between cultivar and location. The mean values for the AMC and APC ranged from 20.86% (Jalene) to 30.58% (Ater Abeba), and 69.42% (Ater Abeba) to 79.14% (Jalene), respectively. The mean AMC index of locations ranged from 24.50% to 26.24% for the Adet and Debretabor sites. The peak viscosity (PV), hot paste viscosity (HPV), breakdown viscosity (BDV), cool paste viscosity (CV) and setback viscosity (SBV) ranged from 225.10 to 426.72, 135.01 to 191.83, 56.47 to 259.32, 173.68 to 247.51 and 27.17 to 68.15 Rapid Visco units (RVU), respectively, while the pasting time (PT) and pasting temperature (Ptemp) ranged between 3.35 to 4.91 minutes and 68.16 to 70.89 °C, respectively. Correlation among starch properties showed significant ($P < 0.01$ and $P < 0.05$) associations except for PV with CPV and HPV with BDV and SBV. The highest PV (538 RVU), HPV (207 RVU), BDV (363 RVU), and CV (265 RVU) values were recorded at the cool Debretabor site. Thus, the study revealed the significant genetic variation present among varieties with regard to the starch chemical composition and pasting properties and the effects of growing location on these properties.

Keywords: potato, starch, amylose, pasting properties, variety, location

INTRODUCTION

Potato (*Solanum tuberosum* L.) is the fourth most important food crop after wheat, rice and maize with a global production of over 324 million t (Food and Agriculture Organization, 2010). It is grown for direct consumption as a major source of carbohydrate energy for hundreds of millions of people around the world and as a raw material for processed products such as crisps (chips), French fries, frozen products, dehydrated products, chilled-peeled potatoes and canned potatoes (Kirkman, 2007). In North America and some European countries, 50 to 60% of the crop is processed (Li *et al*., 2006; Kirkman, 2007). Furthermore, potato is used for production of its unique starch that can form a clear and thick visco-elastic gel upon heating and subsequent cooling

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(Vasanthan *et al*., 1999). These properties of potato starch are attributed to its large granule size, purity, relatively long amylose chain lengths and amylopectin with a relatively higher phosphorus content (approximately 0.08%) than other major starch sources such as corn starch (approximately 0.02%), waxy maize starch (approximately 0.01%), and tapioca starch (approximately 0.01%), according to Li *et al*. (2006). Starch functional properties are determined by factors such as the granule size, chemical composition, amylose and amylopectin content ratios of starch and the pasting properties of potatoes, which vary with the cultivar (Yusuph *et al*., 2003; Li *et al*., 2006; Alvani *et al*., 2010). Guilbot and Mercier (1985) and Schwartz and Whistler (2009) also reported that the granular structure of the starch is essentially determined by genetic factors that govern starch biosynthesis. Furthermore, these starch characteristics are influenced by growing location (Kuar *et al*., 2007), plant growth stage (Liu *et al*., 2003) and growing year (Svegmark *et al*., 2002) among others. These facts clearly underscore the relevance of evaluating different genotypes at different locations in the identification of starches of desired quality.

In Ethiopia, potato is a widely grown and consumed staple food crop by over 2.3 million households, with the Amhara region accounting for over 50% of potato production in Ethiopia (Central Agricultural Census Commission, 2003). It is mainly consumed simply boiled, as a salad and in sauce. Thus, its industrial utility in globally known processed food forms and as an ingredient in the paper, textile, pharmaceutical and glue industries in the country has not fully been exploited. This is partly attributed to the lack of any kind of information related to the starch chemical composition and pasting properties of potato varieties grown in the country. The present study was therefore carried out with the main objective of studying the chemical composition (amylose and amylopectin content) and variability of pasting properties of starches isolated from 25 potato cultivars grown at three different locations in the Amhara region of Ethiopia so that the industrial potential of existing potato varieties and environments in the country can be exploited.

MATERIALS AND METHODS

Materials

A total of 25 potato varieties (18 improved varieties, 3 advanced clones and 4 widely grown farmer's cultivars) differing in maturity date, growth habit, yield level, disease resistance, storage quality and other attributes were used in the study.

Description of the experimental sites

Adet is positioned at $11^0$16'30.3" N and $37^0$30'1.8" E. It has a red brown Nitosol soil. The Merawi experimental site is located at $11^0$25' 0" N latitude and E $37^0$10'0" 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 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 of 120 to 150 d and thus they complete their cycle without requiring any kind of moisture supplement (Tesfaye *et al*., 2012a). Details of the soil pH, cation exchange capacity (CEC), organic matter (OM) content, available N, P, K, texture are provided in Table 1 and for precipitation, sunshine hours, altitude, rainfall and temperatures of these sites in Table 2.

Field experiments

Whole seed tubers at multiple sprouting stages were planted at three different locations in a balanced 5 × 5 lattice design with six replications during the rainy season of 2011. The cultivars were randomly allocated to plots with 40 tubers per plot and arranged as four rows of ten plants per row at 0.75 × 0.3 m spacing between rows and plants, respectively. The plants at Adet and Merawi were fertilized at a rate of 81 and 69 kg.ha^{-1} nitrogen and phosphorus (N and P_2O_5), respectively.

Table 1 Physicochemical properties of soils of three experimental sites.

Experimental site	Altitude above sea level (m)	Soil physical and chemical property						
		Soil pH	Total N (%)	Available P (ppm)	Available K ($Cmol^+.kg^{-1}$)	CEC (Meq per 100 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

Sourced: Adet Agriculture Research Center, Soil and Water Research Department, pers. comm.

Table 2 Range of air temperature, relative humidity, sunshine hours and total rainfall during cropping seasons at experimental sites, 2011.

Experimental site	Cropping season	Cropping season rainfall (mm)	Air temperature (°C)		Relative humidity (%)	Sunshine per day (hr)
			Minimum	Maximum		
Adet	May–October	1,124.3	10.0–18.1	24.2–27.9	54–80	4.6–8.4
Merawi	May–October	1,585.4	12.1–15.0	24.4–28.7	68–74	8.3–11.0
Debretabor	May–October	1,488.1	9.0–15.2	18.9–23.8	54–83	2.9–7.8

Sourced: Ethiopian Meteorological Agency, Bahir dar Branch, pers. comm.

Likewise, plants at Debretabor were fertilized at a rate of 108 and 69 $kg.ha^{-1}$ N and P_2O_5, respectively. The complete amount of phosphorus was applied at planting while the nitrogen source was applied in equal amounts at planting, 2 wk after emergence and at flowering to reduce leaching loss. Disease protection measures were carried by spraying Mancozeb fungicide twice. All other crop husbandry practices were carried out as needed. At maturity, some healthy and marketable-sized tubers were randomly selected from each replication for starch extraction.

Sample preparation

The starch of individual varieties in the study was isolated according to the procedure of Liu *et al.* (2003) with some modifications related to the chemical used to inhibit starch discoloring, microbial growth and the activity of enzymatic amylase (a commonly occurring plant enzyme that hydrolyzes starch), and to the filtration, starch cake drying and milling procedures. Accordingly, in the current study only sodium bisulphate was used to arrest the action of starch browning microbial growth and the enzymatic amylase hydrolysis of starch. In addition, starch filtration and subsequently starch cake drying was carried out using muslin cloth and a hot-air oven (Tesfaye *et al*., 2012a).

Moisture content

Starch samples (circa 100 mg) were weighed into pre-dried aluminum dishes then placed in an air-forced oven for 1 hr at 130 ± 3 °C to dry. The samples were removed, left in desiccators for 40 min to cool and were reweighed. The moisture content was calculated as the percentage weight loss of the sample (Alvani *et al*., 2010).

Amylose and amylopectin content determination

The amylose content of potato starch was quantified by the iodine colorimetric method according to McGrance *et al*. (1998) with a slight modification. Potato starch samples were gelatinized with 0.1 N sodium hydroxide overnight at 5 °C and neutralized with 0.1 N acetic acid. The sample solutions were then diluted to 100 mL with water. A 1 mL solution was mixed with 3 mL of water, followed by the addition of iodine solution (1 mL, 6.5 × 10^{-4} mole.L^{-1} I_2 in 1.3 × 10^{-2} mol.L^{-1} KI). The mixture was allowed to stand for 10 min and the absorbance of samples was then recorded at 600 nm. The amount of amylose was calculated based on the standard curve prepared from a mixture of amylose and amylopectin from potato containing 0, 10, 25, 50, 75 and 100% amylose. The amylopectin content was calculated as the difference (100 – amylose %).

Pasting properties analysis

The pasting properties of the potato starches were evaluated with a Rapid Visco–Analyzer (RVA; Model RVA–4, Newport Scientific, Warriewood, New South Wales, Australia). Starch (3 g, 14% moisture basis) was weighed directly in the aluminum RVA sample canister and distilled water was added to a total weight of 28 g. The samples were held at 50 °C for 1 min, heated to 95 °C in 3.7 min, held at 95 °C for 2.5 min and then held at 50 °C for 2 min. Parameters recorded were the pasting temperature (Ptemp), pasting time (PT), peak viscosity (PV), hot paste viscosity (HPV; the lowest viscosity at 95 °C), cool paste viscosity (CV; final viscosity at 50 °C), breakdown viscosity (PV–HPV) and setback viscosity (CV– HPV). All measurements were done in duplicate.

Statistical analysis

The amylose and amylopectin content data in Table 3 are the average of triplicate determinations of each variety. The starch moisture content and pasting properties data are the average of duplicate determinations with standard deviations computed for each variety. Pearson correlation coefficients (r) were computed to examine the relationships between the starch constituent polymers and pasting properties. This analysis was carried out using the SAS Statistical Software version 9.2 (SAS Institute Inc., 2010).

RESULTS AND DISCUSSION

One–way analysis of variance

A separate analysis of variance was carried out on the amylose, amylopectin and moisture contents and the pasting properties data of starches isolated from the 25 potato varieties evaluated at each location. The results of analyses of these data at each location showed the presence of highly significant ($P < 0.01$) genotypic differences in the amylose, amylopectin and moisture contents (Table 3) and the starch pasting properties (Tables 4, 5 and 6).

Amylose and amylopectin content

The AMC and APC of starches of the 25 different potato varieties are shown in Table 3. Varieties showed highly significant ($P < 0.01$) differences in their AMC and APC values at all locations (Table 3). At Adet, the AMC of the evaluated varieties' starch ranged between 19.40% for Gorebella and 32.22% for farmer's cultivar Ater Abeba. The lowest AMC in the accumulated variety Gorebella was surpassed closely by Jalene (19.58%), Sisay (20.34%) and Guasa (20.75%). On the other hand, the variety with the highest AMC (farmer's cultivar Ater Abeba), was followed by Shenkolla (29.84%) and Ararsa (29.02%). At Merawi, the AMC ranged from 19.96% for Zengena to 33.43% for Tolcha, with CIP-396004.337 (21.29%) and Jalene (21.51%) surpassing Zengena with close proximity to the low AMC groups; Ararsa, Wochecha, Bulle and Gera followed Tolcha with 30.34, 29.87, 29.63 and 29.22%, respectively. At Debretabor, the AMC ranged from 20.12 to 31.68% for Guasa and Ater Abeba, respectively. Jalene was second lowest with 21.50%. Perversely, Aba Adamu and Ararsa followed Ater Abeba with 30.85 and 30.85%, respectively, (Table 3). Grommers and van der Krogt (2009) reported that the starch amylose content of potato normally ranges from 21 to 25%. In a study carried out to investigate the effects of genotype and growing conditions on the chemical composition and properties of the starch granules in potato tubers, Cottrell *et al.* (1995) reported an AMC range of 24.4 to 30.9%. Similarly, Yusuph *et al*. (2003), Liu *et al*. (2007), Kuar *et al.* (2007), Mbougueng *et al.* (2008), Rivero *et al.* (2009) and Alvani *et al.* (2010) reported an AMC range of 25.8 to 31.2%, 29.7 to 33%, 15 to 23.10%, 23.49 to 38.40%, 23.9 to 28.9% and 25.2 to 29.1%, respectively. Noda *et al*. (1998) also noted that the AMC of normal starches should fall between 10 and 30%. The AMC results of the 25 varieties evaluated in the present study were all consistent with all reported literature except for the starch values of Ater Abeba isolated from Adet (approximately 32%) and of Tolcha from Merawi (approximately 31%).

Starches of the 25 different potato varieties also showed highly significant ($P < 0.01$) differences in the APC (Table 3). At Adet, the APC value ranged from 67.78 to 80.42% for Ater Abeba and Jalene, respectively. At Merawi and Debretabor the APC values of the 25 varieties ranged from 66.57% for Tolcha to 80.04% for Zengena, and from 68.32% for Ater Abeba to 79.88% for Guasa, respectively. Grommers and van der Krogt (2009) reported an APC range from 75 to 79%. Similarly, Yusuph *et al.* (2003) reported an APC range of 68.8 to 74.2% among 12 potato varieties evaluated at one location for their starch composition. Liu *et al.* (2007), Kuar *et al*. (2007), Mbougueng *et al.* (2008) and Alvani *et al.* (2010) reported APC values ranging from 67 to 70.3%, 76.9 to 85%, 61.6 to 76.51% and 70.9 to 74.8%, respectively, from studies carried out in different countries on varying numbers of varieties. All APC values recorded among the 25 different potato varieties in the present study were in agreement with the results from earlier reports. Thus, genotypes have a significant effect on the chemical composition of starch granules from potato tubers (Kuar *et al*., 2007; Alvani *et al.*, 2010).

Starch moisture content

The moisture content of the starches of the 25 potato varieties from the three different locations showed highly significant ($P < 0.01$) variation among the different varieties at each location (Table 3). At Adet, the MC of varieties ranged between 13.71% for Ararsa and 17.98% for Tolcha. These same varieties grown at the Merawi and Debretabor locations had an MC range of 14.75% for Tolcha to 15.88% for Belete and 13.00% for Agere and 16.23% for Gorebella, respectively. Mbougueng *et al.* (2008) reported an MC range of 10.29 to 18.33% among three potato varieties. Thus, the MC values obtained in the current study were in agreement with these authors and the generally acceptable level practiced by the European Union for commercial starch (Grommers and van der Krogt, 2009). The differences in the MC of the different varieties of starch could be attributed to differences between the varieties and differences in the extent of drying time (Chen *et al*., 2003). Tsakama *et al.* (2010) reported similar MC differences among starches isolated from 11 sweet potato varieties in Malawi.

Starch pasting properties

The analysis of the starch pasting properties of the different varieties showed the presence of highly significant ($P < 0.01$) differences between genotypes evaluated at each of the locations (Tables 4, 5, and 6). At Adet, the PV of the different varieties ranged between 196 Rapid Visco units (RVU) for Wochecha and 420 RVU for Jalene (Table 4). At Merawi and Debretabor, the PV values of these varieties ranged from 211 RVU (CIP–395096.2) to 430 RVU(Guasa), and from 226 RVU (Gera) to 538 RVU (Gabisa), respectively, (Table 5 and 6). The Mean PV values at the Adet, Merawi and Debretabor locations were 288, 282 and 326 RVU, respectively. This clearly shows the substantial effect of location on genotypes for starch pasting parameters (Tables 4, 5 and 6).

Table 3 Amylose, amylopectin and starch contents of 25 potato varieties tested at three different locations in Amhara region of Ethiopia, 2011.

Variety	AMC (%)			APC (%)			MC (%)		
	Adet	Merawi	Debretabor	Adet	Merawi	Debretabor	Adet	Merawi	Debretabor
Menagesha	24.16^{efghi}	25.62^{defghi}	23.95^{hijk}	75.84^{cedfgh}	74.38^{defghij}	76.05^{bcde}	16.43^{h}	15.75^{ab}	14.72^{h}
Gera	26.28^{def}	29.22^{bcd}	29.54^{abcd}	73.72^{fghij}	71.11^{ijkl}	70.46^{ijkl}	16.79^{ef}	15.86^{a}	16.11^{a}
Challa	24.01^{efghi}	24.62^{efghijk}	27.13^{cdefgh}	75.99^{bcdefg}	75.38^{bcdefg}	72.87^{efghij}	17.11^{cd}	15.08^{fgh}	14.63^{h}
CIP–395096.2	25.64^{defg}	29.14^{bcd}	28.42^{bcdefg}	74.36^{efghi}	70.86^{jkl}	71.58^{fghijk}	16.69^{fg}	15.77^{ab}	14.32^{i}
Wochecha	24.91^{efgh}	29.87^{b}	26.31^{efghi}	75.09^{defgh}	70.13^{l}	73.69^{defgh}	14.09^{m}	15.60^{bcd}	14.66^{h}
Awash	23.30^{ghij}	22.79^{hijkl}	22.15jkl	76.70^{abcdefg}	77.21^{abcde}	77.85^{abc}	13.77^{n}	15.49^{cde}	15.23^{efg}
Gorebella	19.40^{l}	23.05^{ghijkl}	22.04^{jkl}	77.27^{abcdefg}	76.95^{abcdef}	77.96^{abc}	17.60^{b}	14.85^{hij}	16.23^{a}
Zengena	22.64^{hijk}	19.96^{l}	26.23^{efghi}	77.36^{abcdefg}	80.04^{a}	73.77^{defgh}	16.75^{f}	15.25^{ef}	13.62^{j}
Hunde	23.49^{fghij}	27.64^{bcde}	29.81^{abc}	76.51^{abcdefg}	72.36^{hijkl}	70.19^{jkl}	17.48^{b}	15.62^{abcd}	15.27^{ef}
Agere	25.60^{defg}	25.13^{efghij}	26.52^{defghi}	74.40^{efghi}	74.87^{cdefgh}	73.48^{defghi}	17.63^{b}	15.44^{cde}	13.00^{k}
Shenkolla	29.84^{ab}	26.00^{cdefg}	25.62^{ghi}	70.16^{jk}	74.00^{efghijk}	74.38^{def}	16.64^{fg}	14.97^{ghi}	15.66^{bcd}
Belete	24.48^{efgh}	23.48^{fghijkl}	24.42^{hijk}	75.52^{cdefgh}	76.52^{abcdef}	75.58^{bcde}	15.38^{j}	15.88^{a}	16.22^{a}
Ater Abeba	32.22^{a}	27.82^{bcde}	31.68^{a}	67.78^{k}	72.18^{hijkl}	68.32^{l}	15.30^{jk}	14.98^{ghi}	15.90^{ab}
CIP–392640.524	26.19^{def}	27.08^{bcdef}	28.96^{abcdef}	73.81^{fghij}	72.92^{ghijkl}	71.04^{ghijkl}	17.09^{d}	15.68^{abc}	13.19^{k}
Gudene	21.67^{ijkl}	25.35^{efghi}	24.68^{hij}	78.33^{abcde}	74.65^{defghi}	75.32^{cde}	15.58^{i}	15.13^{fg}	15.19^{efg}
Bulle	26.63^{cde}	29.63^{bc}	26.83^{cdefgh}	73.37^{ghij}	70.37^{kl}	73.17^{efghij}	14.96^{l}	15.30^{ef}	15.34^{de}
Gabisa	21.19^{jkl}	23.34^{fghijkl}	23.44^{ijk}	78.81^{abcd}	76.66^{abcdef}	76.56^{bcd}	17.11^{cd}	14.64^{j}	15.19^{efg}
Tolcha	25.84^{defg}	33.43^{a}	29.29^{abcde}	74.16^{fghi}	66.57^{m}	70.71^{hijkl}	17.98^{a}	14.75^{ij}	16.22^{a}
Aba Adamu	24.87^{efgh}	29.75^{bc}	30.85^{ab}	75.13^{defgh}	70.25^{l}	69.15^{kl}	17.13^{cd}	15.83^{ab}	14.97^{fgh}
Marachare	28.06^{bcd}	26.76^{bcdefg}	26.02^{fghi}	71.94^{hij}	73.24^{fghijkl}	73.98^{defg}	15.16^{k}	15.25^{ef}	15.71^{bc}
Sisay	20.34^{kl}	23.64^{fghijkl}	24.14^{hijk}	79.66^{ab}	76.36^{abcdef}	75.86^{bcde}	17.29^{c}	15.08^{fgh}	14.92^{gh}
Ararsa	29.02^{bc}	30.33^{ab}	30.85^{ab}	70.98^{ijk}	69.67^{lm}	69.15^{kl}	13.71^{n}	15.25^{ef}	13.29^{k}
Jalene	19.58^{l}	21.51^{jkl}	21.50^{kl}	80.42^{a}	78.49^{abc}	78.49^{ab}	16.96^{de}	14.84^{hij}	13.25^{k}
Guasa	20.75^{jkl}	22.07^{ijkl}	20.11^{l}	79.66^{abc}	77.93^{abcd}	79.89^{a}	15.20^{k}	15.60^{bcd}	16.07^{a}
CIP–396004.337	22.46^{hijk}	21.29^{kl}	25.51^{ghi}	77.54^{abcdef}	78.71^{ab}	74.49^{def}	16.54^{gh}	15.39^{de}	15.49^{cde}
Mean	24.50	25.94	26.24	75.50	74.06	73.76	16.26	15.33	14.98
CV%	4.61	5.79	4.79	2.06	1.99	1.70	0.39	0.54	0.75
LSD at 1%	2.22	2.95	2.47	3.06	2.91	2.47	0.06	0.08	0.11

AMC = Amylose content; APC = Amylopectin content; MC = Starch moisture content; n = 2 for both AMC and MC.
CV% = Coefficient of variance; LSD = Least significant difference; Means in columns followed by the same superscript letter are not different.

Table 4 Pasting properties of starch of 25 potato varieties tested at Adet during 2011 cropping season.

Variety	PV (RVU)	HPV (RVU)	BDV (RVU)	CV (RVU)	SBV (RVU)	PT (min.)	Ptemp (^{0}C)
Menagesha	316.08^{de}	148.46^{gh}	167.63^{d}	186.38^{jk}	37.92^{efgh}	3.83^{bcd}	68.93^{klmn}
Gera	219.38^{lm}	150.50^{gh}	68.88^{m}	209.88^{ef}	59.38^{b}	3.50^{d}	70.55^{cdefgh}
Challa	291.00^{g}	181.63^{a}	109.38^{hij}	223.92^{cd}	42.29^{defg}	4.64^{a}	69.80^{fghijk}
CIP–395096.2	273.79^{i}	168.96^{bcd}	104.83^{ijk}	223.33^{cd}	54.38^{bc}	3.54^{cd}	71.33^{bc}
Wochecha	195.92^{n}	110.50^{j}	85.42^{l}	156.92^{n}	46.42^{cdef}	3.63^{cd}	69.05^{jklm}
Awash	253.33^{j}	135.53^{i}	117.75^{gh}	173.96^{lm}	38.38^{efgh}	3.76^{bcd}	69.13^{jklm}
Gorebella	282.33^{h}	142.67^{hi}	139.67^{ef}	189.58^{ijk}	46.92^{cde}	3.58^{cd}	68.83^{lmn}
Zengena	279.00^{hi}	166.21^{cde}	112.79^{ghi}	202.42^{fgh}	36.21^{fghij}	3.76^{bcd}	70.63^{cdefg}
Hunde	233.08^{k}	175.46^{ab}	57.63^{n}	227.42^{bc}	51.96^{bcd}	4.51^{ab}	71.68^{ab}
Agere	274.88^{i}	174.25^{ab}	100.63^{jk}	213.46^{de}	39.21^{efgh}	3.60^{cd}	70.35^{defghi}
Shenkolla	213.25^{m}	159.04^{ef}	54.21^{n}	250.46^{a}	91.42^{a}	3.88^{bcd}	72.30^{a}
Belete	253.04^{j}	155.54^{fg}	97.50^{k}	201.21^{fgh}	45.67^{cdefg}	3.44^{d}	70.83^{bcde}
Ater Abeba	274.04^{i}	138.63^{i}	135.42^{f}	200.17^{fgh}	61.54^{b}	3.16^{d}	68.70^{mn}
CIP–392640.524	258.13^{j}	176.38^{ab}	81.75^{l}	236.38^{b}	60.00^{b}	4.77^{a}	70.95^{bcd}
Gudene	319.13^{d}	149.75^{gh}	169.38^{d}	180.00^{kl}	30.25^{hijk}	3.58^{cd}	70.15^{defghi}
Bulle	273.92^{i}	170.29^{bcd}	103.63^{ijk}	217.29^{cde}	47.00^{cde}	4.30^{abc}	70.80^{bcde}
Gabisa	371.54^{b}	162.63^{def}	208.92^{c}	198.21^{ghi}	35.58^{ghij}	3.52^{cd}	69.73^{ghijk}
Tolcha	303.54^{f}	159.21^{ef}	144.33^{ef}	201.46^{fgh}	42.25^{defg}	3.81^{bcd}	69.93^{efghij}
Aba Adamu	345.21^{c}	171.17^{bc}	174.04^{d}	214.00^{de}	42.83^{defg}	3.57^{cd}	68.88^{klmn}
Marachare	276.83^{hi}	155.25^{fg}	121.58^{g}	194.00^{hij}	38.75^{efgh}	3.76^{bcd}	71.38^{bc}
Sisay	366.08^{b}	137.50^{i}	228.58^{b}	164.96^{mn}	27.46^{ijk}	3.44^{d}	69.60^{hijklm}
Ararsa	221.25^{l}	154.79^{fg}	66.46^{m}	209.00^{efg}	54.21^{bc}	3.76^{bcd}	70.73^{cdef}
Jalene	419.71^{a}	162.88^{def}	256.83^{a}	189.21^{ijk}	26.33^{jk}	3.41^{d}	69.55^{ijklm}
Guasa	370.83^{b}	137.92^{i}	232.92^{b}	161.54^{n}	23.63^{k}	3.45^{d}	68.05^{n}
CIP–396004.337	310.63^{e}	162.79^{def}	147.83^{e}	200.08^{fgh}	37.29^{efghi}	3.60^{cd}	70.25^{defghi}
Mean	287.84	156.32	131.52	201.01	44.69	3.75	70.08
CV%	0.81	1.67	2.40	1.72	7.32	6.33	0.43
LSD at 1%	5.83	6.52	7.85	8.62	8.16	0.59	0.75

AMC = Amylose content; APC = Amylopectin content; PV = Peak viscosity; HPV = Hot paste viscosity; BDV = Breakdown viscosity; CV = Cool paste viscosity; SBV = Set back viscosity; PT = Peak time; Ptemp = Peak temperature; min. = Minimum; RVU = Rapid Visco units.

CV% = Coefficient of variance; LSD = Least significant difference; Means in columns followed by the same superscript letter are not different.

Table 5 Pasting properties of starch of 25 potato varieties tested at Merawi during 2011 cropping season.

Variety	PV (RVU)	HPV (RVU)	BDV (RVU)	CV (RVU)	SBV (RVU)	PT (min.)	Ptemp (^{0}C)
Gera	219.38^{lm}	150.50^{gh}	68.88^{m}	209.88^{ef}	59.38^{b}	3.50^{d}	70.55^{cdefgh}
Menagesha	355.54^{b}	168.79^{e}	186.75^{b}	205.67^{h}	36.88^{hijklm}	3.88^{defgh}	70.35^{ghi}
Gera	284.21^{gh}	205.33^{a}	78.88^{lm}	251.67^{b}	46.33^{defgh}	5.10^{a}	71.73^{bcd}
Challa	259.92^{j}	175.96^{d}	83.96^{kl}	219.21^{fg}	43.25^{efghi}	4.17^{cd}	69.80^{ij}
CIP–395096.2	211.33^{n}	139.33^{jkl}	72.00^{m}	192.50^{jk}	53.17^{cde}	3.62^{ghi}	70.95^{defg}
Wochecha	244.79^{k}	158.46^{fg}	86.33^{kl}	214.58^{g}	56.13^{cd}	3.91^{defgh}	69.78^{ij}
Awash	241.50^{kl}	131.04^{m}	110.46^{i}	171.33^{m}	40.29^{ghijk}	3.57^{hi}	69.93^{hij}
Gorebella	277.79^{hi}	144.71^{ij}	133.08^{ef}	186.08^{kl}	41.38^{fghij}	3.60^{ghi}	69.38^{j}
Zengena	229.83^{m}	131.08^{m}	98.75^{j}	162.29^{n}	31.21^{jklm}	3.70^{fgh}	71.25^{cdef}
Hunde	345.50^{c}	197.21^{b}	148.29^{d}	228.79^{de}	31.58^{jklm}	4.22^{cd}	72.68^{a}
Agere	255.17^{j}	134.63^{lm}	120.54^{h}	164.25^{mn}	29.63^{klm}	3.73^{efgh}	69.30^{j}
Shenkolla	235.00^{lm}	137.00^{klm}	98.00^{j}	184.08^{kl}	47.08^{defgh}	3.96^{defg}	70.75^{efgh}
Belete	273.88^{i}	141.83^{ijkl}	132.04^{ef}	172.00^{m}	30.17^{klm}	3.57^{hi}	70.98^{defg}
Ater Abeba	257.46^{j}	136.17^{klm}	121.29^{gh}	189.92^{jkl}	53.75^{cde}	3.26^{i}	69.58^{ij}
CIP–392640.524	277.21^{hi}	187.25^{c}	89.96^{k}	235.00^{cd}	47.75^{defg}	4.73^{b}	71.88^{abc}
Gudene	290.58^{g}	161.79^{f}	128.79^{fg}	195.67^{ij}	33.88^{ijklm}	3.75^{efgh}	71.48^{bcde}
Bulle	320.79^{e}	188.04^{c}	132.75^{ef}	239.38^{c}	51.33^{cdef}	4.11^{cde}	72.18^{ab}
Gabisa	336.50^{d}	152.63^{gh}	183.88^{b}	182.33^{l}	29.71^{klm}	3.73^{efgh}	69.90^{hij}
Tolcha	211.79^{n}	148.08^{hi}	63.71^{n}	215.00^{g}	66.92^{b}	4.17^{cd}	71.13^{cdefg}
Aba Adamu	258.63^{j}	159.88^{f}	98.75^{j}	221.50^{efg}	61.63^{bc}	3.60^{ghi}	70.70^{efgh}
Marachare	321.58^{e}	187.63^{c}	133.96^{ef}	226.38^{def}	38.75^{ghijkl}	4.40^{bc}	71.85^{abc}
Sisay	302.83^{f}	143.38^{ijk}	159.46^{c}	171.67^{m}	28.29^{m}	3.65^{gh}	69.45^{j}
Ararsa	218.75^{n}	177.71^{d}	41.04^{o}	263.04^{a}	85.33^{a}	4.68^{b}	71.40^{bcde}
Jalene	331.50^{d}	174.50^{de}	157.00^{c}	202.13^{hi}	27.63^{m}	4.07^{cdef}	70.70^{efgh}
Guasa	429.54^{a}	193.83^{bc}	235.71^{a}	222.25^{efg}	28.42^{lm}	3.78^{efgh}	70.88^{defg}
CIP–396004.337	275.88^{hi}	135.88^{lm}	140.00^{e}	170.63^{mn}	34.75^{ijklm}	3.62^{ghi}	70.43^{fghi}
Mean	281.90	160.49	121.42	203.49	43.01	3.94	70.74
CV%	1.02	1.48	2.33	1.46	7.90	2.98	0.39
LSD at 1%	7.18	5.93	7.04	7.42	8.46	0.29	0.69

AMC = Amylose content; APC = Amylopectin content; PV = Peak viscosity; HPV = Hot paste viscosity; BDV = Breakdown viscosity; CV = Cool paste viscosity; SBV = Set back viscosity; PT = Peak time; Ptemp = Peak temperature; min. = Minimum; RVU = Rapid Visco units.

CV% = Coefficient of variance; LSD = Least significant difference; Means in columns followed by the same superscript letter are not different.

Table 6 Pasting properties of starch of 25 potato varieties tested at Debretabor during 2011 cropping season.

Variety	PV (RVU)	HPV (RVU)	BDV (RVU)	CV (RVU)	SBV (RVU)	PT (min.)	Ptemp (^{0}C)
Gera	284.21^{gh}	205.33^{a}	78.88^{lm}	251.67^{b}	46.33^{defgh}	5.10^{a}	71.73^{bcd}
Menagesha	348.79^{gh}	151.50^{ij}	197.29^{f}	187.58^{gh}	36.08^{hijk}	3.65^{ef}	67.48^{hi}
Gera	225.63^{q}	161.92^{g}	63.71^{p}	228.79^{c}	66.88^{a}	3.86^{de}	69.30^{b}
Challa	300.96^{k}	175.21^{de}	125.75^{kl}	218.50^{d}	43.29^{efgh}	4.29^{c}	67.70^{ghi}
CIP–395096.2	366.96^{e}	181.38^{cd}	185.58^{gh}	219.38^{d}	38.00^{ghi}	3.62^{ef}	68.60^{cdef}
Wochecha	236.79^{p}	136.08^{lm}	100.71^{m}	184.00^{ghij}	47.92^{def}	3.58^{ef}	67.48^{hi}
Awash	352.33^{fg}	141.96^{kl}	210.38^{e}	175.75^{j}	33.79^{ijkl}	3.27^{ghi}	66.30^{j}
Gorebella	292.88^{l}	140.58^{kl}	152.29^{j}	181.50^{hij}	40.92^{fghi}	3.62^{ef}	66.28^{j}
Zengena	284.29^{m}	206.88^{a}	77.42^{o}	265.29^{a}	58.42^{bc}	4.95^{b}	69.23^{bc}
Hunde	291.67^{l}	202.83^{ab}	88.83^{n}	247.29^{b}	44.46^{efg}	4.42^{c}	70.13^{a}
Agere	271.71^{n}	165.38^{fg}	106.33^{m}	201.54^{ef}	36.17^{hijk}	4.53^{c}	66.28^{j}
Shenkolla	317.04^{j}	186.58^{c}	130.46^{k}	231.33^{c}	44.75^{efg}	4.51^{c}	68.30^{efg}
Belete	252.21^{o}	151.96^{hij}	100.25^{m}	192.67^{fg}	40.71^{fghi}	3.93^{d}	69.45^{b}
Ater Abeba	324.29^{i}	160.04^{gh}	164.25^{i}	209.42^{e}	48.38^{de}	3.62^{ef}	67.08^{i}
CIP–392640.524	268.96^{n}	195.79^{b}	73.17^{o}	254.88^{b}	59.08^{bc}	5.23^{a}	69.10^{bcd}
Gudene	342.42^{h}	150.58^{ij}	191.83^{fg}	177.46^{ij}	26.88^{l}	3.47^{fgh}	68.10^{fgh}
Bulle	302.63^{k}	145.08^{jk}	157.54^{ij}	186.21^{ghi}	41.13^{efghi}	3.83^{de}	67.98^{fgh}
Gabisa	537.58^{a}	174.21^{de}	363.38^{a}	207.88^{e}	33.67^{ijkl}	3.14^{i}	67.33^{i}
Tolcha	357.38^{f}	178.58^{cde}	178.79^{h}	231.46^{c}	52.88^{cd}	4.35^{c}	68.53^{def}
Aba Adamu	246.67^{o}	128.33^{m}	118.33^{l}	182.63^{hij}	54.29^{cd}	3.24^{hi}	68.10^{fgh}
Marachare	281.29^{m}	157.58^{ghi}	123.71^{kl}	192.88^{fg}	35.29^{ijk}	3.73^{def}	69.45^{b}
Sisay	423.83^{c}	173.42^{def}	250.42^{c}	203.88^{e}	30.46^{jkl}	3.60^{ef}	68.10^{fgh}
Ararsa	267.50^{n}	205.58^{a}	61.92^{p}	270.51^{a}	64.92^{ab}	5.18^{ab}	68.93^{bcde}
Jalene	394.21^{d}	172.46^{ef}	221.75^{d}	202.25^{e}	29.79^{kl}	3.50^{fgh}	67.15^{i}
Guasa	479.79^{b}	170.46^{ef}	309.33^{b}	199.92^{ef}	29.46^{kl}	3.16^{i}	67.28^{i}
CIP–396004.337	369.29^{e}	171.42^{ef}	197.88^{f}	209.21^{e}	37.79^{ghij}	3.52^{fg}	68.08^{fgh}
Mean	325.48	167.43	158.05	210.45	43.02	3.91	68.05
CV%	0.71	1.67	1.90	1.44	5.52	2.26	0.31
LSD at 1%	5.72	6.99	7.48	7.55	5.92	0.22	0.64

AMC = Amylose content; APC = Amylopectin content; PV = Peak viscosity; HPV = Hot paste viscosity; BDV = Breakdown viscosity; CV = Cool paste viscosity; SBV = Set back viscosity; PT = Peak time; Ptemp = Peak temperature; min. = Minimum; RVU = Rapid Visco units.

CV% = Coefficient of variance; LSD = Least significant difference; Means in columns followed by the same superscript letter are not different.

The BDV values at Adet ranged from 54.21 RVU for Shenkolla to 256.83 RVU for Jalene (Table 4). Guasa and Sisay had the second and third highest values, respectively. Similarly, the BDV values of the starches isolated from the 25 varieties grown at Merawi ranged from 41.04 RVU for Ararsa to 235.71 RVU for Guasa (Table 5). At the Debretabor site, this same parameter ranged from 61.92 RVU for Ararsa to 363.38 RVU for Gabisa (Table 6). The highest BDV variety (Gabisa) was followed by the variety Guasa (309.33 RVU). The BD is regarded as a measure of paste stability or the degree of disintegration of granules (the ability of the cooked starch to withstand shears induced by disintegration). Noda *et al*. (2004) also found BDV ranges of 93 to 185 RVU, and 103 to 252 RVU among six early and late maturing potato varieties, respectively, which supports the BDV results of the present study. Generally, all varieties that had the highest BDV values were noted to contain the lowest amylose content. On the contrary, all varieties that had the lowest BDV values at all locations had the highest amylose content. In addition, all varieties with the highest BDV values had the highest PV values. Kuar *et al*. (2007) also found a negative association between the AMC and BDV. These results in the current study clearly agree with earlier reports that starches with low amylose or high amylopectin content and high amounts of phosphorus swell more freely because starch swelling is mainly a property of amylopectin (Tsakama *et al*., 2010). The relationship between the phosphorus content and the PV has been reported by Tsakama *et al*. (2010); all varieties that had high PV in the present study had relatively high tuber phosphorus content as reported in other studies at two of the locations in the present study (Tesfaye *et al*., 2012b) and this is consistent with results reported by other workers. In other words, starches with a high amylose content are resistant to breakdown and take more pasting time and higher temperature as noted in the current study too (Table 4, 5, and 6). The values of Ptemp at Adet, Merawi and Debretabor ranged from 68.05 °C for Guasa to 72.30 °C for Shenkolla, 69.45 °C for Sisay to 72.68 °C for Hunde, and 66.28 °C for Gorebella to 70.13 °C for Hunde, respectively, (Tables 4, 5 and 6). Noda *et al*. (2004) also found ranges of 67.80 to 71.50 °C between six early and of 67.10 to 70.70 °C between six late potato varieties. The present study results were consistent with these data.

Factorial analysis of variance

Amylose and amylopectin content

The combined analysis of variance of amylose and amylopectin content showed highly significant ($P < 0.01$) genotype, location and genotype × location mean square values (Table 7). The AMC values of genotypes ranged from 20.86% for Jalene to 30.58% for Ater Abeba (Table 18). The mean AMC values at Adet, Merawi and Debretabor were 24.50, 25.95 and 26.24%, respectively (Table 7). Thus, there were significant differences between genotypes and locations. Kuar *et al*. (2007) also reported similar variation in the AMC across four locations that ranged from 17.41 to 18.90%. Inconsistent genotype performance in the AMC was also noted in the present study as reported by Kuar *et al*. (2007). The highest AMC value was recorded at the Debretabor site where the temperatures are relatively lower than the other two sites. Climatic factors directly influence the crop productive potential, regulating the transpiration, photosynthetic efficiency and respiration processes in such a way as to control the growth and development of the plants throughout their life cycle (Grommers and van der Krogt, 2009). Though the optimum temperature for potato plants varies with the crop growth stage, photoperiod, length of exposure and other factors, a range of 16–24 °C was reported to be ideal for better potato production (Timlin *et al*., 2006). Furthermore, Mohabir and John (1988) observed 21.5 °C as a sharp temperature optimum for ^{14}C sucrose incorporation into starch implying the presence of a relatively lower optimal temperature for starch synthesis. Lafta and Lorenzen (1995)

Table 7 Overall mean amylose, amylopectin and pasting properties of 25 potato varieties grown during 2011 in Amhara region.

Variety	AMC (%)	APC (%)	PV (RVU)	HPV (RVU)	BD (RVU)	CV (RVU)	SB (RVU)	PT (min.)	Ptemp (°C)
Menagesha	24.57^{fgh}	75.43^{bc}	340.14^{e}	156.25^{ij}	183.89^{d}	193.21^{kl}	36.96^{klm}	3.78^{ef}	68.92^{ghi}
Gera	28.35^{cd}	71.76^{fgh}	243.07^{m}	172.58^{d}	70.49^{o}	230.11^{c}	57.53^{bc}	4.15^{cd}	70.53^{bc}
Challa	25.25^{fg}	74.75^{cd}	283.96^{i}	177.60^{c}	106.36^{k}	220.54^{de}	42.94^{ghi}	4.37^{bc}	69.10^{gh}
CIP–395096.2	27.73^{d}	72.27^{fg}	284.03^{i}	163.22^{fg}	120.81^{j}	211.74^{fg}	48.51^{ef}	3.59^{fgh}	70.29^{cd}
Wochecha	27.03^{de}	72.97^{def}	282.39^{i}	135.01^{n}	90.82^{m}	185.17^{m}	50.15^{def}	3.71^{efg}	68.77^{hij}
Awash	22.75^{ij}	77.25^{ab}	225.83^{o}	136.19^{n}	146.19^{f}	173.68^{o}	37.49^{jklm}	3.54^{fgh}	68.45^{jk}
Gorebella	21.50^{jk}	77.39^{ab}	284.33^{i}	142.65^{m}	141.68^{g}	185.72^{m}	43.07^{gh}	3.60^{fgh}	68.16^{k}
Zengena	22.94^{hij}	77.06^{b}	264.38^{j}	168.06^{e}	96.32^{l}	210.0^{gh}	41.94^{ghijk}	4.14^{cd}	70.37^{c}
Hunde	26.98^{de}	73.02^{def}	290.08^{h}	191.83^{a}	98.25^{l}	234.50^{c}	42.67^{ghij}	4.38^{bc}	71.49^{a}
Agere	25.75^{ef}	74.25^{cde}	267.25^{j}	158.08^{hi}	109.17^{k}	193.08^{kl}	35.00^{lmn}	3.95^{de}	68.64^{ij}
Shenkolla	27.16^{de}	72.84^{def}	255.10^{l}	160.88^{gh}	94.22^{lm}	221.96^{d}	61.08^{b}	4.12^{cd}	70.45^{c}
Belete	24.13^{fghi}	75.87^{bc}	259.71^{k}	149.78^{l}	109.93^{k}	188.63^{lm}	38.85^{hijkl}	3.64^{fg}	70.30^{cd}
Ater Abeba	30.58^{a}	69.42^{i}	285.26^{i}	144.94^{m}	140.32^{g}	199.50^{j}	54.56^{cd}	3.35^{h}	68.45^{jk}
CIP–392640.524	27.41^{de}	72.59^{ef}	268.10^{j}	186.42^{b}	81.63^{n}	242.08^{b}	55.61^{c}	4.91^{a}	70.65^{bc}
Gudene	23.90^{ghi}	76.10^{bc}	317.38^{f}	154.04^{ijk}	163.33^{e}	184.38^{mn}	30.33^{nop}	3.60^{fgh}	69.91^{de}
Bulle	27.70^{d}	72.30^{fg}	299.11^{g}	167.81^{e}	131.31^{h}	214.29^{fg}	46.49^{fg}	4.08^{d}	70.32^{cd}
Gabisa	22.66^{ij}	77.34^{ab}	415.21^{b}	163.15^{fg}	252.06^{b}	196.14^{jk}	32.99^{mno}	3.46^{gh}	68.98^{ghi}
Tolcha	29.52^{abc}	70.48^{ghi}	290.90^{h}	161.96^{gh}	128.94^{hi}	215.97^{ef}	54.01^{cd}	4.11^{cd}	69.86^{e}
Aba Adamu	28.49^{bcd}	71.51^{fgh}	283.50^{i}	153.13^{jkl}	130.38^{hi}	206.04^{hi}	52.92^{cde}	3.47^{gh}	69.23^{fg}
Marachare	26.95^{de}	73.05^{def}	293.24^{h}	166.82^{ef}	126.42^{i}	204.42^{i}	37.60^{ijklm}	3.96^{de}	70.89^{b}
Sisay	22.70^{ij}	77.30^{ab}	364.25^{d}	151.43^{kl}	212.82^{c}	180.17^{n}	28.74^{op}	3.56^{fgh}	69.05^{ghi}
Ararsa	30.07^{ab}	69.93^{hi}	235.83^{n}	179.36^{c}	56.47^{p}	247.51^{a}	68.15^{a}	4.54^{b}	70.35^{cd}
Jalene	20.86^{k}	79.14^{a}	381.81^{c}	169.94^{de}	211.86^{c}	197.86^{jk}	27.92^{op}	3.66^{fg}	69.13^{gh}
Guasa	20.98^{k}	79.02^{a}	426.72^{a}	167.40^{e}	259.32^{a}	194.57^{jk}	27.17^{p}	3.46^{gh}	68.73^{hij}
CIP–396004.337	23.09^{hij}	76.91^{b}	318.60^{f}	156.69^{ij}	161.90^{e}	193.31^{kl}	36.61^{klm}	3.58^{fgh}	69.58^{ef}
Mean	25.56	74.40	298.41	161.41	137.00	204.98	43.57	3.87	69.62
CV%	5.11	1.93	0.87	1.56	2.11	1.50	7.26	4.20	0.40
LSD at 1%	1.45	1.59	3.46	3.58	4.12	4.34	4.19	0.22	0.38

AMC = Amylose content; APC = Amylopectin content; PV = Peak viscosity; HPV = Hot paste viscosity; BDV = Breakdown viscosity; CV = Cool paste viscosity; SBV = Set back viscosity; PT = Peak time; Ptemp = Peak temperature; min. = Minimum; RVU = Rapid Visco units.

CV% = Coefficient of variance; LSD = Least significant difference; Means in columns followed by the same superscript letter are not different.

also reported a reduction in the enzyme activity in potato plants exposed to elevated temperature and specifically indicated a 59% and a 72% reduction of sucrose synthase activity in a heat tolerant and susceptible potato cultivars, respectively. Similarly Keeling *et al.* (1994) reported a temperature range of 20–25 °C as maximal for starch synthase activity in cereals. Wang *et al*. (2006) also noted a higher level expression of amylase enzyme-granule bound starch synthase I (the enzyme responsible for amylose synthesis) at low temperature in a rice crop. Thus, the high AMC values at the cool Debretabor site in the current study clearly agreed with these results. Cottrell *et al*. (1995), however, reported high AMC levels in varieties grown under high temperature. Genotypes also exhibited inconsistent AMC values across the three different locations. As a result, the genotype that had highest AMC value at Adet, Merawi and Debretabor was Ater Abeba (32.22%), Tolcha (33.43%) and Ater Abeba (31.68%), respectively (Table 14). Kuar *et al*. (2007) also found similar inconsistencies in the genotypic AMC values among 21 varieties studied at four locations—a clear manifestation for the presence of a genotype × environment interaction.

The mean APC values across locations also ranged from 69.42 to 79.14% for Ater Abeba and Jalene, respectively (Table 7). Liu *et al.* (2007) and Kuar *et al.* (2007) reported similar results of a location effect on the APC of starches isolated from different potato varieties. Such differences in the APC across growing locations are attributed to the prevailing differences in climatic conditions especially in the optimal temperature during the crop growth and development stages. The starch branching enzyme that is responsible in amylopectin synthesis was reported to be affected by high temperature, though not to the level of sucrose synthase (Jenner, 1994; Cheng *et al*., 2005).

Pasting properties

The combined analysis of variance of the pasting properties of starches isolated from the three different locations had highly significant ($P < 0.01$) genotypic, location and genotype × location interactions over all the parameters considered (Table 7). The mean PV values across the three locations (Adet, Merawi and Debretabor) ranged from 225.83 RVU (Awash) to 426.72 RVU (Guasa) with an average of 298.41 RVU (Table 7). Thus, the PV of the evaluated varieties varied significantly ($P < 0.01$) across these three locations indicating the sizeable influence of the climatic conditions in each growing area on this starch pasting property. The mean values for the BDV, CPV, SBV, PT and Ptemp across the three locations ranged from 56.47 RVU (Ararsa) to 259.32 RVU (Guasa), 173.68 RVU (Awash) to 247.51 RVU (Ararsa), 27.17 (Guasa) to 68.16 (Ararsa), 3.35 min (Ater Abeba) to 4.91 min (CIP–392640.524) and 68.16 ^{o}C (Gorebella) to 71.49 ^{o}C (Hunde), respectively (Table 7). The mean PV, HPV, BDV and CPV values at the Debretabor site were higher than for both Merawi and Adet; these latter two sites also had lower Ptemp values. A study by Noda *et al*., (2004) on the pasting properties of six varieties and Fiedorowicz *et al*. (2002) on five varieties reported PV, HPV, BDV, CPV and Ptemp values ranging from 224 to 435.8 RVU, 114.7 to 170.3 RVU, 103 to 252 RVU, 199.9 to 251.3 RVU and 64.7 to 70.7 °C, respectively. While Kuar *et al*., (2007) reported Ptemp and PT ranges of 64.5 to 69.4 ^{0}C and 3.60 to 5.70 min, respectively, for 21 different varieties, Liu *et al*., (2003) reported Ptemp ranges of 66.1 to 71.8 °C for 3 varieties. Despite the variation in genetic material and growing locations from which the starches were isolated, the pasting properties results obtained in the present study fell within the ranges reported in these studies. Kuar *et al*. (2007) reported that the temperature during tuber growth affects the granule size and pasting temperature and as such, a lower temperature prevailing during tuber growth resulted in starch with a higher granule size and lower pasting temperatures. Furthermore, Liu *et al.* (2003) reported some granule size variability between starches isolated from different varieties and at different growth times. Although, the granule size of the starches of varieties included in the current study was not determined, the results of the pasting properties of the starches isolated from the varieties grown at the cool highland Debretabor site as contrasted to the relatively warmer Merawi and Adet sites can probably be attributed to the justifications pointed out by the above authors. The high PT recorded for starches isolated from varieties grown at Merawi and Debretabor also agrees with the high AMC at these sites that required more time for the breakdown of the starch granules. In general, the varieties Guasa, Jalene, Sisay, Gabisa, Gudene and Menagesha had relatively consistently lower AMC and higher APC, PV, HPV, BDV and CPV values across all locations. Contrarily, Gera, Wochecha and Ararsa had consistently higher AMC and lower APC, PV, HPV, BDV and CPV values.

Correlation analysis

The results of Pearson's correlation analysis among the pasting properties of the starches isolated from the 25 varieties grown at the different locations showed nonsignificant relationships of HPV with CV, and of HPV with BD and SB. PT revealed a significant, positive relationship with the AMC (r = 0.20; $P < 0.05$) and a significant, negative relationship with the APC (r = –0.20; $P < 0.05$) (Table 19). The remaining pairs of parameters showed negative or positive relationships based on their differences in the amounts of the two constituent glucose polymers in their composition and ratios as well as granule size differences (emanating from temperature variability in the growing environments) that resulted in different responses in their starch biosynthesis by the different cultivars. A highly significant and positive correlation (r = 0.94, $P < 0.01$) was observed between PV and BDV. Studies on starches isolated from 21 potato varieties (Kuar *et al*., 2007) and 11 sweeet potato varieties (Tsakama *et al.*, 2010) found similar high positive correlation values (r = 0.924, $P < 0.01$ and r = 0.91, $P < 0.01$, respectively). Contrarily, a highly significant negative correlation (r = –0.59, $P < 0.01$) was found between PV and SBV. This result clearly shows that there is high level disintegration or disruption of starch granules when they are subjected to shear or heat in the first case and starch granule resistance to breakdown when subjected to the same shear or heat in the latter case (Singh *et al*., 2006). PV also had negative correlations with the PT (r = –0.27, $P < 0.01$), Ptemp (r = –0. 37, $P < 0.01$) and AMC (r = –0.40, $P < 0.01$) and a positive association with the APC (r = –0.40, $P < 0.01$). These results are in agreement with the results of Kuar *et al*. (2007) and Noda *et al*. (2004) on 21 and 6 potato varieties. Clearly, the high AMC associated with the resistance to granule disintegration or breakdown as heat shear is applied necessitates a longer time and higher temperature for disintegration. Conversely, potato starch with reduced AMC attains its peak viscosity at a lower temperature as swollen granules are weak and can rupture more easily with shear (Grommers and van der Krogt, 2009), a point that justifies the positive association between the PV and APC and negative correlations between the PV and PT, and between the Ptemp and AMC. Thus, such result helps to predict the kind of gel (either a tough gel and a strong film or a soft gel and a weak film) that the starch paste of each variety will produce. In addition, it will help to decide the variety of interest depending on the AMC and APC amounts and proportions contained in the tuber of each variety. Overall, the correlation analysis results of the current study are in accord with Kuar *et al*. (2007) who studied 21 varieties at four different locations except for the difference in values between the PV and CV. The current results are also consistent with Noda *et al.* (2004) who reported on six varieties of tuber at different growth stages. The PV value was negatively associated with the AMC and positively associated with the APC. These results agreed with Yusuph *et al*. (2003); Liu *et al*. (2007) and Kuar *et al.* (2007).

CONCLUSION

Starch isolated from different potato varieties substantially differed in chemical composition and pasting properties. The pasting properties of varieties also varied owing to their differences in chemical and structural content. Growing locations also substantially influenced the chemical composition and pasting properties of starches. Overall, Guasa, Jalene, Sisay, Gabisa, Gudene and Menagesha had relatively consistent lower AMC values and higher APC, PV, HPV, BDV and CV values across all locations. Perversely, Gera, Wochecha and Ararsa had higher AMC values and lower APC, PV, HPV, BDV and CV values. Furthermore, the mean PV, HPV, BDV and CV values at the Debretabor site were higher than at both Merawi and Adet on the one hand, while on the other hand, the values for Ptemp were lower, which is attributed to low temperature that favored biosynthesis of larger granule size starches at Debretabor compared to the other two sites. The relationships observed among the starch pasting properties also clearly reflected the overruling influence of the two starch biopolymers, AMC and APC, and granule size on the composition and pasting properties. Amylose and amylopectin have different properties and as such, while amylose has a high tendency to retrograde and produce tough gels and strong films, amylopectin reacts in the opposite way.

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LITERATURE CITED

Alvani, K., X. Qi, R.F. Tester and C.E. Snape. 2010. Physico-chemical properties of potato starches. **Food Chem.** 125(3): 958–968.

Central Agricultural Census Commission. 2003. Ethiopian agricultural sample enumeration 2001/2002, pp. 63–153. **Statistical Report on Farm Management Practices. Livestock and Farm Implements. Part II.** Addis Ababa, Ethiopia.

Chen, Z., H. Schols and A. Voragen. 2003. Physicochemical properties of starches obtained from three varieties of Chinese sweet potatoes. **J. Food Sci.** 68:431–437.

Cheng, F.M., L.J. Zhong, N.C. Zhao, Y. Liu and G.P. Zhang. 2005. Temperature induced changes in the starch components and biosynthetic enzymes of two rice varieties. **Plant Growth Regulation** 46: 87–95.

Cottrell, J.E., C.M. Duffus, L. Paterson and G.R. Mackay. 1995. Properties of potato starch: Effects of genotype and growing conditions. **Phytochemistry** 40(4): 1057–1064.

Food and Agriculture Organization. 2010. **Production Yearbook.** Rome, Italy. 197pp.

Fiedorowicz, M., C. Lii and P. Tomasik. 2002. Physichochemical properties of potato starch illuminated with visible polarized light. **Carbohydr. polym.** 50: 57–62.

Grommers, H.E. and D.A. van der Krogt. 2009. Potato starch: Production, modifications and uses, pp. 512–538. *In* J. BeMiller and R.L.Whistler, (eds.). **Starch: Chemistry and Technology.** Elsevier Academic Press. New York, U.S.A.

Guilbot, A. and C. Mercier. 1985. Starch, pp. 285–292. *In* G.O. Aspinall, (ed.). **The Polysaccharides.** Vol. 3. Academic Press. New York, U.S.A.

Jenner, C.F. 1994. Starch synthesis in the kernel of wheat under high–temperature conditions. **Australian J. Plt. Phys.** 21: 791–806.

Keeling, P.L., R. Banisadr, L. Barone, B.P. Wasserman and G.W. Singletary. 1994. Effect of temperature on enzymes in the pathway of starch biosynthesis in developing wheat and maize grain. **Aust. J. Plt. Physiol.** 21: 807–827.

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.

Kuar, A., N. Singh, R. Ezekiel and H.S. Guraya. 2007. Physicochemical, thermal and pasting properties of starches separated from different potato cultivars grown at different locations. **Food Chem.** 101: 643–651

Lafta, A.M. and J.H. Lorenzen. 1995. Effect of high temperature on plant growth and carbohydrate metabolism in potato. **Plant Physiol.** 109: 637–643.

Li, X., M.G. Scanlon, Q. Liu and W.K. Coleman. 2006. Processing and value addition, pp. 523–555. *In* J. Gopal and A.M.P. Khurana, (ed.). **Potato Production Improvement and Post–harvest Management.** Haworth Press. New York, NY, USA.

Liu, Q., E. Weber, V. Currie and R. Yada. 2003. Physicochemical properties of starches during potato growth. **Carbohydr. Polym.** 51(2): 213–221.

Liu, Q., R. Tarn, D. Lynch and N.M. Skjodt. 2007. Physicochemical properties of dry matter and starch from potatoes grown in Canada. **Food Chem.**105: 897–907

Mbougueng, P.D., D. Tenin, J. Scher and C. Tchiégang. 2008. Physicochemical and functional properties of some cultivars of Irish potato and cassava starches. **J. Food Technol.** 6(3): 139–146.

McGrance, S.J., H.J. Cornell and C.J. Rix. 1998. A simple and rapid colorimetric method for the determination of amylose in starch products. **Starch/Starke** 50: 158–163.

Mohabir, G. and P. John. 1988. Effect of temperature on starch synthesis in potato tuber tissue and in amyloplasts. **Plant Physiol.** 88: 1222–1228**.**

Noda, T., Y. Takahata, T. Sato, I. Suda, T. Morishita and K. Ishiguro. 1998. Relationship between chain length distribution of amylopectin and gelatinization properties within same botanical origin for sweet potato and buckwheat. **Carbohydr. Polym.** 37: 153–158.

Noda, T., S. Tsuda, M. Mori, S. Takigawa, C. Matsuura–Endo, K. Saito, W.H.A Mangalika, A. Hanaoka, Y. Suzuki and Y. Yamauchi. 2004. The effect of harvest dates on the starch properties of various potato cultivars. **Food Chem.** 86: 119–125.

Rivero, R.C., P.L. Suárez Hernández, E.M. Rodríguez Rodríguez and C. Díaz Romero

Chemical composition of eight cultivars of potatoes. application of multivariate analysis. 2009. **Acta Alimentaria** 38(4): 405–414.

SAS Institute Inc. 2010. **SAS System.** Cary, NC, USA.

Schwartz, D. and R.L. Whistler. 2009. History and future of starch, pp. 1–10. *In* J. BeMiller and R.L.Whistler, (ed.). **Starch: Chemistry and Technology.** Elsevier Academic Press. New York, U.S.A.

Svegmark, K., K. Helmersson, G. Nilsson, P.O. Nilsson, R. Andersson and E. Svensson. 2002. Comparison of potato amylopectin starches and potato starches–influence of year and variety. **Carbohydr. Polym.** 47: 331–340.

Tesfaye, A., S. Wongchaochant, T. Taychasinpitak and O. Leelapon. 2012a. Dry matter content, starch content and starch yield variability and stability of potato varieties in Amhara region of Ethiopia. **Kasetsart J. (Nat. Sci.)** 46(5): 671–683.

Tesfaye, A., S. Wongchaochant, T. Taychasinpitak and O. Leelapon. 2012b. Variation of mineral concentrations among different potato varieties grown at two distinct locations in Ethiopia. **Kasetsart J. (Nat. Sci.)** 46(6): 837–850.

Timlin, D., S.M.L. Rahman, J.T. Baker, V. R. Reddy, D. Fleisher and B. Quebedeaux.2006. Whole plant photosynthesis, development, and carbon partitioning in potato as a function of temperature. **Agronomy J.** 98: 1195–1203.

Tsakama, M., A.M. Mwangwela, T.A. Manani and N.M. Mahungu. 2010. Physicochemical and pasting properties of starch extracted from eleven sweet potato varieties. **Afr. J. Food**

Sci. Technol. 1(4): 90–98.

Vasanthan, T., W. Bergthaller, D. Driedger, J. Yeung and P. Sporns. 1999. Starch from Alberta potatoes: Wet-isolation and some physicochemical properties. **Food Res. Int.** 32: 355–365.

Wang, S.J., L.F. Liu, C.K. Chen and LW. Chen. 2006. Regulations of granule–bound starch synthase I gene expression in rice leaves by temperature and drought stress. **Biologia Plantarum** 50(4): 537–541.

Yusuph, M., R.F. Tester, R. Ansell and C.E. Snape. 2003. Composition and properties of starches extracted from tubers of different potato varieties grown under the same environmental conditions. **Food Chem.** 82: 283–289.