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THESIS

EVALUATION OF DIVERSITY AMONG POTATO (*Solanum tuberosum* L.) CULTIVARS IN ETHIOPIA BASED ON MORPHOLOGICAL CHARACTERISTICS AND SSR MARKERS

TESFAYE ABEBE DESTA

A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
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Evaluation of the processing quality, starch chemical composition and pasting properties, mineral concentration, phenotypic and genetic diversity of 25 potato varieties in Ethiopia were carried out with the main objectives of determining their variability and proper production areas to maximize potato's versatile utility in Ethiopia.

The dry matter and starch content evaluation had shown the presence of highly significant ($P < 0.01$) differences among varieties and values ranged from 17.82% to 26.70% and 9.75% to 17.85%, respectively. Specific gravity and starch yield ranged from 1.058 to 1.102 and 2.21 to 6.91 $t.ha^{-1}$, respectively. Nutritional concentration study identified highly significant ($P < 0.01$) variability among varieties. Accordingly, protein and fiber content and iron, zinc, and phosphorus concentrations ranged from 3.77% to 7.36%, 1.18% to 2.20%, 17.13 to 164.83, 7.07 to 20.21 and 143.68 to 357.76 $mg.kg^{-1}$, respectively. Chemical and pasting properties analysis of starches also showed highly significant ($P < 0.01$) variability among varieties, locations and their interaction. Amylose and amylopectin content ranged from 20.86% to 30.58% and 69.42% to 79.14%, respectively.

The morphological diversity analysis study showed significant ($P < 0.01$) genetic variability among varieties and grouped them into three main clusters and one singleton. Contrarily, the microsatellite analysis carried out using 11 SSRs primers revealed their narrow variability over these genome loci.

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Student's signature Thesis Advisor's signature

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Tesfaye Abebe Desta

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LIST OF ABBREVIATIONS

ANRS	=	Amhara National Regioanal State
AMMI	=	Additive main effects and multiplicative interaction
AMC	=	Amylose content
APC	=	Amylopectin content
^{0}C	=	Degree Celsius
µL	=	micro litre
%	=	Percentage
w/v	=	Percentage weight by volume
ANOVA	=	Analysis of variance
BDV	=	Breakdown viscosity
bp	=	Base pair
Kb	=	Killo base
CACC	=	Central Agricultural Census Commission
CEC	=	Cation exchange capacity
CIP	=	Centro Internacional dela Papa
cm	=	Centimeter
CV%	=	Percent coefficient of variance
CPV	=	Cool paste viscosity
db	=	Dry basis
df	=	Degree of freedom
DF	=	Days to flowering
DM	=	Days to maturity
DMC	=	Dry matter content
DV	=	Daily value
EHNRI	=	Ethiopian Health and Nutrition Research Institute
FC	=	Fiber content
Fe	=	Iron
g	=	Gram

LIST OF ABBREVIATIONS (Continued)

HPV	=	Hot paste viscosity
IPCA	=	Interaction principal component axis
K	=	Potassium
KG	=	Killogram
LL	=	Leaf length
LLL	=	Leaflet length
LLWD	=	Leaflet length to width ratio
LSD	=	Least significant difference
LW	=	Leaflet width
MC	=	Moisture content
mg	=	Milligram
mm	=	Millimetere
ml	=	Mililiter
MS	=	Mean square
MTY	=	Marketable tuber yield
N	=	Nitrogen
M	=	Meter
OM	=	Organic matter
P	=	Phosphorus
PC	=	Protein content
pH	=	Concentration of hydrogen
ppp	=	Parts per million
PT	=	Peak time
Ptemp	=	Peak temperature
PV	=	Peak viscosity
RDA	=	Recommended daily allowance
RNI	=	Recommended Nutrient Intake
RVU	=	Rapid Visco Unit

LIST OF ABBREVIATIONS (Continued)

SB	=	Setback viscosity
SC	=	Starch content
SH	=	Stem height
SN	=	Stem number
Spg	=	Specific gravity
SS	=	Sum of square
SSR	=	Simple sequence repeat
SWHISA	=	Sustainable water harvesting and institutional strengthening in Amhara region
SY	=	Starch yield
TN	=	Tuber number
TW	=	Tuber weight
TY	=	Tuber yield
UK	=	United Kingdom
US	=	United States
USDA	=	United States Department of Agriculture
USDA/ARS	=	United States Department of Agriculture/Agricultural Research Service
WHO	=	World Health Organization
Zn	=	Zinc

EVALUATION OF DIVERSITY AMONG POTATO (*Solanum tuberosum* L.) CULTIVARS IN ETHIOPIA BASED ON MORPHOLOGICAL CHARACTERISTICS AND SSR MARKERS

INTRODUCTION

The cultivated potato (*Solanum tuberosum*) possesses more wild species than probably any other crop with extraordinarily wide range of adaptation from 65^0 N to 50^0 S latitude and greater diversity (Hawkes, 1994). It is grown across 149 countries of tropical and temperate areas (Hijmans, 2001). As a result, now adays potato is one of the the fourth important non-cereal food crop after wheat, rice and maize (FAO, 2011) and one of the world's three most important sources of starch (Christensen and Madsen, 1995) with a global production of over 324 million metric tons and area of over 18.6 million hectare (FAO, 2011). It is one of the most efficient crops for converting natural resources, labor and capital into a high quality food (Horton, 1981). It produces more dry matter per hectare than the major cereal crops in the world (Gray and Hughes, 1978), more protein per unit area than any other crop except soybeans (Smith, 1984) and more food per unit of water than any other major crop (www.potato2008.org). As a result, a hectare of potato can feed 22 persons a year as compared to rice of equivalent area feeding 19 persons (Spedding, 1990). Potato yields approximately three times more energy than wheat, barley and oat. As a result, just 0.20 hecare of potato can provide the total energy demands (42 magajoules or ~ 10, 000 calories per day) of a family of two adults and three young children (Nunn and Qian, 2011). Potato production area in UK accounts for approximately 5% of cereal's area. Yet its contribution per hectare to the agricultural industry's revenue is more than seven times that generated by cereals (McGregor, 2009). This clearly point out the lucrative quality of potatoes more than cereal enterprises. Thus, potato has considerable potential contribution to ensuring food security and eradicating poverty

through provision of not only food but also employment and income as a cash crop (Bradshaw and Bonierbale, 2010).

Potatoes are consumed directly as boiled and steamed or processed form. In North America and some European countries, 50% to 60% of the annual crop is consumed in processed form (Li et al., 2006; Kirkman, 2007). These include potato chips, French fries and various other frozen products, dehydrated potato products, chilled-peeled potatoes and canned potatoes. These different forms of potato products are highly governed by the quality of potato variety. Dry matters content (DMC) and starch content (SC) are the two overriding factors that form the basis of the important part of the potato tuber (Shannon and Garwood, 1984; Burton, 1966), govern the quality of potato varieties (Kirkam, 2007) and determine the quantity and quality of processed products (Mondal and Hossain, 2006). They have very close association with the culinary quality of potatoes (Cobb, 1935) and determine the textural properties of both whole cooked tuber and quality of potato starch based foods (Chen *et al*., 2003). Dry matter accounts for 13.1% to 36.8% (average 24%) of the tuber (Leszczyński, 1989). The dry matter content of most varieties selected for commercial usage ranges from 18 to 26% (Burton 1989). Equally starch constitutes 65-80% of the dry matter content (Gray and Hughes, 1978) and determines the mealiness or sogginess of a potato variety (Murphy *et al*., 1963). Consequently, DMC and SC have a vital role in setting the cut-off point of the utility of potato varieties (Kirkman, 2007; Högy and Fangmeier, 2009). All varieties with dry matter content of less than 19.5% and 20% fall short of meeting the standard set for use in French fries and chips manufacturing industries, respectively as reported by various workers (Akeley and Stevenson, 1944; Houghland, *et al*., 1961; Burton, 1966; Kooman and Rabbinger, 1996; Liu *et al*., 2003). Dry matter and starch content of potato varieties can be determined using the procedures of oven dry methods of chopped potato tubers and wet extraction procedure and indirectly based on specific gravity method that has positive correlation with dry matter content of tubers (Lulai and Orr, 1979). It has also generally been considered as the most practical index of mealiness (Warren and

Woodman, 1974). Thus, it is extensively used by processors to assess the suitability of tubers for the production of processed products (Murphy and Goven, 1959; Gray and Hughes, 1978).

Dry matter content of potato varieties are highly affected by variety, cultural and environmental conditions during the growing season and storage, and by processing methods and techniques (Karenlampi and White, 2009). Likewise, the SC variability of potato varieties was reported by Barios *et al.* (1963) and Rivero *et al.* (2009). DMC and SC, like any genetic characters, are a function of the hereditary factor and environment working together (Kooman *et al*., 1996). As a result a potentially high dry matter producing genotype will not achieve its potential unless 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). Likewise, genotype has a decisive effect in determining the specific gravity of potato varieties (Rivero *et al*., 2009). However, its effect is modified by cultural and environmental factors during the growing season (Killick and Simmonds, 1974). Significant genotype by locations (Love and Pavek, 1991; Asmamaw *et al*., 2005; Elfnesh *et al*., 2011), genotype by season (Abubaker *et al*., 2011) and genotype by year (Ekin, 2011) interactions were also reported. This underscores the relevance of evaluating genotypes across locations and seasons to resolve the suitable environment at which varieties could manifest their maximum performance potential.

Nutritionally potato is an excellent source of carbohydrate, vitamins and essential minerals; its protein notably contains a high proportion of the essential amino acid lysine than most cereals and it is used to fortify cereal products such as rice and pasta (Dale and Mackay, 1994). Potato is also an important source of vitamins, particularly ascorbic acid (vitamin C) and minerals, such as calcium, potassium, phosphorus, and iron (Dale and Mackay, 1994; Smith, 1968) and dietary antioxidants (Andre *et al*., 2007). Thus, 100 gm of boiled potato can provide 10% and

5%, respectively, of the daily requirement of protein of a child and an adult. A rise to 200 gm can meet the daily adult requirement of vitamin C of 100–120 $mg.d^{-1}$ (Naidu, 2003). An average of 175 g serving potato tuber provides 44% of Recommended Daily Allowance (RDA) of vitamin C, 29% vitamin B6, 16% vitamin B1, and 16% foliate (British Potato Council, 2004). Humans require at least 22 mineral elements for their well-being (White and Broaley, 2005) and these mineral elements enter the food chain through plants. The concentration of these essential minerals in plants varies with their nutrient use efficiency differences and phytoavailability of these minerals to the plants. At the same time lack of some of these mineral nutrients in human diet is caused by either insufficient intake or poor absorption from the food/low bioavailability to human body. As a result, FAO/WHO's daily recommended intake (RNI) of essential minerals depends on their bioavailability. For example, the daily RNI of Fe for children of 1-3 years, men, and women of reproductive ages in developing countries based on 5% assumed bioavailability is considered to be 12, 27.4 and 58.8 mg day^{-1}, respectively. Conversely, the RNI value of Fe for the same group of society in developed countries based on 12% assumed bioavailability is considered to be 5, 11.4 and 24.5 mg day^{-1} (Anonymous, 2002). Likewise, the daily RNI of Zn for children, men and women at a high bioavailability (50%) is 1.67, 4.3 and 3.6 mg kg^{-1}, respectively. This value varies with the assumed percent of bioavailability. As a result, the FAO/WHO's daily RNI of children, men and women at a low Zn bioavailability of 20.4% is specified to be 4.1, 6 and 4.3 mg day^{-1}, respectively. The more interesting thing with potato's tuber minerals is their higher bioavailability compared to those in other major food crops due to the high concentrations of compounds such as ascorbic acid that promote micronutrient absorption by the body (US Department of Agriculture, Agricultural Research Service, 2007), and low concentration of anti-nutrients compounds that limit micronutrient absorption, such as phytate (0.11-0.27% dry-matter; Phillippy *et al*., 2004) and oxalate (0.03% dry-matter; Bushway *et al*., 1984). Also, potato contains dietary antioxidants (Andre *et al*., 2007) and fibers that can help limit colon cancer. Thus, potato could be an alternative

cheap source of these essential mineral nutrients to cereal crops that are either low in their concentration or low in their bioavailability.

As a starchy tuber crop potatoes are also widely used in the food and non-food industrial manufacturings of product such as as textile, pharmaceutical drugs, paper, glue, cosmotics and many other manufacturing industries.

In Ethiopia, potato is widely grown in the cool highland parts of the country. It provides food and employment opportunities to over 2.3 million rural households (CACC, 2003) dwelling in the cool highlands that is conducive for production of good quality and better tuber yield. Moreover, it is an important cash crop that helps growers earns sizeable income. In recent years potato production has shown a dramatic increase by about 64%, i.e., from 349 000 tons in 1993 to 572 332 tons in 2010 (FAOSTAT, 2011). Likewise, potato is among the staple non-cereal food crops in the highland parts of the Amhara Regional State. This parts of the country accounts for over 50% of the total potato production area in the country. In some districts it is grown thrice per annum and forms the main portion of growers diet for about 8 months of the year. To backstop this trend, the Ethiopian agricultural research system has undertaken multifaceted research endeavors and recommended over 30 improved varieties that can improve the productivity and profitability of potato among growers. Nevertheless, very little attention was paid (Asmamaw *et al*., 2005; Elfnesh *et al*, 2011) to study their post-harvest qualities that vary with variety, production environments and cultural practices. Thus, information related to their dry matter and starch content, and starch yield is generally unavailable for most of the varieties. Essentially, no research work has been done to determine the mineral concentrations of these varieties which could have contributed to the management of the country wide prevalent mineral malnutrition.The starches chemical constituents and pasting properties of all potato varieties in the country was not totally studied which would have helped maximize the versatile utility of potato in both the food and non-food industries. These quality factors are functions of the hereditary factor or varieties

genetic make up and production environments and thus determination of their optimal production environments has not been addressed during the past three decades of potato research history. This has resulted in a serious gap for even shaping the performance of emerging fast-food processing enterprises in different towns for quality products and starch manufacturing plants put in place in one hand and the contribution of potato in averting the ill-effects of macro- and micro-nutrient malnutrition (Umeta *et al*., 2000; 2003; Medhin *et al*., 2010) related morbidity, mortality, underweight and height on childrens below below 5 years of age and women suffering from iron, zinc and protein deficiency in the country at large and in the Amhara Regional State in particular. Thus, it is high time to undertake a comprehensive evaluation of the genetic resources on hand for the subsequent rational and enhanced use of the germplasm resources present in the country. Such information will also have a far reaching implication on proper policy formulation related to such vital food and industrial crop that has not been given the appropriate attention in earlier periods. The objectives of this study are therefore coined with consideration of all these notions and are summarized in the following section in detail.

OBJECTIVES

Analysis of the research efforts made on potato during the past three decades and its present status had shown an evident research gaps were identified. These, gaps ultimately translated into six different workable research agenda. The overall objectives of these activities were determination of the post-harvest qualities, morphological and genetic variability within the prominent potato varieties in Ethiopia and identify appropriate areas of production that can help meet the desired quality standards. The specific objectives of these different experiments therefore are:

1. To evaluate the dry-matter and starch content and starch yields of released varieties, elite clones and prominent farmer's cultivars;

2. To assess tuber macro-and micro-nutrient concentrations of these same varieties;

3. To generate information on table type and processing type potato varieties and determine their ideal production environments;

4. To examine the chemical and pasting properties of starches isolated from of these same varieties grown under three distinct environments;

5. To examine the phenotypic diversity present among them based on morphological characteristics;

6. To study the variability of these 25 varieties using locus specific microsatellite molecular marker technique.

LITERATURE REVIEW

1. Introduction

Potato (*Solanum tuberosum* L.) is an herbaceous annual that grows up to 100 cm (40 inches) tall and produces a tuber – also called potato - so rich in starch (Figure 1). It is the fourth most important non-cereal food crop after wheat, rice and maize (FAO, 2011) and one of the world's three most important sources of starch after maize and wheat (Christensen and Madsen, 1996) with a global production of over 324 million metric tons and production area of over 18.6 million hectare (FAO, 2011). Potatoes are grown under various environmental conditions of both temperate and tropical regions in 149 countries that are lying from 65^0 N to 50^0 S latitudes and from sea level to 4,000 m altitudes (Hijmans, 2001). They are one of the most efficient crops for converting natural resources, labor and capital into a high quality food (Horton, 1981) in comparatively short period of time such as after only 60 days. Accordingly, potatoes produce more dry matter per hectare than the major cereal crops in the world (Gray and Hughes, 1978), more protein per unit area than any other crop except soybeans (Smith, 1984) and more food per unit of water than any other major crop (http://www.potato2008.org). With productivity potential, a hectare of potato can feed 22 persons a year compared to rice of equivalent area feeding 19 persons (Spedding, 1990). A family of two adults and three young children's 42 megajoule (or approximately 10, 000 calories) daily energy need can be met from only 0.2 hectare which otherwise would be from 0.60 hectare if it were to grow wheat, oats, or barley (Nunn and Quian, 2011). Nutritionally, humans can have healthy diets from consuming potatoes, supplemented with only dairy for vitamins A and D missing in potatoes (Connell, 1962; Davidson *et al*., 1975). It has also been reported that potatoes provide cheap nutritious food to more than two billion small land-holders and consumers in Africa, Asia and Latin America (Horton, 1987). Overall, potatoes has substantial role in ensuring food security to the alarmingly growing world population and eradicating poverty through provision of wholesome nutritious food, employment

and income as a cash crop under the unfavorable climate change taking place (Haverkort and Verhagen, 2008; Bradshaw and Bonierbale, 2010). Moreover, with development of soilless crop production techniques such as hydroponics and aeroponics, potato has been chosen as an ideal candidate crop for human life support in space (Wheeler, 2009). Moreover, potato has versataile utility in the non-food industry for more than 500 differeent products (Kempf, 1986).These all qualities of potatoes are attributed to the diversity present in its wide range of wild relative species that are far more than any other staple food crops. Sustainability of potatoes versatile utility in the food and non-food industries, however, requires continued efforts of evaluation of germplasm to identify pairs of divergent parental lines with complementary features that can help agricultural scientists respond to contemporary challenges of humanbeings need. Thus, it is imperative to evaluate germplasm present in various areas of the world for proper utilization of the special attributes present in them in the on-going crop improvement programmes, for characterization and devise their appropriate conservation.

2. Domestication of cultivated potatoes

The cultivated potatoes belong to the large and diversified genus, *Solanum* (Hawkes, 1994). There are seven cultivated species of potato with a chromosome base number of 12, occurring in a polyploidy series ranging from diploid (2n = 2x = 24) to pentaploid (2n = 5x = 60) (Hawkes, 1994). The homeland where the first intentional cultivation or domestication of potatoes has been started is western parts of South America, i.e., the Andes of present territories of Peru, Chile, Bolivia and Ecuador (Lisińska and Leszcyński, 1989; Hawkes, 1994).

3. Genetic diversity of potato

The term genetic diversity in its simplest description refers to all the variety of genes that exist in a particular variety or species (Long *et al*., 2000). Thus, genetic diversity has a vital role in increasing and sustaining agricultural production levels

and nutritional diversity throughout the full range of different agroecological condition. As a result the taxonomy of cultivated and its wild relative species and evaluation and characterization of landraces and improved varieties has been the subject of study since human directed evolution and crop improvement started and continue to be critical future concern for enhanced ecosystems function and resilience for risk mitigation.

Evaluation of the genetic diversity present among germplasm is also vital for either gene bank managers or curators that undertake such capital intensive business of genetic resources maintenance activities for quite extended periods of time against the declining financial support in one hand and the development led environmental crimes of human beings that made the world rather suitable for genetic erosion than conservation due to the global warming facilitated by natural forest destruction and carbon saturation emitted from industries. Genetic diversity and variability analysis also plays vital role for a successful and effective plant–breeding program enabling the choice of distinct parents useful for hybridization and development of high yielding cultivars (Griffing and Lindsstromm, 1954; Haydar *et al*., 2007; Gaur *et al*., 1978) and to meet the diversified goals of plant breeding (Haydar *et al*., 2007). Thus, genetic diversity will help to make agriculture responsive to providing sufficient quantity and quality of agricultural products that can meet the food and non-food industrial input needs to the rapidly growing world populations under the constant threat by the sub-optimal environmental conditions (Mittler and Blumwald, 2010). Its utility for proper variety registry and property right protection is also critical.

The cultivated potatoes are among genetically diverse and an unusual crop plants that possess 228 related wild species with similar base number (x = 12) chromosome. They occur in a polyploid series ranging from diploid (2n = 2x = 24) to hexaploid (2n = 6x = 72) (Hawkes, 1994) and nearly all of them hybridize. Thus, it ease introgression of genes from these genetically diverse and geographically widely spread relatives into the cool temperate climate confined cultivated potatoes. These

wild relative species displays wide range of variability in ecological adaptation, disease and insect pest resistance (Hawkes, 1994), essential mineral concentrations, dry matter and starch content (Burgos *et al*., 2007) among others and served as a source of agronomically and agriculturally useful traits of relevenace to the cultivated varieties.

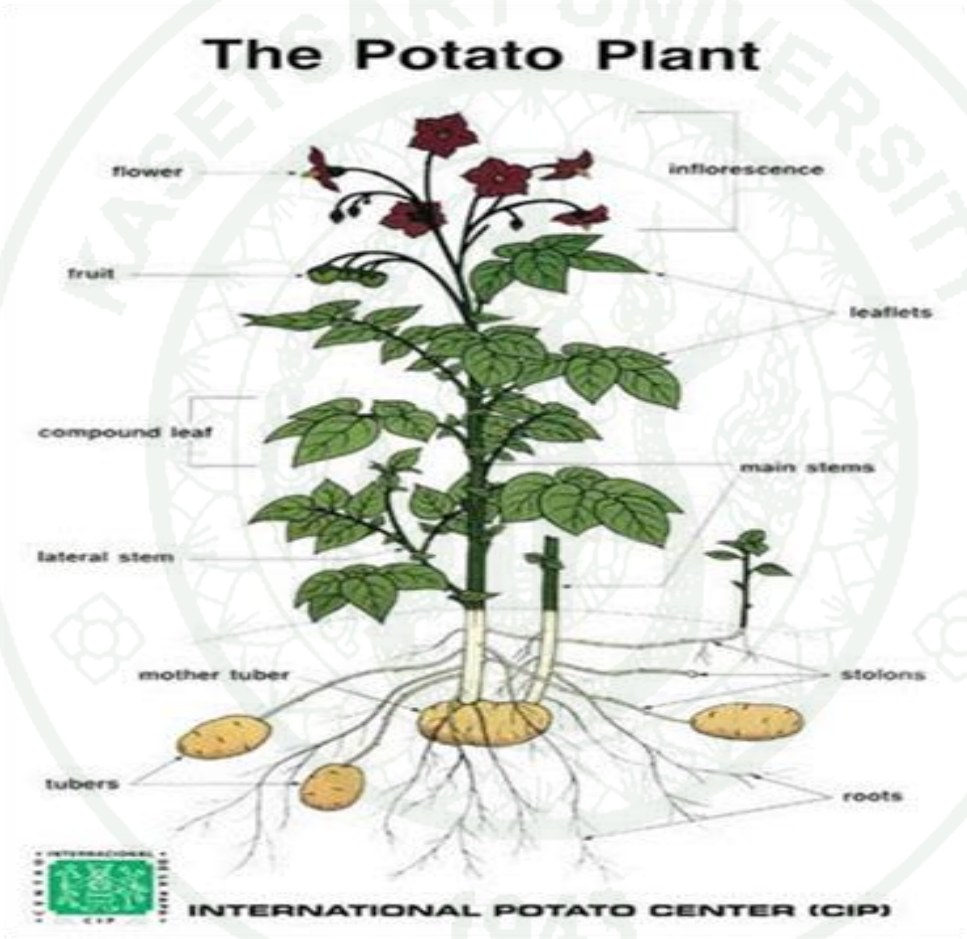

Figure 1 A potato plant illustrating all its parts.

3.1 Morphological diversity in potato

Morphological description system has been used since olden times for taxonomic classification of genetic resources (Hawkes, 1994; Smith and Smith, 1989), and still being used for genetic diversity analysis (Chimote, 2007; Mondal, 2007), for

studying phylogenetic relationship of wild potatoes and cultivated varieties (Raui *et al*., 1997) and characterization of released cultivars (Onildo, 2009; Arslanoglu *et al*., 2011; Ahmadizadeh and Felenji, 2011). Characterization of the diversity present in the germplasm through the use of morphological descriptor list involves description of variation for morphological traits, particularly agro-morphological characteristics of direct interest to users. This system relies on the precise recording of traits such as leaf type, flower color, growth habit, tuber flesh, skin, shape, and sprout appearance. In the morphological descriptor system highly heritable traits often show little variation over much of the material studied while some other traits expression is subject to environmental variation and may be difficult to measure. Corell (1962) and Hawkes (1990) have described and classified numerous species into 26 and 21 series, respectively based on morphological characters. Arslanoglu *et al*. (2011) characterized 146 collections of local potato genotypes based on four plant, two flower, seven tuber and two physiological characteristics and grouped them into 27 clusters containing useful genotypes for breeders in Turkey. Likewise, Ahmadizadeh and Felenji (2011) evaluated the diversity present among 22 potato cultivars in Iran based on four plant and 6 tuber yield agro-morphological characters and grouped them into two clusters of different attributes beneficial for plant breeders to choose from for their improvement program. Ríos (2002) classified and identified duplicates among Tenerife potato cultivars based on morphological and ecophysiological chracateristics. The discordance or inconsistency between Corell (1962) and Howkes (1990) series number is the manifestation of the subjective element involved in this method as description is made based on overall phenotypic resemblance or differences judged from the phenotype of the organism without any implication as to their relationship by ancestry (Sneath and Sokal, 1973). van den Berg and Jacobs (2007) further attributes such inconsistency to the narrow typological species concept emplopyed in potato classification unlike in that used for other groups within *Solanum* and the extensive variability in some of the key morphological characteristics employed in classification. Moreover, the phenotypic plasticity, or a phenomenon in which a given genotype may develop different states for a character or group of characters in

different environments due to genotype-environment interaction, nature of potatoes could add for the above observed discord in the two authors. Despite this shortfall in morphological characterization technique, a common feature in all other techniques too as there is no one marker system that can fully describe genetic resources alone, it remains to be a useful complementary technique to other systems in the characterization of genetic resources. The careful and selective use of characters that are stable across various environments will help maximize the efficiency of morphological description technique for an appropriate evaluation of gerrmplasm, characterization and their diversity analysis.

3.2 Dry matter content variability in potato

Dry matter content is a critical component of efficiency in manufacturing industries producing processed products from potatoes. Generally, potato tubers that are less than 19.5% and 20% dry matter content are not fit for French fries and chips purpose, respectively (Kirkman, 2007). The potato tuber is composed of 75 to 80% water and 20% to 25% dry matter or solid (Nunn and Qian, 2011). Nevertheless, this composition values is highly influenced by a wide range of factors, most importantly genetic feature of varieties, environmental factors during growth of the crop and development of the tuber (Storey, 2007), tubers size (Beukoma and Van der Zaag, 1990; Kolbe and Stephan-Beckman, 1997), age and maturity, soil temperatures, available soil moisture, fertilization, pests and diseases (Leszczyński, 1989; Karenlampi and White, 2009). Hardenburg (1933) claimed quality in potato is more dependent on soil, climate and maturity than variety itself since properly grown and matured varieties could have as high levels of DMC as other ones. In contrast, Stevenson and Whitman (1935), Haddocka and Blood (1939), Akeley and Stevenson (1944) and Mondal and Hosain (2006) claimed a superseding influence of genetic make-up and inherent differences of varieties commonly manifested in their mean differences. In the same way, Squirrell and M'acLennan (1928) underscored the overriding influence of the variety on potato quality compared to 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). This has been indicated by different authors. Burton (1989) reported dry matter content ranges of 18% to 26% among potato varieties selected for commercial usag in England. Similarly, Pérez de Camacaro *et al.* (2006) reported dry matter content range of 20% to 26.56% among 14 new potato genotypes evaluated at a single location in Venezuela and classified them into table and processing types. Equally, Burgos *et al*. (2007) reported dry matter content range of 23.2% to 36.2% among 37 potato genotypes of six different species at one location and 20.1% to 33.8% at another location from the same set of genetic materials. Dry matter content studies carried on four varieties at one location by Tekaligne and Hammes (2005), on seven varieties by Asmamaw *et al*. (2010) at three different locations, and on five varieties by Elfnesh *et al*. (2011) at three distinct locations in Ethiopia also displayed a range of 18.60% to 22.80%, 22.46% to 25.24%, and 20.95% to 24.43% respectively. Results of dry matter content variability studies carried in Malawi on 20 different genotypes of cassava and 11 different sweetpotato varieties also showed similar features of genetic materials in which dry matter content in cassava ranged from 38.85% to 47.68% (Benesi *et al.*, 2004) and in sweetpotato ranged from 29% to 39.07% (Tsakama *et al.*, 2010). Benesi *et al*. (2004) further noted the greater contribution (36%) of genotypes to the total variation observed in dry matter content of studied genotypes. Results the aforestated workers clearly shown the larger effects of the genetic make on the dry matter content of varieties as observed from the inherent differences of varieties grown under similar environmental condition. Nevertheless, a variety with high dry matter accumulation potential from the stand point of its heredity will yield to its capacity if the environment is right (Akely and Stevenson, 1943). This has been noted from the different dry matter content of the same across different sites and/or seasons at the same site (Barrios *et al*., 1961; Elfenesh *et al*., 2011). Thus, locations had a pronounced effect for varieties to manifest their inherent differences. Wide differences in the dry matter content percent of the same variety were found when grown in different parts of the country (Akeley and Stevenson, 1944). Accordingly, dry matter content is found to be low under cool and dull years and short growing seasons

compared to warm, sunny years with long growing seasons and adequate water suppy (Storey, 2007). Overall, the existing reports clearly portrays the relevance of evaluating available germplasm resources at hand at different parts of the country in order to identify varieties with greater potential of dry matter acculation ability and appropriate areas of production of either table or processing types. This will ultimately help identify possible parental lines for future breeding program targeted at improving the processing quality of potatoes in the country.

3.3 Nutrient concentrations variability in potato

Humans require at least 22 minerals elements for their well-being (White and Broadley, 2005). Inadquate consumption of even one of these nutrients will result in adverse metabolic disturbances leading to sickness, poor health, impaired development in children, and large economic costs to the society (Golden, 1991; Grantham-MacGregor and Ani, 1999; Ramakrishnan *et. al*., 1999; Branaca and Ferrari, 2002). Importantly, all these essential mineral nutrients enter the food chains through plants (White and Broadley, 2005). They are embedded or set in the edible storage tissue or dry matter portion of grain, roots, tubers, vegetables or fruits.

The 20% to 25% dry matter portion of potato's tuber harbor all the chemical composition ingrained in potato tuber, i.e., starch (65% to 75%), total sugar (2.1%), crude protein (7.94%), crude fiber (2.32%), crude lipds (0.5%) and ash/minerals (4.41%) (Leszcyński, 1989). Thus, potatoes represent a non-fattening, nutritious and wholesome food, which supply important nutrients to human diet. They are very good source of vitamins particularly ascorbic acid (vitamin C), vitamin B6 and B1, foliate, and high-quality proteins notably essential amino acid lysine (Friedman, 1996), which is used to fortify cereal products (Dale and Mackay, 1994; Smith and Smith, 1968). A 100 gram boild potato can provide 10% and 5%, respectively of the daily requirement of protein of a child and an adult (Naidu, 2003). Furthermore, according to the U. S. Department of Agriculture (2007), a medium potato (150 grams) with the skin provides 29.55 milligrams of vitamin C (45% of the daily value [DV]), 632

milligrams of potassium (18% of DV), 17% to 18% phosphorus, 26% of copper, 5% to 13% of zinc, magnesium and manganese. Naidu (2003) also reported that 200 gram of potato can help meet the daily adult requirement of vitmin C (100 to 120 $mg.d^{-1}$). According to the British Potato Council (2004) an average of 175 gram serving potato tuber provides 29% of Recommended Daily Allowance (RDA) of vitamin B6, 16% vitamin B1, and 16% foliate. Moreover, the fiber content of a potato with the skin (3.5 grams) is similar to that of many cereals such as wheat (U. S. Department of Agriculture, 2007). Potatoes are also rich in dietary antioxidants comprising polyphenols, carotenoids, and tocopherols (Andre *et al*., 2007; Storey, 2007). Potato dry matter, is composed of crude protein (7.94%) and ash (4.40%) (Leszczyński, 1989). Among ashes or mineral nutrients, potatoes provides substantial amount of the two critical mineral nutrients, i.e., iron and zinc (Karenlampi and White, 2009) due to the high amount of ascorbate, that promote micronutrient bioavailability to the body (U. S. Department of Agriculture-Agricultural Research Service, 2007) and low levels of phytic acid (0.11 to 0.27% of the dry matter), an anti-nutrient compound that limit micronutrient absorption by the body (Fairweather-Tait, 1983; Frossard *et al*., 2000; Phillippy *et al*., 2004) and oxalate (0.03% of tuber dry matter) (Bushway *et al*., 1984). Because of these reasons, potatoes support life better than any other crop when eaten as the sole article of diet (Davidson *et al*., 1975; Reader, 2008). However, all those factors affecting the dry matter content of potato's tuber such as variety, growing conditions, fertilization, pests and diseases, environmental conditions, such as climatic and soil conditions, age and maturity of the tubers highly affects the chemical composition of potato tuber (Leszczyński, 1989). This has been reported from research carried on different crops in different parts of the world. Mineral concentration study carried out on potato in Turkey by Ekin (2011) on eight varieties for two years identified a protein content ranging from 10.1% to 12.2%, and iron and zinc concentration of 75.03 to 122.69 and 12.50 to 16.78 milligram/kilogram, respectively during the first year and from 11.6% to 13.50%, and 48.85 to 77.40 and 15.21 to 18.96 milligram/kilogram, respectively for protein, iron and zionc. Anderson *et al*. (1999) also reported Fe concentration ranging from 11.71 to 131.05

milligram/kilogram. These results clearly indicate the effects of genetic material and climatic conditions during different years at a particular location on mineral content of varieties. Similarly, Burgose *et al*., (2007) also reported iron and zinc mineral concentrations ranging from 16.1 to 36.7 and 8.3 to 14.7 milligram/kg at one location and 13.6 to 29.4 and 9.9 to 20.2, respectively among 37 potato genotypes of five different taxonomic groups of cultivate types. Similar to the results reported by Ekin (2011), this one also had clearly portrayed the influence of genetic material and area of cultivation on mineral concentration. Tekaligne and Hammes (2005) in a similar way reported protein, iron and zinc mineral concentrations ranges of 5.6% to 10.1%, 51.33 to 59.67 and 13.17 to 20.83 milligram/kilogram, respectively among four genotypes evaluated at a single location for one year. Andre *et al*. (2007) reported Zn cocentrtaion ranges of 12.60 to 28.83 milligram/kilogram among different potato varieties. Considerable genetic variations in mineral concentrations were also reported among accessions of wheat (Monasterio and Graham, 2000; Velu *et al*., 2011), maize (Bänziger and Long, 2000), rice (Welch and Graham, 200), beans (Beebe *et al*., 2000), cassava (Chavez *et al*., 2000). This variability of crop varieties in their tissue minerals concentrations are caused by the inherent differences in their nutrient use efficiency and phytoavailability of these minerals to the plants. More importanatly, the bioavailability of essential minerals vary from one plant to another (White *et al*., 2009). As a result FAO/WHO's daily recommended intake (RNI) for iron depends on the bioavailability of the mineral. Accordingly, the daily RNI of Fe for children of 1-3 years, men, and women of reproductive ages in developing countries based on 5% assumed bioavailability is considered to be 12, 27.4 and 58.8 mg day^{-1}, respectively. Conversely, the RNI value of Fe for the same group of society in developed countries based on 12% assumed bioavailability is considered to be 5, 11.4 and 24.5 mg day^{-1} (Anonymous, 2002). Likewise, the daily RNI of Zn for children, men and women at a high bioavailability (50%) is 1.67, 4.3 and 3.6 mg kg^{-1}, respectively. This value varies with the assumed percent of bioavailability. As a result, the FAO/WHO's daily RNI of children, men and women at a low Zn bioavailability of 20.4% is specified to be 4.1, 6 and 4.3 mg day^{-1}, respectively. Yet, the bioavailability minerals in potato tuber is

higher than other major cereal crops due to high concentration of promoter chemical (USDA/ARS, 2007) and low level of inhiboitor chemicals (Phillippy *et al*., 2004; Bushway *et al*., 1984). This makes potato a crop of choice to manage malnutrition of Fe which affects 60-80% and Zn which affects > 30% of world'd 6 billion people (White and Broadley, 2005). The observed considerable variation among cultivated varieties and related wild species imply the relevance of evaluating mineral concentarions within germplasms at hand under different environmental location. This ultimately will help identify genotypes with higher concentration for either direct use or parental lines that can be used to develop varieties with elevated mineral concentration which is a sustainable strategy of addressing mineral malnutrition-biofortification. Moreover, as mineral concentrations are embedded in the dry matter content of the edible parts of the crops, it is pertinent to consider effects soil fertility and mineral nutrient gradients across different growing areas that either inhibit or facilitate minerals phytoavailability and thus obtain the desired level of mineral concentrations in the edible portion of this crop plant.

3.4 Starch content, chemical composition and functional properties variability in potato

The history of the practical use of starch products and perhaps of starch itself, dates back to when Egyptian in the pre-dynastic period (6 000–3 000 BC) used adhesive made of ground wheat flour boiled with diluted vinegar to size and cement stripes of papyrus for paper sheet (Schwartz and Whistler, 2009). Later the Romans used this substance as an adhesive whilst ancient Greeks for medical preparations (Kuar *et al*., 2007). Starch was also used to whiten clothes and powder hair (Schwartz and Whistler, 2009). Now adays starch is used in the food industry as a thickener and in the non-food industry for more than 500 different products (Kempf, 1986) such as as textile, pharmaceutical, paper, glue, cosmetics and many other manufacturing industries.

Potato is one of the world'd three most important sources of starch after maize and wheat. Starch constitutes 65% to 75% of the tuber total dry matter (Gray and Hughes, 1978; Storey, 2007) and is the main source of energy provides 2.5% of daily energy expenditure of the world's population (Parsapour and Lame, 2005). Starch content is one of factors that affect the culinary or food quality of potatoes (Cobb, 1935) and determines the mealiness and sogginess of apotato variety (Murphy *et al*., 1963). It does also determine the textural properties of whole cooked potato tuber and quality of starch based foods (Chen *et al*., 2003). Starch content, like any genetic characters, is a function of the hereditary factor and environment working together (Kooman *et al*., 1996). Yet the genetic make make up or hereditary factor has sizeable effect on the starch content of varieties. Starch content variability of potato varieties was reported by different workers (Barios *et al*., 1963; Rivero *et al*., 2009). Potato is used for production of its unique starch that can form clear and thick visco-elastic gel upon heating and subsequent cooling (Vasanthan, 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 (~0.08%) than other major starches sources such as corn starch (~0.02%), waxy maize starch (~0.01%), and Tapioca starch (~0.01%) (Li *et al*., 2006). Starch granules isolated from either potato or other plant species are certainly similar in their primary structures of the major components, i.e., amylose molecule, a linear chain of glucose monomers linked by 1,4-glucosidic bonds (Figure 2), and amylopectin molecules, a polymer of glucose molecules in which the chain is branched by addition of 1,6-glucosidic bonds (Banks and Greenwood, 1975; Guilbot and Mercier,1985; Moorthy, 2002; Schwartz and Whistler,2009; Shannon *et al*., 2009; Storey, 2007; Figure 3). However, the fine structures of both the amylose and amylopectin components and their ratio do vary depending on plant species, cultivars of a species, the environment in which a cultivar is grown, and genetic mutations (Mishra and Rai, 2006; Kuar *et al*., 2007; Tsakama *et al*., 2010; Özcan *et al*., 2010). Accordingly, the degree of polymerization of amylose molecules of potato is higher than that in starches of cereals (Morison and Karkalas, 1992) and amylopectin chain length distribution of starches isolated from tuber and

cereal in one hand and starches of different cereal species (Hizukuri *et al*., 1997) on the other were found to be significantly different. Moreover, starches of different botanical sources do vary in the actual and relative amounts of non-carbohydrate constituents such as lipids (<1g kg^{-1}, wheat starch granules >10g $kg.^{-1}$), protein (cereals have 3 to 4 fold than potatoes) (Ellis *et al*., 1998) and phosphate (high in potatoes) (Lim *et al*., 1994). The concentration level of these three constituents allowed potato starch to have higher viscosities, water binding abilities, lower pasting temperature, clear gel and highest consistency on pasting than cereals (Galliard and Bowler, 1987), and excels in film forming and binding characteristics (Alexander, 1995).

The functional properties of starch depends on a number of integrated physical and chemical characteristics such as polymer composition (amylose and amylopectin composition and ratio), molecular structure/morphology, interchain organization, and minor constituents such as lipids, phosphate ester groups and proteins (Singh *et al*., 2003; Biliaderis, 2009). These qualities of starch are to a larger extent under genetic control (Biliaderis, 2009). Genetic differences among different crops varieties including potato over these starch qualities have also been reported by different authors (Morrison *et al*., 2000; Kuar *et al*., 2003; Noda *et al*, 2004; Liu *et al*., 2007; Mbougueng *et al*., 2008; Alvani *et al*., 2010; Tsakama *et al*., 2010). Environmental conditions during starch synthesis could also affect the packing of starch polymers within granules. A study carried out by Kuar *et al*. (2007) on the physicochemical, thermal and pasting properties of starch isolated from 21 different Indian potato varieties grown under four different locations showed that low temperature during tuber growth resulted in starches with large granule size and lower pasting temperature and transition temperature. Likewise, a study made by Haase and Plate (1996) on starches of different potato varieties grown under different growing conditions revealed the significant effects of both genotypes and environments on total starch, starch granule size distributions, starch phosphorus contents, and starch viscosity. A review paper of Thitisaksaku *et al*. (2012) on effects of environmental

factors presented the effects of temperatures, moisture, and soil chemical properties and heat on cereal starch biosynthesis and composition. Similarly, Furthermore, Kuar *et al*. (2007), Liu *et al*. (2003) and Svegmark *et al*. (2002) reported the effects of growing locations, plant growth stage and growing year on starch characteristics. These facts clearly underscore the relevance of evaluating different genotypes at different locations to identifying starches of desired quality.

The existing research results of different authors dealt on dry matter content, nutrient concentration levels in dry matter content, starch content and starch physicochemical properties of potato certainly suggest the vital contribution of inherent genetic make up of genotypes and environments, climatic, soil, and cultural practices, hence it imperative to evaluate germplasms on hand under varying environmental conditions in order to group them into different functional category depending on inherent differences and identify varieties that can serve as parental lines for future improvement work.

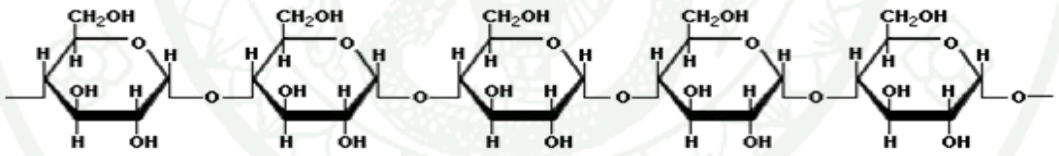

Figure 2 Amylose molecule chain.

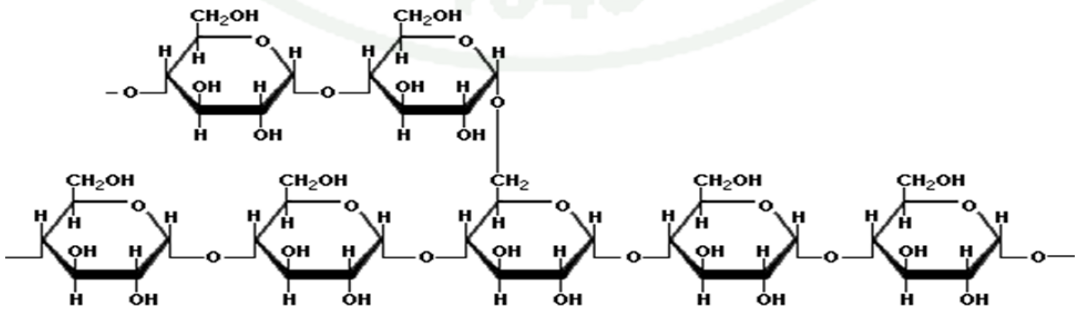

Figure 3 Amylopectin molecule chain.

3.5. Molecular level variability in potato

Following the advances in the field of molecular genetics, several procedures that are fast, reliable and environment independent marker systems have been developed for detecting genetic polymorphism at DNA level. With advent of PCR based molecular markers efficient and complementary techniques were emerged for plant breeding programs (Powell *et al*., 1995; Gupta and Varshney, 2000). Molecular markers are useful for cultivar identification (Douches and Ludlam, 1991), biodiversity analyses, and phylogenetic studies (Ritter *et al*., 2005). These techniques have also been widely applied in potatoes genetic diversity analysis (Fu *et al*., 2009), in genetic relationship studies (Kim *et al*., 1998), characterization of germplasms (Yasmine *et al*., 2006), cultivar identification (Moisan-Thiery *et al*., 2005) and development of linkage map (Tanksley *et al*., 1992). These DNA based genetic markers may differ with respect to features, such as genomic abundance, level of polymorphism detected, locus specificity, reproducibility, technical requirements and cost (Spooner *et al*., 2005). No marker is superior to all others for a wide range of applications. However, some techniques are clearly more appropriate than others for some specific applications. The most appropriate genetic marker of choice will depend among others on the specific purpose of application or specific question to be addressed and the presumed level of polymorphism. Microsatellite also called simple sequence repeats (SSRs) has a unique quality of meeting several of the merits of marker types. The uniqueness and value of microsatellites arises from their multi-allelic or highly polymorphic nature, co-dominant transmission, ease of detection by PCR, relative abundance, extensive genomic coverage and requirement of small quantities of template DNA (10–100 ng per reaction) for PCR amplification (Powell *et al*., 1996a). Furthermore, microsatellites are highly reproducible due to the use of long PCR primers, which facilitate distribution between labs as primer sequences. Simple sequence repeats (SSRs or microsatellites) are highly polymorphic, co-dominant markers that are genetically well-conserved across related species. Moreover, they are simple to use in PCR reactions (Powell *et al*., 1996). They have

also many other advantages over other markers types such as low operational costs, high variability, high quality and reproducible bands, amenability to automation and ease of multiplexing. Microsatellite marker were used for potato diversity studies, genetic structure determination and classification (Spooner *et al*., 2007), for tracing germplasm migration (Ames and Spooner, 2008; Ríos *et al*., 2007; Spooner 2005a,b), relationship among cultivars (Ruiz de Galarreta *et al*., 2007), fingerprinting (Moisan-Thiery *et al*., 2005; Reid and Kerr, 2007; Provan *et al*., 1996; Schneider and Douches, 1997) and genetic linkage mapping (Feingold *et al*., 2005; Ghislain *et al*., 2001). Thus, SSRs provide a common language for collaborative research and acts as universal genetic mapping reagents (Morgante *et al*., 2002).

SSRs has the capacity of reflecting ploidy status and heterozygosity and thus becomes a marker of choice in the genetic diversity study of the polyploid potato (Milbourne *et al*., 1998; Ghislain *et al*., 2001b). This has been demonstrated by Ghislain, *et al.* (2004) where they have characterized 1, 000 cultivated accession in the CIP collections using SSRs marker system. Yi *et al.* (2010) also reported results of phylogenetic analysis and association of markers and traits related to starch contents of 30 Korean potato cultivars using 14 microsatellite markers. These produced two distinct groups using these SSRs markers. Its high reproducibility, genotypic index, i.e., the mean number of band profile generated per primer set per cultivar (McGregor, 2000), high polymorphism that measures the informativeness of a given DNA marker (Milbourne *et al*., 1997; Provan *et al*., 1996; Ghislain *et al.*, 2009; Yi *et al*., 2010), wide genome coverage (Ghislain *et al*., 2004; Ashkenazi *et al.*, 2001) and high heterozygosity level to determine the hybridity of intraspecific somatic hybrids (Provan *et al*, 1996) has been reported. These merits of SSRs help sufficiently detect the genetic diversity among both closely and distantly related heterogeneous germplasms and investigating genome introgression through breeding. The presence of locus specific markers related to starch content gene signify the use this molecular technique in the current study as a complement to the morphological characters based evaluation of the diversity of released and widely grown farmer's varieties in Ethiopia.

4. Importance of potato and research endeavors in Ethiopia

In Ethiopia, potato is the leading tuber crops widely grown for different purposes. It provides food and employment opportunities to over 2.3 million rural households (CACC, 2003) dwelling in the cool highlands that is conducive for production of good quality and better tuber yield. Moreover, it is an important lucrative cash crop that helps growers generates sizeable income. In recent years potato production has shown a remarkable increase in less that two decades period by about 64%, i.e., from 349, 000 tons in 1993 to 572, 332 tons in 2010 (FAOSTAT, 2011). Among African countries, Ethiopia has possibly the greatest potential for potato production since 70% of the arable land in the country is located at above 1, 500 meters elevation- believed to be suitable for potato. Moreover, potato could play vital role in ensuring food security since 90% of the population do also reside in this highland area (FAO, 2008). To backstop this trend and take full advantage of potatoes key role in food security within the country, sizeable efforts were made and still being made by public research and higher learning institutions to develop widely adaptable, high yielding, disease and insect pest tolerant potato varieties for the past three decades. During these periods over 30 improved potato varieties that can help improve the productivity and profitability of potato among small-sacle potato growers were officially released and registered by the National Variety Registry Office (Ministry of Agriculture, 2008). Despite this fact, potatoes are still widely regarded as secondary crop, and annual per capita consumption is estimated at just 5 killogram (FAO, 2008). Its utilization has also largely been limited to consumption of boiled tubers, in stew where potato tubers are incorporated as an ingredient and currently flourishing roadside frying business (Tesfaye *et al*., 2010). One of the main reasons for such limited use of potato is attributed to low attention paid by the research system to post-harvest studies to spearhead and unlock the potential contribution of potato in its diversified form, processed food and non-food industrial products such as French fries, crisps, canned potatoes and starch production. Despite, the increasing demand for processed products among the urban dwellers following the changes in their

lifestyle and dietary diversification, presently there are no variety as such lablelled to be appropriate for processing purpose in the country. So far only three fragmented studies related to dry matter content and chipping potential were carried (Tekaligne and Hammes, 2005; Asmamaw *et al*., 2010; Elfnesh *et al*., 2011). And no single research has been done to evaluate the starch content, starch yield and starch chemical and pasting properties of varieties official registered in the country. Commercial utilization of potato for processed food industrial raw material and starch that can help add value to the produce and create new domestic and export market requires a thorough understanding of their processing quality governing factors, and chemical and pasting properties of starches of potato varieties isolated from environmentally divergent locations in the coutry.

Moreover, the world Food and Agriculture report indicated that sub-Saharan Africa and South and East Asia embrace the world's hungry people (FAO, 2012). Although, South and East Asia contained the greatest number of hunger people, the prevalence in sub-Saharan Africa is highest with one in every three people suffering from chronic hunger (FAO, 2012). The term hunger covers all those issues related to food access and poverty, food availability, nutritional balance and time in its negative concept. Ethiopia is among the 17 sub-Saharan Africa countries where food insecurity and nutritional deficiencies is manifested at higher level and infectious diseases caued by these limitations are the leading health problem in the country ((Interdepartmental Committee on Nutrition for National Defense, 1959; Wolde-Gebriel *et al*., 1991; 1993; Haidar *et al*., 1999). At national level 64% of the children < 5 years old in the country are moderately or severely stunted, where 47% are underweight and 8% are wasted (Central Statistic Authority of the Federal Democratic Republic of Ethiopia/FDRE, 1992). This problem does also high in the surplus region of the country such as west Gojjam (Medhin *et al*., 2010) where a stunting prevalence of 75% is recorded. Moreover, about 17% of children are reported to have low birth weight (< 2, 500 g) (Ministry of Health of FDRE, 1995). Such prevalence level is among the highest in the world. Umeta *et al.* (2000) also reported that 57% of infants

aged 6–11 months in Ethiopia are stunted. Malnutrition of these nutrients is critical for they impair physical and cognitive development of children and increase morbidity and mortality. It also reduces the productivity of both adult men and women due to increased risk of illness and reduced work capacity (Bouis and Welch, 2010). Zinc deficiency had significant contribution to child stunting as evidenced from supplementation program held in developing (Ferguson *et al*., 1993; Dirren *et al*., 1994; Rivera *et al*., 1998) and developed countries (Hambidge *et al*., 1976; Walravens and Hambidge, 1976; Walravens *et al*., 1992). Traditional interventions to address mineral malnutrition have focused on supplementation, fortification and selective diet diversification (White and Broadley, 2005). Biofortification has recently been emerged as a cost effective and sustainable way of reducing global micronutrient malnutrition problem (Horton, 2006). This approach focuses on elevating the concentration of micronutrients in the edible parts of staple crops. Genetic enhancement largely depends on genetic variability present within the available gene pool. Thus, the potato – which is the most efficient crop for converting natural resources, labor and capital into a high quality food, and nutritionally well balanced and containing highly bioavailable micronutrients such as iron and zinc could contribute a lot to the majority of highland dwellers in Ethiopia. Nevertheless, research related to mineral concentration of released varieties in the country is certainly unavaialable, where only one study was carried on advanced clones that have not been promoted to official release and subsequent registry (Tekaligne and Hammes, 2005). Inaddition only a single study was undertaken to evaluate the gentic diversity of these released varieties (Tesfaye *et al*., 2004). This clearly revealed the information gap present on available varieties grown by potato producers at varying scale.

Analysis of current contribution potato's in the food system of over 2.3 million household lives, the potential suitable agro-ecological conditions in the country, the dynamics in the food habits of urban dwellers and current development targets set by the government in planting of various manufacturing industries such as pharmaceutical, textile, paper and food versus the research efforts made during the

past more than three decades and its present status, certainly there are clear gaps that needs to be addressed to magnify the key role of this crop in the country. To this end a comprehensive evaluation of genetic diversity, post-harvest qualities, nutritional composition and the starch chemical composition and pasting properties of available varieties and factors influencing these traits is a timely concern. Addressing these core research gaps of the potato sector will first and for most help categorize existing varieties into their end use potentials and respond to the emerging demands on the potato sector. It will also contribute to alleviating the prevailing food shortage and malnutrition problems and unlock the potential role of potato as a raw material in starch industry to be of use as an ingredient in the food and non-food industries. Moreover, the information obtained from both morphological and molecular level diversity analysis will help identify divergent parents having complementary features for future varietal development program activities targeted at improving the processing and nutritional quality of varieties.

5. The scope of current study

5.1 Scope of current study

The current study was carried after a thorough review of past and present day research activities in potato research project in Ethiopia and identification of the gaps observed in its more than 30 years of research history. Overall the research topics addressed in this thesis traverse through evaluation of the dry matter and starch content diversity of improved potato varieties, widely grown farmer's cultivars and advanced elite clones in the country, essential minerals concentration, starch yield, starch chemical composition and pasting properties as a criterion determining their nutritional value, texture and functional properties in the whole cooked potato tubers for direct consumption and in non-food industrial products. Finally, the phenotypic diversity and genetic causes of their post-harvest quality diversity present among these germplasms were evaluated at morphological and DNA level with special emphasis to gene associated with starch biosynthesis was evaluated. And as such all activities

included in this thesis centered on the 20% to 25% dry matter portion of the potato tuber, which harbors all essential product of this commodity, and the phenotypic and genotypic causes of variation present among existing potato grermpalsm in Ethiopia for either nutritional or processing qualities that determine their end use. Thus, all these interrelated activities addressed in the current thesis will in one hand provide the complete picture of the potato germplasm in the country and directs to future research dimension on this commodity to respond to the emerging need for nutritious agricultural products and processing type varieties on the other hand.Therefore, the results of these studies are also organized in such a way that the clear picture of these interrelated activities will be vividly captured. The first two experiments contained to experiments that deals with dry matter and starch content and starch yield variability while the second with specific gravity variability the 25 potato varieties as a criterion of determining their dry matter content under different set of production environments. The third, fourth, fifth and sixth experiments of the thesis presents the variability of the 25 varieties in tuber mineral concentration, chemical and pasting properties of their starches isolated from different environments, and finally the morphological and genetic divergence. Thus, the whole story or accounts of this thesis ultimately enables development of data basis of potato varieties present in the country for further action in enhancing the versatile utility of potato.

MATERIALS AND METHODS

Description of the study areas

Three field trials of experiment I, II, IV and V were conducted in all the three environmentally distinct districts of the Amhara Regional State, one of the nine ethnic divisions (*kilil*), in Ethiopia (Figure 4). Experiment III was undertaken at all the three locations, but due to the technical problem encountered in the laboratory facilities of the Ethiopian Health and Nutrition Research Institute (EHNRI) only the mineral concentrations of tubers of the 21 of the 25 varieties grown at Merawi and Debretabor locations were successfully carried. Thus, the analysis results of four of the 25 varieties listed in Table 3 and that of the third site, Ade, was not carried out and thus could not included in the results and discussion part of experiment III. The three districts, Adet, Merawi and Debretabor were deliberately selected for these studies considering their representativeness to major potato production agroecologies in the Region. Adet is positioned at $11^0 16' 32''$ N latitude and $37^0 29' 30''$ E longitude. It has a red brown Nitosol soil. This site represents highland potato production parts. The Merawi experimental site is located at $11^0 30' 0''$ N latitude and $37^0 0' 0''$ E longitude. The soil is a heavy clay-textured red Nitosol. Merawi is selected to represent mid-altitude potato production areas in the Region. Debretabor is located at $11^0 51' 0''$ N latitude and $38^0 1' 0''$ E longitude and has a soil type classified as Luvisol. Debretabor site represents at the cool highland areas of major potato production belts in the Region. The rainy season at these 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.

Table 1 Physicochemical properties of soils of the three experimental sites

Site	Altitude (m)	Soil physical and chemical property						
		Soil pH	Total N (%)	Available P (ppm)	Available K ($Cmol^{+}.kg^{-1}$)	CEC (Meq/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

Data analyzed by Adet Agricultural Research Center soil and Water Research Department.

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

Site	Cropping season Months	Mean monthly rainfall, (mm)	Mean air temperature, (^{0}C) Min.	Max.	Relative humidity, (%)	Sunshine hours (hr)
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.

Genetic materials

A total of 25 potato genotypes containing 18 improved varieties, 3 elite clones and 4 widely cultivated farmers' cultivars were evaluated (Table 3).

Table 3 List of potato varieties evaluated in the current studies

No.	**Name**	Status	Parentage of varieties
1	Menagesha	Released variety	I-1058 x 700764
2	Gera	”	NO
3	Challa	”	NO
4	CIP-395096.2	Elite clone	393085.5 x 393053.6
5	Wochecha	Released Variety	NO
6	Awash	”	1058B x 700111(adg)
7	Gorebella	”	NO
8	Zengena	”	NO
9	Hunde	”	NO
10	Agere	Farmers' cultivar	NO
11	Shenkolla	Released variety	NO
12	Belete	”	387170.16 x 389746.2
13	Ater Abeba	Farmers' cultivar	NO
14	CIP-392640.524	Elite clone	NO
15	Gudene	Released variety	BL-2.9 X 575049
16	Bulle	”	NO
17	Gabisa	”	NO
18	Tolcha	”	NO
19	Aba Adamu	Farmers' cultivar	NO
20	Marachare	Released variety	CIP-382132.14 X XY.13
21	Sisay	Farmers' cultivar	I-1058B x 700111(adg)
22	Ararsa	Released variety	NO
23	Jalene	”	NO
24	Guasa	”	NO
25	CIP-396004.337	Elite clone	391002.6 x 393382.64

NO – Not obtained; CIP-382132.14 contains the blood of 700111 back two generation.

Although, no comprehensive and systematic characterization work on these varieties that can of help to distinctly classify and identify each them for any kind of subsequent activities has not been carried out, the data collected during their separate evaluation period indicates that these varieties do display varying maturity period, tuber number per plant, size grade distribution, disease resistance and starability among others. In addition prior to their registry in the Official Variety Registry Bulletins in the country, these varieties had passed through a rigorous evaluation of variety development to examine their adaptability to wider environments, yield potential and disease resistance. Furthermore, eight of them had been evaluated for their processing quality in two different set of experiments conducted at different times in different parts of the country. They do also manifest contrasting plant growth habits. All field experiments were planted during the rainy season of the year 2011. The material and methods that are common to all the experimets, such as decription of location, planting design, fertilization, soils and climatic conditions are presented under this section. The detail procedures that are unique to each experiment are presented under each experimental material and methods sections belw for an easy follow up and smooth flow of and coherence the experiments.

Experimental Design and Field Experimentation

In all the experimental sites, the 25 varieties were planted in a 5 × 5 fully balanced 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 phosphorus.ha^{-1} P_2O_5. At Debretabor, each plot was supplied with 108 $kg.ha^{-1}$ nitrogen and 69 $kg.ha^{-1}$ P_2O_5 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 week 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, yield components and all morphological data data of each variety were recorded from each replication. The details of laboratory protocols, statistical analysis procedure and softwares employed in the remaining studies are described under each experiment in the thesis.

Figure 4 General location of the three experimental sites.

Experiment- I

Dry-matter content, starch content, and starch yield variability and stability of potato varieties in amhara region of Ethiopia

Genetic materials

All the varieties described in Tables 3.

Field experimentation and design

Details are described in the materials and methods part.

Dry-matter content (DMC) analysis

Twelve randomly selected healthy and blameless tubers were selected and used for dry matter determination. The dry matter determination procedure of Liu *et al*. (2002) was followed with slight modification in drying method. In 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 percentage. A duplicate run was carried out for all of the 25 varieties tested at each experimental site.

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. Accordingly the following detail steps were followed in the current study.

Sample selection and preparation

At this step healthy tubers devoid of any type of disease symptoms were randomly selected from all the replicates. This had helped to capture all possible

sources of variations among tubers caused partly by experimental plots soil heterogeneity. For this purpose a total of 500 g of healthy sample tubers were randomly drawn or selected from all replicates and then thoroughly washed with tap water to clean from adhering soil particles and plant debris. Then tubers were lightly peeled and once again washed with tap water. The peeled tubers were then sliced into smaller pieces and about 200 g of homogenate sample were immediately immersed into juice maker filled with distilled water containing sodium bisulphite at a concentration level of 0.01% (w/v) to inhibit microbial growth, starch browning and the activity of amylase (a commonly occurring plant enzyme that hydrolyzes starch). The tubers were then disintegrated and slurred in water with the juice maker. The blending of plant material and water was carried out until a smooth slurry forms (usually 5 to 10 min) with sufficient care must to avoid heat-induced damage to starch granules. The slurred juice was then poured through muslin clot and the starch milk was collected in a baker. The residue remaining on the muslin cloth was again re-slurried in the juice maker for 2 x to recover the maximum possible amounts of the starch grains pouring water on the slurry until a clear white water pass through the muslin cloth.

Centrifugation

The milk was allowed to sediment for a minimum of 10 min, after which the suspended liquid was removed by decantation, and the starch sediment was re-suspended in water, centrifuged for 15 minutes (1, 500 x , 20 ^{0}C) and then the supernatant was decanted while the starch cake was poured onto an aluminum foil. The starch cake was then placed in hot air oven set at 40 ^{0}C and dried for 48 hr. Finally the dried starch was finely ground manually in mortar using pestle, sifted through a 125µm stainless steel sieve and kept packed in air-tight plastic bags for further starch chemical composition and pasting properties analysis.

Statistical analysis

The DMC and SC data of each sites was subjected into separate analysis of variance (ANOVA) for each location and combined ANOVA across location using SAS statistical analysis package by the command PROC GLM (*procedure of general linear model*) do SAS (SAS Institute Inc. 2000, 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, AGROBASE statistical package is employed for AMMI analysis in which performance stability of cultivars across the three sites and environments are presented graphically in a biplot.

Experiment- II

Evaluation of genetic variability of potato varieties in specific-gravity as a criterion determining processing quality

Gnetic materials

All varieties described in Tables 3.

Field experimentation

Details of field level experimental procedures followed for this experiment is illustrated in the general material and methods part.

Specific-gravity (SG) determination

In determining the SG of each variety evaluated across the three distinct environments, healthy and marketable size grade tubers were selected randomly from the central rows of two of the six replications. Then these tubers were cleaned from

soils and adhering plant debris and weighed in both air and water by the method of Murphy and Goven (1959). Finally, the SG value is computed following the formula.

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

Statistical analysis

To determine the effects of genotypes on the SG value, the data of each site was subjected to simple analysis of variance (ANOVA). Concurrently, a combined ANOVA was carried to see the effects of genotypes x environment interaction and to identify superior varieties with desirable quality attributes. All the statistical analyses were carried out using SAS package (SAS Institute Inc. 2009, USA) by the command PROC GLM (procedure of general linear model). Moreover, to convert tuber specific gravity (SG) to dry matter and starch content percent equivalents, the conversion equations of Von Schéele *et al.* (1937) and Klienkopf *et al.* (1987), and Von Schéele *et al.* (1937) and the brine/salt solution-based conversion table, respectively, were compared. Results of both group correlation analyses were highly significant ($r = 0.99$; $P < 0.01$). Consequently, the equation from Von Schéele's *et al.* (1937) of starch (%) = 17.565 + 199.07 (specific gravity - 1.0988) and the equation from Klienkopf *et al.* (1987) of dry matter (%) = -214.9206 + 218.1852 (specific gravity) were used to convert the SG value of varieties in this study to starch content and dry matter content, respectively. Finally, additive and main effects and multiplicative interaction analysis was carried using Agrobase 20 for Windows package (Agromix Software, Inc. 2000) to identify the response of varieties to change in environment.

Experiment-III

Genetic variation in tuber minerals concentration of potato varieties as an option to curb malnutrition syndrome

Genetic Material

All the varieties described in Table 3 but Agere, Awash, Gudene, and Ararsa.

Experimental location

Although this experiment was carried out in all the three locations in the presence all the varieties selected for thesis, due to the technical problem encountered in the laboratory facility, only the data of Merawi and Debretabor were generated for the 21 of the 25 varieties indicated above.

Description of the experimental sites

The description indicated in the general material and methods part.

Field Experimentation

This can be referred in the general materials and methods part.

Sample preparation

At maturity a total of one kilo gram of healthy sample tubers were randomly drawn from all the three replicate plots of each variety planted at each location for the purpose of nutrient concentration analysis. First, sample tubers of each variety were thoroughly washed with tap water and rinsed with distilled water and freed from any soil and inert materials on the tubers. Then, the tubers were lightly peeled

with peeler and shredded into pieces. Subsequently, a 500 g composite sample tubers were randomly drawn to help capture minor differences across plots and then these tubers were placed on to a cleaned, dried and desiccated cap. The sliced tubers in the cap was then dried with hot air of oven set at 40 ^{0}c for 48 hours, after which the samples were removed from the oven and weighed to compute the moisture and dry-matter content of each sample. Finally the dried sample was finely ground into a powder with a laboratory grade sample miller and subsequently used for mineral concentration analysis.

Mineral Determination

The dried and ground analytical samples were analyzed for total nitrogen by Kjeldahl method (AOAC, 1984) and used for the computation of the crude protein concentration by multiplying by a conversion factor of 6.25 (Van Gelder, 1981). Following wet-ash digestion, phosphorus was determined by spectrophotometry where as iron and zinc was determined using atomic absorption spectrophotometry.

Statistical analysis

Analysis of variance (ANOVA) was performed on protein and fiber contents, and iron (Fe), zinc (Zn), and phosphorus (P) concentration of the 21 potato varieties tested at each location to examine genotypic variation. Furthermore, the pooled data of Merawi and Debretabor were subjected into a combined ANOVA to investigate genotypes performance across location, locations and genotype x locations interaction effects. Correlation analysis was also conducted using Pearson test to examine the strength of link between the different minerals, tuber dry-matter and marketable tuber yield. The varieties mineral concentration distribution at the two different locations bar graph was also produced using Microsoft windows EXCEL programs. Finally, means were compared using Duncan's multiple range test procedure with significance

determined at 1% level of probability. All the statistical computations were performed using SAS (Version 9.2) software (SAS, 2009).

Experiment- IV

Variation in chemical composition and pasting properties of starches of different potato varieties grown at different locations in amhara region

Genetic materials

All listed in Table 3.

Description of the experimental sites

As illustrated in the general materials and methods part.

Field experiments

As described in the general materials and methods section**.**

Sample preparation

The starch of each variety tuber was isolated according to Liu *et al.* (2003) procedure with some modification related to chemical used to inhibit starch discoloring microbial growth and activity of enzymatic amylase (a commonly occurring plant enzyme that hydrolyzes starch), filtration, starch cake drying and milling procedure employed. In the current study unlike the procedure described by Lie *et al*. (2003), only sodium bisulphate chemical was used to inhibit microbial discoloration of the starch. In addition, filtration was done using musline cloth unlike vacuum filtration in the above protocol. The starch was also dried with a hot air oven (Tesfaye *et. al*., 2012).

Moisture content

Starch samples (circa 100 mg) were weighed into pre-dried aluminium dishes then placed in an air forced oven for 1 hour at 130 °C ± 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 *el al*., 2010)

Amylose and amylopectin content determination

The amylose content of potato starch was quantified by iodine colorimetric method, according to McGrance *et al*. (1998) method with a slight modification. Potato starch samples were gelatinized with 0.1 N sodium hydroxide overnight at 5 degree Celsius 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 1 mL of 6.5 x 10^{-4} mol/L I_2/1.3 x 10^{-2} mol/L 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. Amylopectin content was calculated by difference (100 - amylose %).

Pasting properties analysis

The pasting properties of potato starches were evaluated with a Rapid Visco-Analyzer (RVA-4, Newport Scientific, Warriewood, 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 50^0C for 1 min, heated to 95^0C in 3.7 min, held at 95^0C for 2.5 min and holding at 50^0C for 2 min. Parameters recorded were pasting temperature (Ptemp), Pasting time (PT), peak

viscosity (PV), hot paste viscosity (HPV) (the lowest viscosity at 95^0C), cool paste viscosity/CPV (final viscosity at 50^0C), breakdown viscosity (PV–HPV), and setback viscosity (CPV– HPV). All measurements were done in duplicate. Finally stability ratio (SR) and setback ratio (SBR) were computed with the earlier as a ratio of HPV/PV and the latter as the ratio of CPV/HPV.

Statistical analysis

Both simple and combined analyses of variances were carried to determine the amylose and amylopectin content and starches pasting properties differences between varieties and locations and the interaction between genotype by locations. Amylose and amylopectin content data indicated in the following table were generated from triplicate determination while starch moisture content and pasting properties data were results of duplicate determination. Pearson correlation coefficients (r) were also computed to examine the relationships between the starch constituent polymers and pasting properties. All the simple and combined analyses of variance and the correlation analysis were carried out using SAS Statistical Software v9.2 (SAS Institute Inc. 2009, USA). Mean comparison between varieties where significant differences were detected was computed at 1% level of significance.

Experiment- V

Phenotypic diversity analysis within cultivated potato (*solanum tuberosum* l.) in Ethiopia at three distinct locations based on morphological characteristics

Genetic materials

A total of 25 varieties listed in Table 3 above.

Description of study area

The details indicated in the general materials and methods part.

Experimental design and procedures

Details of experimental design, plot size, within row and between row spacing, fertilizer type, amount and time of application, and other cultural practices are illustrated in the main materials and methods part of this thesis.

Data collection

Eleven quantitative and 18 qualitative data related to leaf, stem, flower and tubers morphological characteristics and yield and yield components were recorded from all experiments at the three locations. The 11 quantitative characteristics were days to emergence, days to 50% flowering, days to maturity, number of primary stem, plant height at flowering, leaf length, leaflet length, leaflet width, leaflet length to width ratio, tuber number per hill, average tuber weight and marketable tuber yield. All these quantitative data were collected from the central 16 individual plants of each replication. Likewise, the 18 qualitative morphological characteristics collected were leaf dissection, leaf insertion, leaf green color intensity, leaf midribs pigmentation, growth habit, predominant flower color, secondary flower color, secondary flower color distribution, degree of flowering, duration of flowering, corolla shape, predominant skin color, secondary skin color, secondary color distribution, tuber skin type, predominant flesh color, general tuber shape and depth of tuber eyes. All these qualitative characters were recorded from randomly selected 10 plants. The morphological characters were described according the morphological descriptors published by the International Board for Plant Genetic Resources (IBPGR) (Huamán *et al*., 1977)

Data analysis

Considering the inherent characteristics of these two categories of data in terms of their consistency or stability across environments and their distinct weakness

and strength in typifying varieties for morphological characterization, separate analyses were carried on the 11 quantitative and 18 qualitative characteristics, respectively. The 11 quantitative data which do take different values with a change in environment was subjected to simple analysis of variance using IRRISTAT statistical computer package (IRRISTAT; Ver. 5.0; 2005). Thus, since they are highly influenced by environment and show high genotype by environment interaction, they were not used for genetic distance and clustering purposes rather for agronomic evaluation across environment. On the other hand, the 18 qualitative characteristics that are stable across locations were used to compute the genetic distance matrix that ultimately used for cluster analysis. And for this purpose, they were first converted into binary data matrix. And this conversion was done following stevens's classification system of data (Stevens, 1966). Traits with only two categories of description were converted simply into binary score. Traits with more than two category classes such as color, shape, growth habit etc were converted into binary matrix against each category of that particular class. Accordingly, corolla shape for example has three categories as semistellate, pentagonal and stellate. A variety with semi-stellate corolla shape was scored as 1 against CS1 (semi-stellate) and 0 for CS2 (pentagonal flower shape) and for CS3 (stellate flower shape category). Finally, the "average" taxonomic genetic distance (Eij) for individuals i and j and morphological traits k was computed using Euclidian distance function,

$$E_{ij} = [\Sigma_k (n^{-1})(X_{ki} - X_{kj})^2]^{1/2}$$

For p variables the Euclidian distance is then computed as the square root of the sum of squared differences between the coordinates of each variable for the two observations. Then hierarchical agglomerative clustering method using the Unweighted Pair-Group Method with Arithmetic Mean (UPGMA) was carried-out on this distance matrix to examine the resemblance and grouping of genotypes using the Numbers Cruncher Statistical System for windows (NCSS and PASS, 2001).

Experiment- VI

Microsatellite analysis of genetic diversity within cultivated potato (*solanum tuberosum* l.) varieties in Ethiopia

Genetic materials

A total of 25 varieties which are composed of improved varieties released by the research system, widely grown cultivars and elite breeding clones that are indicated in Table 3 under the general material and methods section of this thesis.

SSR primer employed in the study

A total 11 primer pairs reported in earlier published studies of Kwachuk *et. al.* (1996), Provan *et al*. (1996) on potato were chosen and subsequently designed to amplify SSR products for analysis of genotypes. The name, sequence, loci chosen and melting temperature of the primers are listed in Appendex Table C.

DNA isolation

The DNA extraction started with the selection and planting of three healthy and well sprouted tubers of each of the 25 varieties under insect proof meshhouse in Adet Agricultural Research Center, Amhara Region, Ethiopia. When grown plants reach five leaf stages, fresh, succulent and disease free leaf at the top were collected and cleaned with tap water to avoid possible contaminants. The wet leaf was then pat with tissue paper to dry the moisture. Then each leaf was separately squashed or crushed physically with pestle on an FTA® Card matrix until the card was stained. The bound leaf squash on the chemically coated FTA® Card was then allowed to dry under non-direct sunlight at dry place in the laboratory. The chemical coating on the FTA® Card inactivates pathogens, protects the DNA from degradation and allows the cards to be stored at room temperature for extended periods of time. To avoid any squash

leftover or carry over to the next sample, the pestle was thoroughly cleaned with water and disinfected with alcohol.

Extraction of DNA from impregnated FTA® Card was then carried by cutting with alcohol cleaned scissor approximately 5 mm size from the center of the dried sample area of FTA® Card and transferring it into a 1.5 mL microfuge tube. Then 200 µL FTA® purification reagent (Whatman Inc., England) was added into the 1.5 mL microfuge tube containing DNA impregnated FTA® Card and then vortexed for 5 seconds and incubated for 5 minutes. This was repeated three times decanting or emptying the reagent using pipette after each 5 minutes. The FTA® Card disc was then rinsed with 200 µL once with TE buffer (10 mM Tris, 0.1 mM EDTA). Finally, 60 µL of TE buffer was added and incubated and used subsequent PCR reaction based on the following procedures.

PCR amplification and electrophoresis of PCR product

PCR amplification

All the amplifications were carried out using Biometra® thermocycler (Göttingen, Germany) as described by Provan *et al.* (1996). The reaction mixture (25 µL) contained: 2 µL samples genomic DNA, 2.5 µL 10X PCR buffer, 2.5 µL of 50mM $MgCl_2$, 2.5 µL of 10mM dNTP, 0.2 µL Taq, 0.5 µL of each primer (forward and reverse) and 14.3 µL distilled water. The PCR was performed with the above machine using the following cycling profile: (1) 94 ^{0}C for 3 min., [Tm] for 2 min., 72 ^{0}C for 1.5 min X 1 cycle; (2) 94 ^{0}C for 1 min., [Tm] for 2 min., 72 ^{0}C for 1.5 min X 29 cycles; and (3) a final elongation step at 72 ^{0}C for 5 min. The Tm values of each primer pairs are indicated in Table 24.

Electrophoresis

After the conclusion of the themal cycling parameters amplified DNA products were electrophoresed by running mixtures of 6 µL loading dye and 3 µL samples PCR product on a 3% agarose gel in 1 X TE buffer at 100 volt constant power for 25 minutes using Mupid® -exu submarine electrophoresis system apparatus. After the 25 minutes running time the agarose gels were stained by placing inside GelRed staining solution containing plastic box. The gel containing plastic box was then placed on shaker and agitated for 50 minutes. Finally the stained gel was viewed under UV transilluminator and photographed using GeneSnap computer soft ware program. Amplified bands were then scored for each lane against the standard 100 bp DNA ladder that was run with the PCR product during electrophoresis.

Data analysis

Microsatellite markers (SSR) data was scored as 1 for presence and 0 for absence of each band from the gel picture of all the 25 varieties. The number of SSR fragments and polymorphic fragments detected by each SSR markers are indicated in Table 30. The polymorphic information content (PIC) value of each primer, a measure of allelic diversity or heterozygosity value, was then calculated from the scored banding pattern data according to Nei's formula, $1-[\Sigma pij]^2$, where Pij is the frequency of the j^{th} common band pattern out of the bands of marker i (Anderson *et al*., 1993).

RESULTS AND DISCUSSION

Experiment- I

Dry-matter content, starch content, and starch yield variability and stability of potato varieties in amhara region of Ethiopia

Results

One-way analysis of variance (ANOVA)

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 ($P < 0.001$) genotypic mean square for both DMC and SC (Table 4 and 5).

The mean DMC at Adet ranged between 18.44% and 26.93%. At Merawi, 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 4). Nevertheless, the varieties containing the highest DMC differed across the three sites. At Adet, the maximum DMC value was recorded from Ater Abeba while at Merawi and Debretabor the maximum DMC value were for Guasa and Agere/Guasa, respectively (Table 4). Another interesting observation in this study was the surfacing of certain group of varieties at the top rank at varying magnitude 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 to the right niche. Overall, almost all varieties produced their maximum DMC at Debretabor (Table 4). As a result (except the variety Menagesha which showed a consistently low DMC at all

sites), the remaining varieties had a DMC value made them ideal for processing. This clearly revealed the contribution of environment in enabling cultivars to manifest their built in hereditary potential.

Table 4 Mean dry matter content (%) of the 25 varieties in Ethiopia during 2011 cropping season.

Variety	Location		
	Adet	**Merawi**	**Debretabor**
Menagesha	18.44^{k}	17.45^{l}	17.05^{l}
Gera	22.06^{ghi}	19.98^{ghijk}	23.80^{ijk}
Challa	26.59^{ab}	23.25^{cd}	27.83^{bc}
CIP-395096.2	21.82^{ghi}	20.85^{fgh}	24.58^{hij}
Wochecha	23.73^{cdefg}	18.65^{kl}	26.55^{cdefg}
Awash	19.99^{ijk}	18.83^{jkl}	22.43^{k}
Gorebella	25.09^{abcde}	22.33^{def}	29.18^{ab}
Zengena	23.64^{cdefg}	18.50^{kl}	23.25^{jk}
Hunde	19.95^{ijk}	18.35^{kl}	23.75^{ijk}
Agere	24.24^{cdef}	20.70^{ghi}	29.98^{a}
Shenkolla	22.82^{fgh}	21.43^{efg}	26.10^{defghi}
Belete	24.60^{bcdef}	23.05^{cd}	29.00^{ab}
Ater Abeba	26.93^{a}	25.50^{ab}	27.68^{bcd}
CIP-392640.524	21.76^{ghi}	19.73^{hijk}	26.00^{defgh}
Gudene	24.49^{cdef}	23.43^{cd}	26.75^{cdef}
Bulle	21.01^{hij}	20.88^{fgh}	27.33^{cde}
Gabisa	23.60^{cdefg}	19.10^{ijk}	23.65^{ijk}
Tolcha	25.70^{abc}	20.30^{ghij}	24.93^{ghi}
Aba Adamu	25.42^{abcd}	19.75^{hijk}	25.88^{efgh}
Marachare	21.19^{hij}	22.58^{cde}	25.10^{fghi}
Sisay	21.76^{ghi}	21.15^{efgh}	26.15^{defgh}
Ararsa	19.59^{jk}	20.53^{ghi}	24.25^{ij}
Jalene	21.97^{ghi}	24.18^{bc}	26.68^{cdef}
Guasa	23.09^{efgh}	25.85^{a}	29.95^{a}
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
LSD	1.67	2.07	2.12

Note: Means are separated using Duncan multiple range test at $P < 0.01$ level of probability. Means in the same column that are followed by the same letter/s are not different from each other.

CV = Coefficientof variance; LSD = Least significant difference.

In the same way, the SC of varieties showed significant differences within and across sites (Table 5). 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 from 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 high yield at Adet. This was followed by the framer's cultivar Ater Abeba (15.92%) and elite cultivar CIP-396004.337 (15.18%). Similar to the Adet and Merawi results, at 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 differential performance of varieties across sites.

Genotypic variation was also observed among the 25 varieties in their starch yield performance (Table 5). At Adet Guasa gave the highest starch yield of 6.60 $t.ha^{-1}$. Gorebella and Belete followed it with 6.47 and 5.79 $t.ha^{-1}$, respectively, while Awash (2.03 $t.ha^{-1}$), Wochecha (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 Debretabor site, Gorebella gave the highest starch yield of 8.04 $t.ha^{-1}$ followed by CIP-396004.337, Guasa, Belete and Gabisa with values 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 score 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

are very pronounced when they are grown under similar conditions. Thus, a combined ANOVA across sites was carried out to determine the magnitude of genotype x environment interaction and identify those genotypes with better DMC, SC and starch yield.

Table 5 Mean starch content and starch yield of the 25 varieties in Ethiopia during 2011 cropping season.

Variety	Starch content (%)			Starch yield (t.ha^{-1})		
	Adet	Merawi	Debretabor	Adet	Merawi	Debretabor
Menagesha	10.44^{o}	8.04^{w}	10.76^{r}	2.56^{jk}	2.13^{kl}	2.76^{ghi}
Gera	13.64^{j}	13.84^{h}	17.71^{e}	3.78^{fghij}	4.43^{cdefg}	5.61^{bcd}
Challa	17.25^{c}	13.44^{j}	18.05^{d}	5.60^{abcd}	5.10^{bcde}	5.74^{bcd}
CIP-395096.2	11.60^{n}	14.44^{f}	17.38^{f}	3.26^{ghijk}	4.06^{defgh}	5.36^{bcd}
Wochecha	12.05^{m}	12.68^{p}	11.58^{q}	2.45^{jk}	2.59^{ijkl}	2.03^{i}
Awash	12.03^{m}	13.21^{l}	13.14^{p}	2.03^{k}	2.27^{jkl}	2.33^{hi}
Gorebella	18.39^{a}	14.97^{e}	20.12^{a}	5.79^{abc}	6.40^{b}	8.04^{a}
Zengena	12.40^{l}	9.87^{v}	15.22^{k}	3.30^{ghijk}	2.95^{hijk}	4.85^{cde}
Hunde	18.51^{a}	11.44^{t}	11.67^{q}	4.79^{cdef}	4.52^{cdefg}	3.53^{efgh}
Agere	16.98^{de}	13.48^{i}	14.30^{o}	3.82^{efghij}	3.37^{ghijk}	3.86^{efg}
Shenkolla	13.77^{j}	13.12^{m}	14.76^{m}	3.73^{fghij}	4.02^{defgh}	4.73^{cde}
Belete	17.98^{b}	16.66^{a}	16.68^{h}	6.47^{ab}	8.01^{a}	6.26^{b}
Ater Abeba	16.07^{h}	15.92^{b}	18.42^{c}	4.35^{defgh}	5.34^{bcd}	5.67^{bcd}
CIP-392640.524	16.27^{h}	13.44^{j}	14.44^{n}	4.23^{defghi}	3.76^{efghi}	3.37^{fgh}
Gudene	16.82^{ef}	14.14^{g}	16.83^{g}	4.43^{cdefg}	3.76^{efghi}	4.58^{def}
Bulle	12.73^{k}	12.17^{r}	16.31^{i}	2.89^{ijk}	2.99^{hijk}	3.96^{efg}
Gabisa	17.96^{b}	11.72^{s}	17.92^{d}	4.53^{cdefg}	3.71^{fghi}	6.20^{b}
Tolcha	17.82^{b}	10.89^{u}	15.27^{k}	3.68^{fghij}	1.62^{l}	3.08^{ghi}
Aba Adamu	16.93^{def}	12.74^{o}	14.92^{l}	4.71^{cdef}	3.72^{fghi}	4.03^{efg}
Marachare	15.49^{i}	13.24^{k}	13.19^{p}	5.03^{cdef}	5.10^{bcde}	4.08^{efg}
Sisay	16.58^{g}	13.13^{m}	14.94^{l}	4.35^{defgh}	3.36^{ghijk}	4.60^{def}
Ararsa	11.64^{n}	12.29^{q}	13.22^{p}	3.00^{hijk}	3.56^{ghij}	3.56^{efgh}
Jalene	16.73^{gf}	15.04^{d}	16.17^{j}	5.21^{bcde}	5.74^{bc}	5.95^{bc}
Guasa	17.12^{cd}	12.81^{n}	18.06^{d}	6.60^{a}	5.55^{bc}	6.34^{b}
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
LSD	0.25	0.02	0.12	1.08	1.06	1.02

Note: Means are separated using Duncan multiple range test at $P < 0.01$ level of probability. Means in the same column that are followed by the same letter/s are not different from each other.

CV = Coefficientof variance; LSD = Least significant difference.

Factorial-analysis of variance

The results of the combined ANOVA indicated a highly significant ($P < 0.01$) variety, location, and genotype x location mean square for DMC, SC and starch yield (Table 6). 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%). Equivalently, 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% (Table 6). 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 6).

Considering all three sites, Debretabor showed 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 an overall mean DMC value of 22.91% and 21.18%, of SC of 15.38% and 13.11% and starch yield of 4.24 and 4.12 $t.ha^{-1}$, respectively. The significant genotype by 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 environments and gives better above average values of DMC, SC, and starch yield are imperative. To this effect an Additive main effects and multiplicative interaction (AMMI) was carried to identify genotypes that were relatively stable in their performance.

Extractable starch

Extarctability of starch is an important aspect of variety for it determines the amount of starch recovered from the total dry matter content of each variety. Thus, the

amount of starch recoverd does not only depend on the dry matter content of variety. This was clearly noted from the third column in Table 6 where varieties that had comparable DM (Wochecha and Marachare) gave different values of starch content on both fesh weight basis and on dry-weight basis.

Table 6 Mean results of combined ANOVA of dry-matter content, starch content and starch yield of the 25 potato varieties in Ethiopia during 2011 cropping season.

Varieties	Dry matter content (%)	Starch content (%)		Starch yield ($t.ha^{-1}$)
		Fresh weight basis	Dry-matter basis	
Menagesha	17.65^{m}	9.75^{q}	55.33^{lm}	2.48^{j}
Gera	21.95^{jk}	15.86^{g}	68.50^{abc}	4.60^{def}
Challa	25.89^{b}	16.25^{d}	62.27^{fhgi}	5.48^{c}
CIP-395096.2	22.41^{ij}	14.47^{j}	64.50^{defgh}	4.21^{efg}
Wochecha	22.98^{hi}	12.10^{p}	54.17^{m}	2.35^{j}
Awash	20.41^{l}	12.49^{m}	63.00^{efghi}	2.21^{j}
Gorebella	25.53^{bc}	17.82^{a}	69.83^{ab}	6.74^{a}
Zengena	21.80^{jk}	12.79^{n}	57.17^{klm}	3.68^{gh}
Hunde	20.68^{l}	13.87^{k}	68.17^{abc}	4.28^{efg}
Agere	24.97^{cd}	14.92^{h}	61.00^{hij}	3.68^{gh}
Shenkolla	23.45^{gh}	13.88^{k}	59.33^{ijk}	4.16^{fg}
Belete	25.55^{bc}	17.10^{b}	67.83^{abcd}	6.91^{a}
Ater Abeba	26.70^{a}	16.80^{c}	63.00^{efghi}	5.12^{cd}
CIP-392640.524	22.50^{ij}	14.72^{i}	66.17^{cdef}	3.79^{gh}
Gudene	24.89^{cde}	15.93^{ef}	63.83^{efgh}	4.25^{efg}
Bulle	23.07^{hi}	13.73^{l}	59.67^{ijk}	3.28^{hi}
Gabisa	22.12^{jk}	15.93^{f}	71.00^{a}	4.81^{de}
Tolcha	23.64^{fgh}	14.66^{i}	61.67^{ghi}	2.79^{ij}
Aba Adamu	23.68^{fgh}	14.86^{h}	63.00^{efghi}	4.15^{fg}
Marachare	22.95^{hi}	13.97^{k}	61.33^{hij}	4.73^{def}
Sisay	23.02^{hi}	14.88^{h}	65.33^{cdefg}	4.10^{fg}
Ararsa	21.46^{k}	12.38^{o}	58.00^{jkl}	3.37^{h}
Jalene	24.27^{def}	15.98^{e}	66.67^{bcde}	5.63^{bc}
Guasa	26.30^{ab}	15.99^{e}	61.33^{hij}	6.16^{b}
CIP-396004.337	24.19^{efg}	17.04^{b}	70.33^{a}	5.63^{bc}
Mean	23.28	14.69	63.31	4.34
CV%	3.11	0.44	3.32	8.23
LSD	1.08	0.09	3.82	0.58

Note: Mean 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 different.
CV = Coefficient of variance; LSD = Least significant difference.

AMMI Analysis

AMMI analysis of the DMC and SC of the 25 varieties across the three varying environments distinctly sorted out varieties with minimal or smallest interaction with environments and environments with better DMC and SC performance and subsequently high starch yield (Figure 5 and 6).

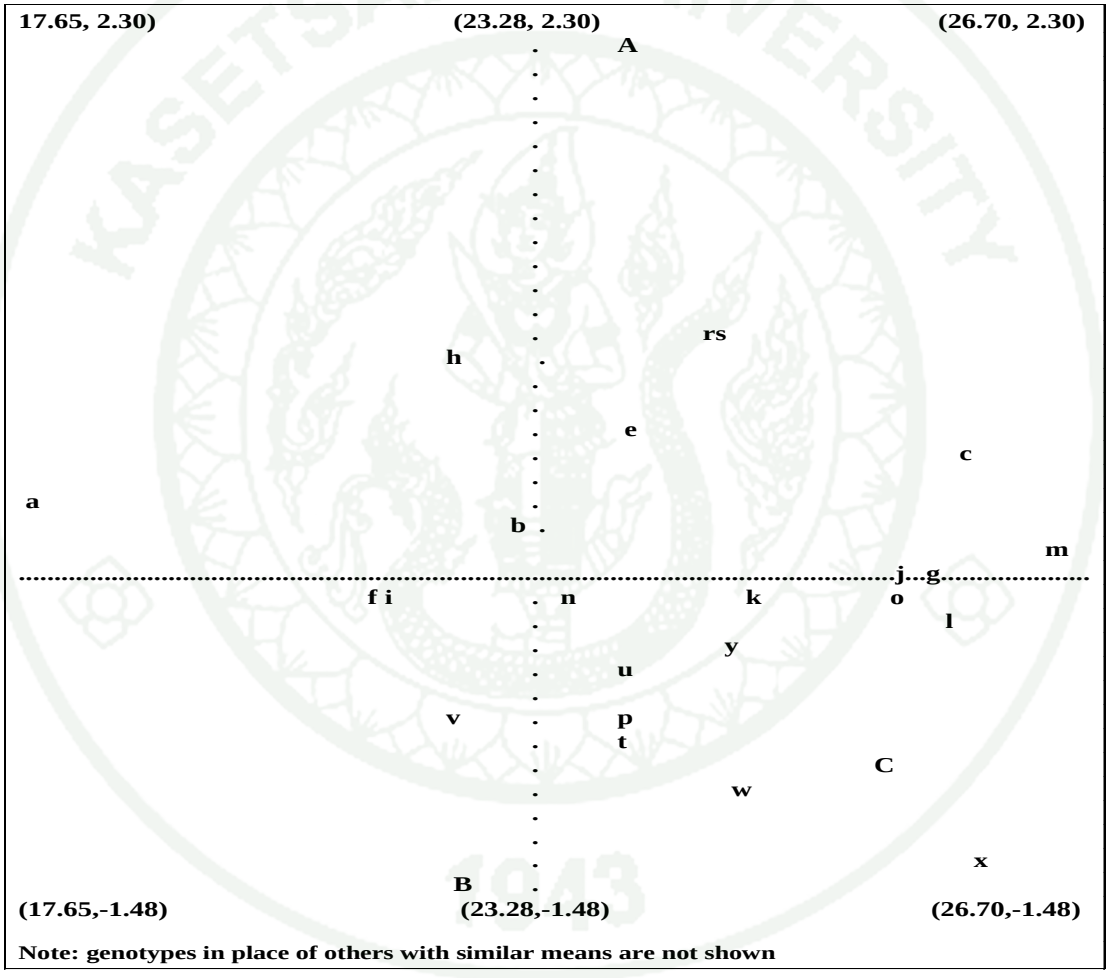

Figure 5 Biplot with x-axis plotting means of dry matter content and y-axis plots interaction principal component axis 1. Genotypes are plotted as a,b,c, ... and environments as A (Adet), B(Merawi), C (Debretabor).

The results of these analyses had shown that Gorebella, Agere, Ater Abeba, Gudene and Belet were identified as stable for DMC. Interaction principal component

axis 1(IPCA) accounted for about 60 percent of the explained genotype by environment interaction (G x E) value. The IPCA scores of these varieties was very small ranging -0.19 for Belete through 0.15 for Ater Abeba. Gorebella and Agere had IPCA score of 0.06 and 0.02, respectively indicating their close proximity to the x-axis.

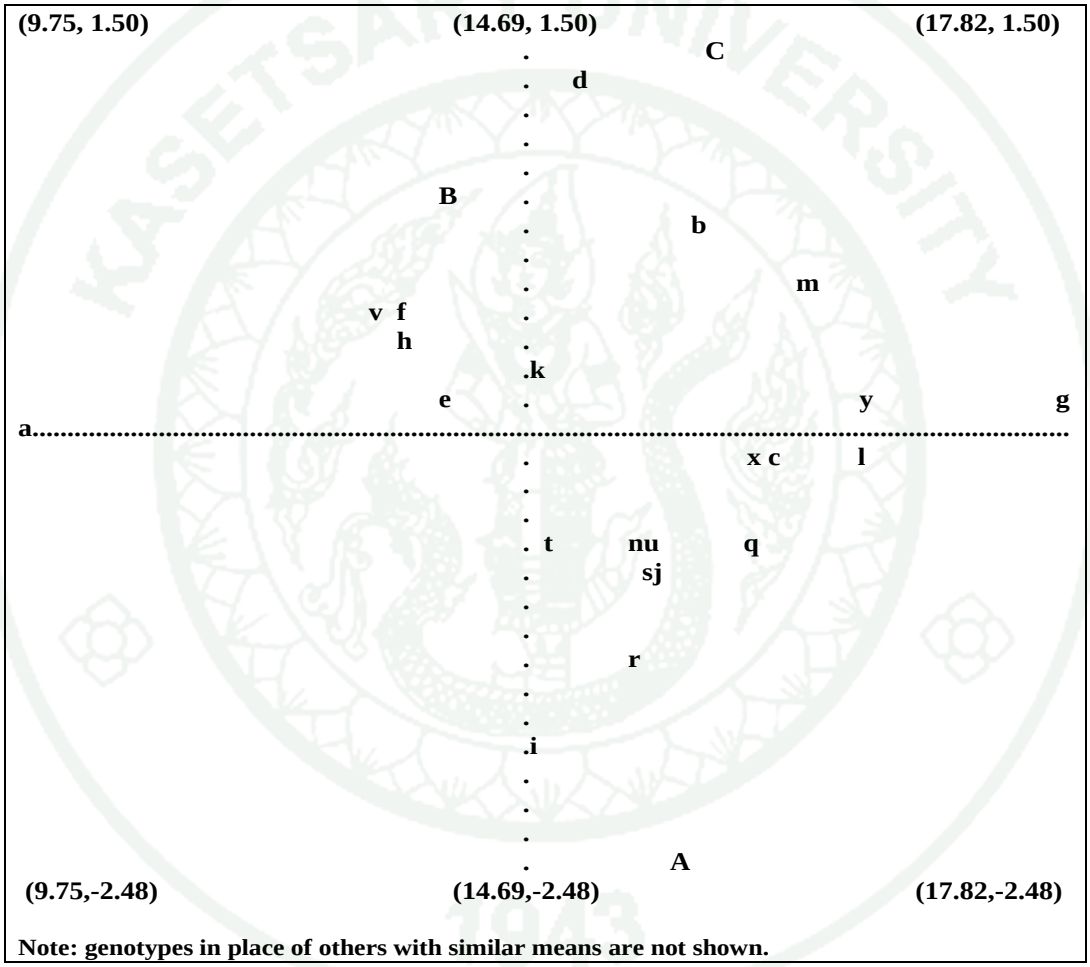

Figure 6 Biplot with x-axis plotting means of starch content and y-axis plotting IPCA1 from genotypes plotted as a,b,c, ... and environments as A,B,C, ...

In the same manner Gorebella, Belet, CIP-396004.337, Challa and Guasa were identified as stable varieties for SC across location. In this case IPCA1 explained 65% of the GXE value. Accordingly, the IPCA score 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 environments. The improved variety Menagesha invariably had the lowest DMC and SC across all locations (Figure 5 and 6). 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 gave the highest starch yields, showed specifically adaptation to Debretabor and Merawi, where they produced the maximum yield of both tuber and starch content. Overall, Debretabor site was identified as the most suitable site with better DMC, SC and high starch yield production followed by Adet. Merawi was also found to be an appropriate site for table-type potato production.

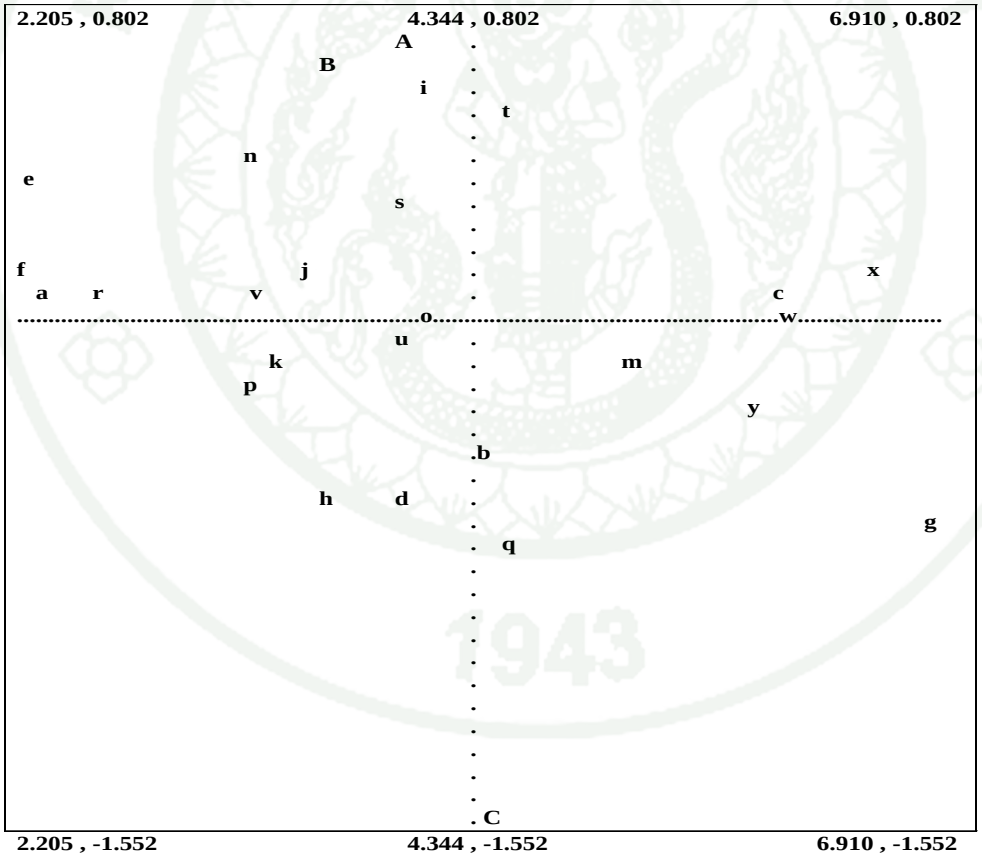

Figure 7 Biplot with X-axis plotting genotypes starch yield means and Y-axis plotting IPCA1. Genotypes plotted as a,b,c, ... and environments as A,B,C,

AMMI analysis for genotypes starch yield performance stability plotted both varieties and locations at different quadrants of the biplot (Figure 7). Accordingly, Jalene, Challa, Guassa, and Ater Abeba lied very close to the X-axis indicating their very low interaction or consistent performance across different locations. The improved variety Gorebella and elite clone CIP-396004.337 also had above average starch yield and very low inconsistent performance across the different environments. Of the three locations, Debretabor had a general performance index of above average value (4.68 $t.ha^{-1}$) than that of Adet (4.24 $t.ha^{-1}$) and Merawi (4.12 $t.ha^{-1}$), with below average performance index value for starch yield.

Correlation analysis

Pearson correlation analysis among quality governing factors was carried out (Table 7). The results of this analysis revealed the presence of strong positive association between DMC and SC (r = 0.81; $P < 0.001$), DMC and SY (r = 0.67; $P < 0.01$) and SC and SY (r = 0.82; $P < 0.001$) as shown in Table 6. Hence, simultaneous improvement of these quality governing factors is possible as they are controlled by same genetic factors.

Table 7 Correlation among dry-matter content, starch content, and starch yield of the 25 varieties in Ethiopia during 2011 cropping season.

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 ($P < 0.01$).

Discussion

The significant ($P < 0.01$) genotypic variation observed among the varieties evaluated in this study over dry-matter and starch content agreed with earlier reports (Benesi *et al.*, 2004; Rivero *et al*, 2009; Elfnesh *et al.* 2011; Ekin, 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. High heritability estimates of maturity dates, growth habit, leaf area, number of main stems, and tuber size were also reported by different authors at different times (Killick, 1977; Brown and Caligari, 1989; Moris, 1989; Neele *et al.*, 1991). Such fundamental differences among varieties regarding these characteristics could account for the observed DMC and SC differences among the studied varieties as clearly noted from the differences in their maturity time, tuber size, plant growth habit, leaf area cover and number of main stems. Gray and Hughes (1978) also reported that tubers from late-maturing potato varieties usually have high 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 relatively long maturity cycle ranging from 102 to106 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, noted from morphological diversity study parts of this thesis, that enabled them to trap maximum radiant-energy to produce food energy beyond their metabolic requirement and channeled to their storage organs for deposition. The significant role of such plant morphology for increased efficiency of light utilization in contrast to varieties having 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 umbrellas type of vine. The tuber

sizes grade distributions of the varieties Ater Abeba, Challa, Guasa, Belete and Gorebelle (56-112 gm) were the larger ones which would have contributed to the high DMC as well as the high SC. Generally, all the above results of this research clearly corroborate with an already established fact reported in earlier studies.

Likewise, the significant variation in yield parameters among the experimental sites was attributed to the prevailing differences in environmental variable such as temperature, relative humidity and sunshine hours and the soil physicochemical properties of these sites as seen in Table 1 and 2. Burton (1966) reported prolonged and greater top growth of both early and late varieties under long-day than short-day conditions. The observed mean plant height of varieties at Adet (61cm) and Merawi (55 cm) sites that have comparatively longer day lengths than that at Debertabor (44 cm) 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 in short than long days owing to a lowered gibberllins 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 leaves and tubers size reduces as temperature rises over the range of 20-29 ^{0}C, with no tuber forming at the upper temperature. The high DMC, SC and SY obtained at 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 was partly attributed to the high temperature at 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 for low evapo-transpiration and 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 mineral nutrients needed by the crop.

Gray and Hughes (1978) reported that potato starch constitutes 65-80% of the dry-matter content of potato tuber on dry weight basis. The 54.17% to 71% in the current study clearly agreed with the ranges reported for potato. The positive, strong linkage observed in the current study between DMC and SC endorses this concept as clearly portrayed in the analysis result. The same explanation holds true for the strong link observed between SC and SY as starch yield is the function of starch content and tuber yield. Extractability difference noted in current study has also been reported in sweetpotato by Tsakama *et. al.* (2010) and Rahman *et. al.* (2003). This is claimed to stem from the softness of the tuber, insufficient hogenization and the manner the starch is held.

Conclusion

The genotypic variability observed in this study over the DMC, SC and SY agreed with earlier reports of different authors on similar line of investigation 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 valuable opportunity for improving them simultaneously as they are controlled by the same genetic factors. In general this study highlighted the on-hand resource to be exploited in the breeding program hunting for improved DMC, SC and SY in Ethiopia. Furthermore, environments suitable for production of the desired types of potatoes were clearly identified. Accordingly, though all varieties with a DMC value of greater than 19.5 and SC value of greater than 13% are suitable for processing products and starch production respectively, Gorebella, Belete, Guasa, Challa, CIP-396004.337 and Ater Abeba were found ideal for processing purposes, especially for high starch production pertaining to their high tuber yield responsible

for their high starch yield while Menagesha, Awash, Ararsa, and Bulle were found to be most suitable for home consumption or for use asa table-type potato. Likewise, while Debretabor site is apposite for high DMC, SC and SY production, 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 national level.

Experiment- II

Evaluation of genetic variability of potato varieties in specific-gravity as a criterion determining processing quality

Results

Simple ANOVA

The specific gravity (SG) results of the simple ANOVA at each location among tubers of the 25 varieties were highly significant ($P < 0.01$). The specific gravity of varieties was also influenced by location (Table 8). Accordingly, the specific gravity of tubers grown at Debretabor was higher than that of corresponding varieties grown at both Adet and Merawi (Table 8). The highest SG value (1.119) at Debretabor was obtained from the improved variety Belete. At Merawi and Adet, the highest SG value was 1.103 and 1.092, respectively. These values were obtained from elite clone CIP-396004.337 and the widely cultivated farmer's cultivar Ater Abeba,

respectively (Table 8). Perversely, the lowest SG value in all three trial sites was recorded from the improved variety Menagesha (Table 8). Moreover, the differences in the SG values of the same genotype across locations were as high as the differences observed between the different genotypes tested in one location (Table 8). This in turn has resulted in ranking order shift among genotypes across the tested environments. Hence, this underscored the presence of significant genotype by environment interaction.

The presence of such statistically significant genotype x environment interactions usually impedes selection progress owing to the considerable impact of the environment on the overall observed variances. Therefore, further combined ANOVA across the trial locations and additive main effects and multiplicative interactions analyses were carried out in order to examine the extent of contribution of genetic variance and environmental variance and be able to distinctly sort out those varieties with minimum fluctuation with change in environments.

Combined ANOVA

The combined ANOVA results revealed a statistically significant ($P < 0.05$) genotype x environment interaction (Table 9). This caused a ranking order shift of genotypes across locations and as such genotypes which had the highest rank in one location did not maintain the same ranking level in the other locations. Accordingly, the highest combined SG value of 1.102 was recorded from the improved variety Belete. This variety ranked second both at Adet and Merawi. The elite clone CIP-3396004.337 was ranked second and the farmer's cultivar Ater Abeba and improved variety Challa were ranked third with SG values of 1.098 and 1.097 and 1.097, respectively. Though, its SG values had met the cut-off point set by the processing industries (1.077 and 1.079), the second ranking genotype in the combined analysis was 10^{th} and 5^{th} at Adet and Debretabor sites, respectively (Table 8).

Table 8 Mean specific-gravity of 25 potato varieties evaluated under three distinct environments in Amhara region of Ethiopia during 2011 rainy season.

Variety	Specific gravity (gcm^{-3})				Marketable tuber yield ($t.ha^{-1}$)
	Adet	Merawi	Debretabor	Grand mean	
Menagesha	1.050^{d}	1.055^{i}	1.072^{e}	1.058^{j}	25.38^{ij}
Gera	1.077^{bcd}	1.073^{defg}	1.095^{abcde}	1.081^{fghi}	30.45^{defg}
Challa	1.091^{ab}	1.087^{bcde}	1.112^{abc}	1.097^{abc}	34.06^{cd}
CIP-395096.2	1.076^{abc}	1.060^{gh}	1.087^{cde}	1.074^{i}	29.10^{efghi}
Wochecha	1.072^{c}	1.071^{efg}	1.081^{de}	1.075^{hi}	19.41^{k}
Awash	1.068^{c}	1.068^{fgh}	1.082^{de}	1.075^{ghi}	17.22^{k}
Gorebella	1.088^{abc}	1.081^{bcdef}	1.113^{abc}	1.094^{abcde}	38.05^{ab}
Zengena	1.089^{abc}	1.085^{bcde}	1.100^{abcd}	1.091^{abcdef}	29.31^{efghi}
Hunde	1.091^{abcd}	1.076^{defg}	1.110^{abc}	1.092^{abcdef}	31.87^{def}
Agere	1.088^{abc}	1.089^{abcd}	1.109^{abc}	1.095^{abcd}	24.80^{j}
Shenkolla	1.082^{abc}	1.073^{defg}	1.103^{abcd}	1.086^{cdefgh}	29.93^{defghh}
Belete	1.092^{ab}	1.095^{ab}	1.119^{a}	1.102^{a}	40.51^{a}
Ater Abeba	1.093^{a}	1.088^{abcd}	1.111^{abc}	1.097^{abc}	30.46^{defg}
CIP-392640.524	1.083^{abc}	1.083^{cdef}	1.092^{bcde}	1.084^{defghi}	25.75^{hij}
Gudene	1.091^{ab}	1.074^{efg}	1.103^{abcd}	1.089^{bcdef}	26.69^{ghij}
Bulle	1.072^{abc}	1.072^{efg}	1.104^{abcd}	1.084^{defghi}	23.85^{j}
Gabisa	1.077^{abc}	1.074^{defg}	1.091^{bcde}	1.082^{efghi}	30.51^{defg}
Tolcha	1.074^{bc}	1.071^{efg}	1.103^{abcd}	1.082^{efghi}	18.54^{k}
Aba Adamu	1.089^{abc}	1.093^{abc}	1.102^{abcd}	1.094^{abcd}	27.96^{fghi}
Marachare	1.077^{abc}	1.088^{abcd}	1.094^{abcde}	1.086^{cdefg}	33.94^{cd}
Sisay	1.081^{abc}	1.080^{bcdef}	1.098^{abcd}	1.086^{cdefg}	27.52^{ghij}
Ararsa	1.073^{c}	1.088^{abcd}	1.093^{bcde}	1.084^{defghi}	27.18^{ghij}
Jalene	1.084^{abc}	1.086^{bcde}	1.113^{ab}	1.094^{abcde}	36.24^{bc}
Guasa	1.080^{abc}	1.089^{abcd}	1.113^{ab}	1.094^{abcde}	38.96^{ab}
CIP-396004.337	1.081^{abc}	1.103^{a}	1.111^{abc}	1.098^{ab}	32.99^{cde}
Grand mean	1.081	1.080	1.101	1.087	29.22
C.V%	0.50	0.47	0.71	0.60	8.14
LSD	0.014	0.013	0.020	0.005	7.13

Mean separation using Duncan's multiple range test at $P < 0.01$ level of probability.
Means in the same columns followed by the same letter (s) are not significantly different.
CV = Coefficient of variance; LSD = Least significant difference.

The dry matter content and starch content equivalents of the tuber SG values showed highly significant ($P < 0.01$) differences between treatments tested at a site and across locations (Table 9). The dry matter content at Adet, Merawi and Debretabor ranged from 13.96 to 23.45%, 15.24 to 25.84% and 18.88 to 29.25%, respectively (Table 9). At all three sites, the lowest value were recorded from the

variety Menagesha while the highest from Ater Abeba, CIP-396004.337 and Belete, for Adet, Merawi and Debretabor, respectively (Table 9). Likewise, the starch content for Adet, Merawi and Debretabor ranged from 7.63 to 16.29, 8.81 to 18.47, and 12.13 to 21.59, respectively. The lowest and highest valued varieties were those that had the lowest and highest dry matter content (Table 9).

Table 9 Mean dry matter and starch content of the 25 potato varieties at three distinct environments in Amhara region of Ethiopia during 2011 rainy season.

Varieties	Dry matter content (%)			Starch content (%)		
	Adet	Merawi	Debretabor	Adet	Merawi	Debretabor
Menagesha	13.96^{d}	15.24^{i}	18.88^{e}	7.63^{d}	8.81^{h}	12.13^{e}
Gera	20.00^{abc}	19.08^{defgh}	23.98^{abcde}	13.15^{abc}	12.31^{defg}	16.78^{abcde}
Challa	23.20^{ab}	22.25^{bcdef}	27.71^{abc}	16.07^{ab}	15.20^{bcde}	20.18^{abc}
CIP-395096.2	19.74^{abc}	16.36^{hi}	22.22^{cde}	12.91^{abc}	9.83^{gh}	15.17^{cde}
Wochecha	18.97^{c}	18.67^{fgh}	20.99^{de}	12.21^{c}	11.94^{efg}	14.05^{de}
Awash	19.85^{abc}	17.99^{ghi}	21.20^{de}	13.01^{abc}	11.32^{fgh}	14.24^{de}
Gorebella	22.45^{abc}	20.93^{bcdefg}	27.87^{abc}	15.39^{abc}	14.00^{bcdef}	20.33^{abc}
Zengena	22.72^{abc}	21.81^{bcdef}	25.06^{abcd}	15.63^{abc}	14.80^{bcde}	17.76^{abcd}
Hunde	23.11^{ab}	19.74^{defgh}	27.24^{abc}	15.99^{ab}	12.91^{defg}	19.75^{abc}
Agere	22.47^{abc}	22.71^{abcd}	27.09^{abc}	15.40^{abc}	15.62^{abcd}	19.62^{abc}
Shenkolla	21.13^{abc}	19.08^{defgh}	25.84^{abcd}	14.18^{abc}	12.31^{defg}	18.47^{abcd}
Belete	23.34^{ab}	23.91^{ab}	29.25^{a}	16.19^{ab}	16.72^{ab}	21.59^{a}
Ater Abeba	23.45^{a}	22.47^{abcde}	27.53^{abc}	16.29^{a}	15.40^{abcd}	20.02^{abc}
CIP-392640.524	21.35^{abc}	20.17^{cdefg}	23.40^{bcde}	14.38^{abc}	13.31^{cdef}	16.25^{bcde}
Gudene	23.15^{ab}	19.41^{defgh}	25.83^{abcd}	16.02^{ab}	12.61^{defg}	18.47^{abcd}
Bulle	19.96^{abc}	18.87^{efgh}	26.04^{abcd}	13.11^{abc}	12.11^{efg}	18.65^{abcd}
Gabisa	21.35^{abc}	19.30^{defgh}	23.13^{bcde}	14.38^{abc}	12.51^{defg}	16.00^{bcde}
Tolcha	19.41^{bc}	18.65^{fgh}	25.66^{abcd}	12.61^{bc}	11.91^{efg}	18.31^{abcd}
Aba Adamu	22.57^{abc}	23.52^{abc}	25.54^{abcd}	15.50^{abc}	16.36^{abc}	18.20^{abcd}
Marachare	20.07^{abc}	22.50^{abcd}	23.85^{abcde}	13.21^{abc}	15.43^{abcd}	16.61^{abcde}
Sisay	20.83^{abc}	20.69^{bcdefg}	24.73^{abcd}	13.90^{abc}	13.78^{bcdef}	17.46^{abcd}
Ararsa	19.08^{c}	22.52^{abcd}	23.52^{bcde}	12.31^{c}	15.45^{abcd}	16.36^{bcde}
Jalene	21.48^{abc}	21.91^{bcdef}	27.95^{ab}	14.50^{abc}	14.93^{bcde}	20.40^{ab}
Guasa	20.72^{abc}	22.62^{abcd}	28.03^{ab}	13.80^{abc}	15.54^{abcd}	20.47^{ab}
CIP-396004.337	20.94^{abc}	25.84^{a}	27.38^{abc}	14.00^{abc}	18.47^{a}	19.88^{abc}
Mean	21.01	20.65	25.19	14.07	13.74	17.89
CV%	5.64	5.35	6.79	7.68	7.32	8.72
LSD	2.96	2.75	4.26	2.68	2.49	3.87

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

Means in the same columns followed by the same letter/s are not different from each other.

CV = Coefficient of variance; LSD = Least significant difference.

Additive main effects and multiplicative interactions (AMMI) analysis of SG across the three locations had clearly showed genotypes response to changing environmental variables across locations (Figure 8). Accordingly, CIP-392640.524, Zengena and Jalene were found to have similar SG value across locations. Similarly, Belete, Challa, Ater Abeba, and Gorebella had shown small interaction but with SG values far greater than overall mean value. High SG value is normally associated with more product yield compared with those varieties having lower SG values. Besides, marketable yield level of these varieties is essential yard stick in identifying varieties with cumulative high products during processing. Contrarily, Wochecha, Awash and Menagesha were positioned in the lower SG frames of the biplot quadrant with lower interaction value.

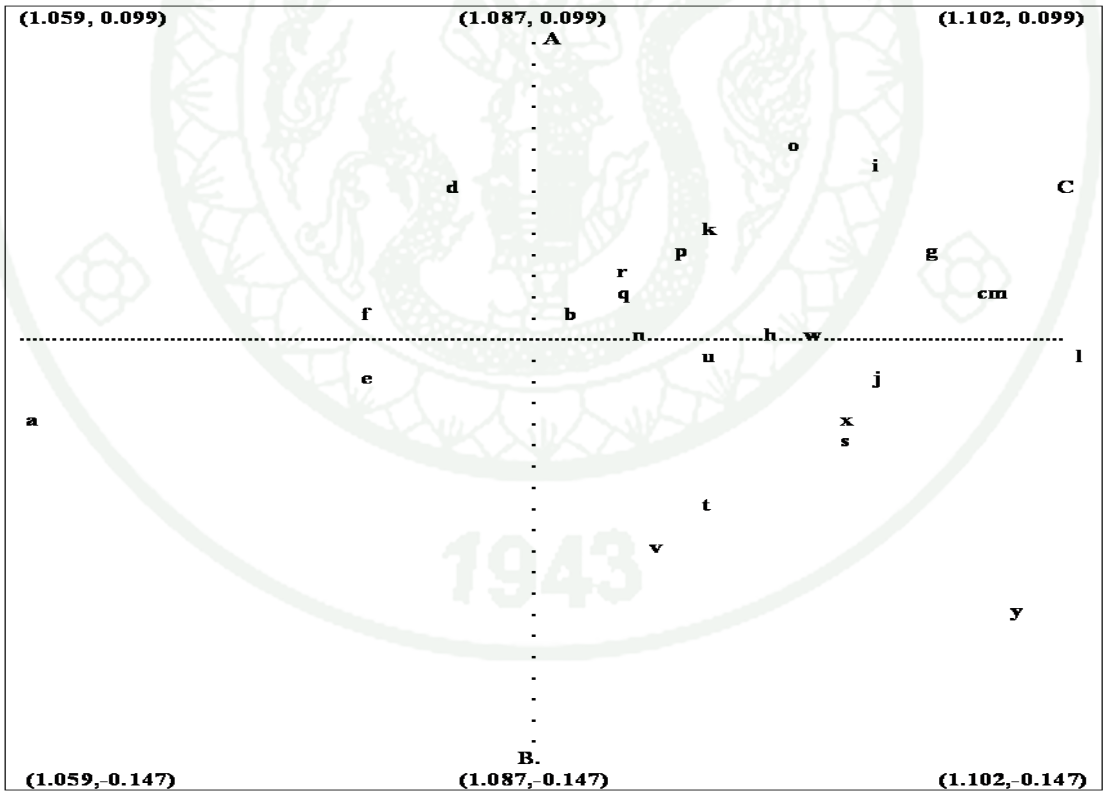

Figure 8 Biplot with abscissa plotting genotypes specific gravity means as a,b,c,..., from 1.059 to 1.102 and ordinate plotting IPCA1 from -0.147 to 0.099. Environments are plotted as A, B and C.

Discussion

The differences in specific gravity of tubers of potato varieties reported in this study generally agreed with earlier research reports (Asmamaw *et al*., 2010; Elfnesh *et al*., 2011; Ekin, 2011). Asmamaw *et al*. (2010) and Elfnesh *et al*. (2011) reported a specific gravity range of 1.064 to 1.094 and 1.078 to 1.10, respectively. Likewise, Ekin (2011) reported SG values ranging from 1.065 to 1.077 from a study of eight varieties over two consecuitive years. Despite the divergent environmental conditions under which Elfnesh's *et al*. (2011) and the current studies were carried out, the SG values reported for two of the common varieties in both studies, i.e., Gabisa (1.086 to 1.103) and Challa (1.086 to 1.10) were similar to the SG values in the current study of 1.074 to 1.091 for Gabissa and 1.087 to 1.112 for Challa. Equally, the SG values of Gera, Tolcha, Wochecha, Marachare, Zengena, Guasa and Jalene reported in Asmamaw's *et al*. (2010) agreed with the trend recorded in the current study. The small difference observed between these two studies presumably emanated from the varying temperature, soil type and rainfall of the different sites and varying conditions of different years at the same site. The different crop protection measures during these experiments might have also contributed for the observed differences for improper control of late blight leaf of potato (a serious potato disease worldwide) can have a substantial effect on the photosynthetic efficiency of the growing crop and starch deposition in the tuber that in turn can result in either low or high SG values (Hide and Lapwood, 1978). In general, the agreement observed among these research results clearly indicates that specific gravity of tubers is of value as a measure of potato processing quality.

The significant effects of location on tuber SG of varieties have also been reported by different workers (Killick and Simmonds, 1974; Asmamaw *et al*., 2007; Elfnesh *el al*., 2011). Clearly, the effect of location on the SG of varieties originates from the differential climatic variables tha prevail in each environmentduring crop growth. According to Govindakrishan and Haverkort (2006) the ideal average daily

temperature for better yield and quality potato production should be below 21^0C and above 5^0C. Similarly, Struik (2007) reported day and night temperatures of 20 and 16^0C as optimal temperature for total and tuber dry matter production and dry matter apportioning or allocation to tuber. Moreover, it has been reported that tubers produced at high temperatures will have a very low dry matter concentration and starch content associated with it (Struik, 2007). The high SG values, dry matter concentration, and starch content obtained at Debretabor as contrasted to those of Adet and Merawi presumably resulted from the optimal temperature range that favored better photosynthesis, high dry matter production and partioning to the tubers as clearly noted from the climatic data table of the study period. Moreover, the high organic matter content and high cation exchange capacity soils at Debretabor with sufficient adsorption site for mineral nutrients could substantially contribute to better moisture retention and essential minerals availability for better crop performance. Contrarily, the temperature ranges at Adet and Merawi were higher than the optimal ceiling that facilitated senescence and poor source-sink relations in respective sites as Reynolds *et al*. (1990) cited by Struik (2007). Ekin (2011) has also reported results of a similar kind from a study carried out in two seasons with marked differences in both temperature and moisture during the two years. Similarly, Krauss and Marschner (1984) on one hand and Haynes *et al.* (1988) and Van den Berg *et al*. (1989) on the other, respectively, were cited by Struik (2007) for their report stating tubers produced under high temperatures will have low starch content and very low dry-matter concentration associated with low starch content. The high starch and dry-matter content of all the 25 varieties at Debretabor as compared to Adet and Merawi in this study presumably attributed to the ideal cool condition that does not interfere with source to sink strength or assimilate partitioning. Additionally, the short photoperiod that limits gibrellic acid levels in the leaves and high light intensity that facilitate both early initiation and tuber bulking possibly contributed for the observed differences of Debretabor (Moorby, 1978).

The significant effect of locations on genotypes SG value and its consequent effect on genotypes inconsistent superiority across the current study sites have resulted in ranking order shift of varieties and ultimately significant genotype by environment interactions. Such significant genotype by environment interaction is a common feature of plant characters that are conditioned by multiple genes. Similar reports have also been made by earlier workers (Killick and Simmonds, 1974; Asmamaw *et al.*, 2007; Ekin, 2011; Elfnesh *et al.*, 2011; Abubaker *et al.*, 2011). The additive main effects and multiplicative interactions (AMMI) analysis plotted varieties differently on an x- and y-axis based on their magnitude of interaction or oscillations across environments and mean SG values against the overall SG mean (Figure 1). Consequently, CIP-392640.524, Zengena, Jalene and Belete were found as most stable varieties across the study sites in their increasing order for their mean SG values. Challa, Ater Abeba and Gorebella followed with higher mean SG value and little more interaction value than CIP-392640.524, Zengena and Jalene. Contrarily, the variety Wochecha, Awash and Menagesha positioned in the lower SG biplot quadrant with lower interaction value. Under such situations, any recommendation ought to take into account the cumulative role of genotypes SG value, interaction value and ultimately marketable yield for profitable potato production by growers. Thus, Belete, Challa, Grebella, Jalene and Ater Abeba were recommended for processing purposes based on their SG values, performance stability and tuber yield. Similarly, Debretabor site was found ideal environment for processing potato production. Moreover, Belete, Challa and Gorebella were found apt for French fry due to their long-axis to transverse-axis tuber shape. Equally, the round shaped Ater Abeba would be apposite for crisp manufacturing purposes. Yet, this does not rule out use of other varieties provided they fulfill the global quality standards, i.e., dry-matter content of 20% or higher, starch content of 13% and above and/or SG of 1.08 $gmcm^{-3}$or higher, and enable potato growers earn maximum profit.

The benefits of using various methods of determining total solids in widening the confidence limit of study results has been noted by Fitzpatrick *et al*. (1968). For

this purpose, a correlation analysis were carried to examine the degree of closeness of the dry-matter content/solids content and starch content data generated through converted SG of weight in air/weight in water method and weight loss or drying methods for the 25 potato varieties considered in the current. Despite an apparent pitfalls of most literatures as to the length of time and degree of temperatures of drying for weight loss procedures and depth of water of submersion in the weight in air and weight in water procedure, an interesting result was observed in the correlation of results obtained using the existing procedures. Accordingly, a very highly significant correlation coefficient for dry-matter content data and starch content data ($r = 0.80$; $P < 0.001$) of the two procedures were found. Moreover, varieties that surfaced on the high as well as the lowest levels matched under both procedures with few discrepancies in the starch content and dry-matter content values of tubers of some varieties.

Conclusion

This study had confirmed the presence of sufficient genetic variability in SG of tubers of potato varieties in the country. Besides, environment had a marked influenced on varieties tuber SG value. Significant genotype by location interaction was also observed owing to their differences in climatic factors such as temperature regimes, photoperiod, and the soil environment that either favor or otherwise photosynthetic efficiency of varieties and that affect assimilate partitioning among various parts. Since potato quality is subject to soil and climatic conditions, we strongly suggest the continuation of this study at a nationwide scale to come up with country wide recommendations.

Experiment-III

Genetic variation in tuber minerals concentration of potato varieties as an option to curb malnutrition syndrome

Results

Simple analysis of variance

The results of each site separate ANOVA on protein and fiber content, and the iron, zinc and phosphorus concentration (on dry-weight basis as the remaining tuber constituent water has no nutritional value) are indicated in Table 10 and 11. Accordingly, significant ($P < 0.01$) genotypic variation in mineral concentrations was observed among the varieties at each location.

Protein

At Merawi protein content of these varieties ranged from 3.58% in the improved variety Belete to 7.94% in the improved variety Menagesha (Table 10). The distribution of protein content values of varieties also revealed that 48 percent of them had above average value for Merawi site (Figure 9). Thus, sufficient genetic variability was present among the germplasm pool in the country. Likewise, at Debretabor, protein content of these same varieties ranged between 3.44% (CIP-395096.2) and 6.77% (Menagesha) as shown in Table 10. In addition, 52% of the varieties tested had protein content above the overall average obtained at this site (Figure 10). Hence, there was a similar trend to that seen at Merawi substantiating the available genotypic variability within the genetic pool on hand.

Fiber

Fiber content of these same varieties at Merawi ranged between 1.25 and 2.51%. The lowest and highest contents, respectively, was recorded from the elite clone CIP-396004.337 and the improved variety Tolcha (Table 10). At Debretabor

site, the fiber content ranged between 1.1 and 1.9% for the improved varieties Guasa and Tolcha, respectively (Table 3). The total number of varieties that had above average values for Merawi and Debretabor sites was 8 and 10 (Table 10 and 11).

Iron

Sizeable differences were also observed in the Fe concentrations which ranged from 12.85 to 266 $mg.kg^{-1}$ at Merawi and from 5.12 to 112.81 $mg.kg^{-1}$ at Debretabor (Tables 10 and 11). At Merawi, the lowest value was obtained from the improved variety Jalene while the highest was from improved variety Challa (Table 10). This was followed by the farmer's cultivar Sisay. Equally, the lowest and the highest Fe concentrations accrued at Debretabor site were from the improved variety Gabisa and elite clone CIP-396004.337, respectively (Table 11). Sisay, the second at Merawi, followed CIP-396004.337. The total number of varieties with a concentration greater than the overall average at Merawi and Debretabor were 6 (29%) and 9 (43%), respectively (Tables 10 and 11). The results of these mineral concentrations at Merawi site were generally higher than tose recorded at the Debretabor site.

Zinc

Varieties also displayed considerable variations over their Zn concentrations at both sites. This ranged from 7.24 to 24.12 $mg.kg^{-1}$ at Merawi and from 6.05 to 16.30 $mg.\ kg^{-1}$ at Debretabor (Tables 10 and 11). At Merawi, the lowest value was obtained from the improved variety Belete while the highest was from Menagesha (Table 10). The lowest and the highest Zn concentration at Debretabor site were accrued from the improved variety Hunde and Menagesha, respectively (Table 11). A total of 9 (43%) varieties at Merawi and 9 (43%) varieties at Debretabor had a concentration value well above the average obtained at each respective location (Tables 10 and 11). Of the two locations, the tested varieties obtained their highest Zn concentrations at the Merawi site.

Table 10 Mean protein and fiber content and iron, zinc and phosphorus mineral nutrient concentration and dry-matter content of potato varieties tested at Merawi site, 2011.

Varieties	Protein Content (%)	Fiber Content (%)	Fe Conc. (mg/kg)	Zn, Conc. (mg/kg)	P Conc. (mg/kg)	DMC, (%)
Menagesha	7.94^{a}	2.31^{ab}	67.80^{g}	24.12^{a}	469.19^{a}	17.45^{j}
Gera	4.33^{jk}	1.75^{cde}	181.10^{d}	15.41^{b}	283.03^{j}	19.98^{efghij}
Challa	5.44^{g}	1.63^{defg}	266.00^{a}	14.58^{b}	382.14^{c}	23.25^{abcd}
CIP-395096.2	6.76^{c}	1.78^{cde}	42.25^{i}	13.20^{cd}	350.49^{f}	20.85^{defghi}
Wochecha	6.86^{c}	2.48^{a}	198.90^{c}	12.98^{de}	360.04^{d}	18.65^{hij}
Gorebella	4.98^{h}	1.82^{cd}	37.20^{j}	11.83^{ef}	398.31^{b}	22.33^{cdef}
Zengena	6.15^{d}	2.02^{bc}	22.00^{q}	11.30^{fg}	246.23^{k}	18.50^{hij}
Hunde	5.76^{ef}	1.60^{defg}	85.60^{f}	9.62^{hi}	238.63^{m}	18.35^{ij}
Shenkolla	7.63^{b}	1.57^{defgh}	30.20^{m}	14.28^{bc}	181.95^{s}	21.43^{defg}
Belete	3.58^{l}	1.32^{gh}	26.40^{o}	7.24^{k}	145.74^{t}	23.05^{bcd}
Ater Abeba	4.89^{h}	1.70^{cdef}	25.40^{po}	10.42^{gh}	181.68^{s}	23.50^{ab}
CIP-392640.524	4.81^{hi}	1.82^{cd}	31.55^{l}	8.70^{ij}	243.94^{l}	19.73^{fghij}
Bulle	4.57^{ij}	1.62^{defg}	20.50^{r}	9.63^{hi}	205.09^{p}	20.88^{defghi}
Gabisa	5.56^{efg}	1.71^{cdef}	89.90^{e}	9.25^{hi}	217.12^{o}	19.10^{ghij}
Tolcha	6.31^{d}	2.51^{a}	26.05^{po}	9.02^{ij}	230.65^{n}	20.30^{efghi}
Aba Adamu	6.83^{c}	1.51^{defgh}	27.95^{n}	12.00^{ef}	189.54^{q}	19.75^{fghij}
Marachare	5.48^{fg}	1.45^{efgh}	24.90^{p}	11.06^{fg}	184.71^{r}	22.58^{cde}
Sisay	6.90^{c}	1.40^{fgh}	264.45^{b}	14.24^{bc}	353.46^{e}	21.15^{defgh}
Jalene	5.82^{e}	1.70^{cdef}	12.85^{s}	11.14^{fg}	292.29^{h}	24.18^{abc}
Guassa	3.69^{l}	1.32^{gh}	35.00^{k}	7.94^{jk}	309.96^{g}	25.85^{a}
CIP-396004.337	4.11^{k}	1.25^{h}	47.10^{h}	9.15^{i}	290.34^{i}	23.28^{abcd}
Mean	5.64	1.73	74.43	11.76	274.02	21.24
C.V.%	1.73	6.13	0.64	3.30	0.07	3.95
LSD	0.25	0.27	1.19	0.98	0.50	2.52

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

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

CV = Coefficient of variation; LSD = Least significant difference; DMC = Dry-matter content.

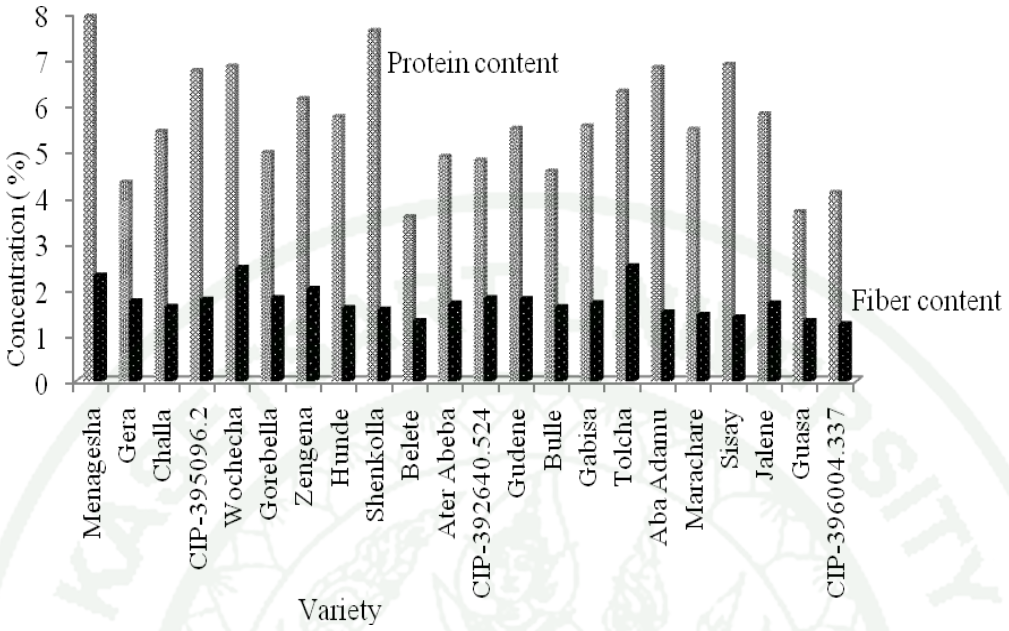

Figure 9 Protein and fiber concentration values distribution of varieties at Merawi site.

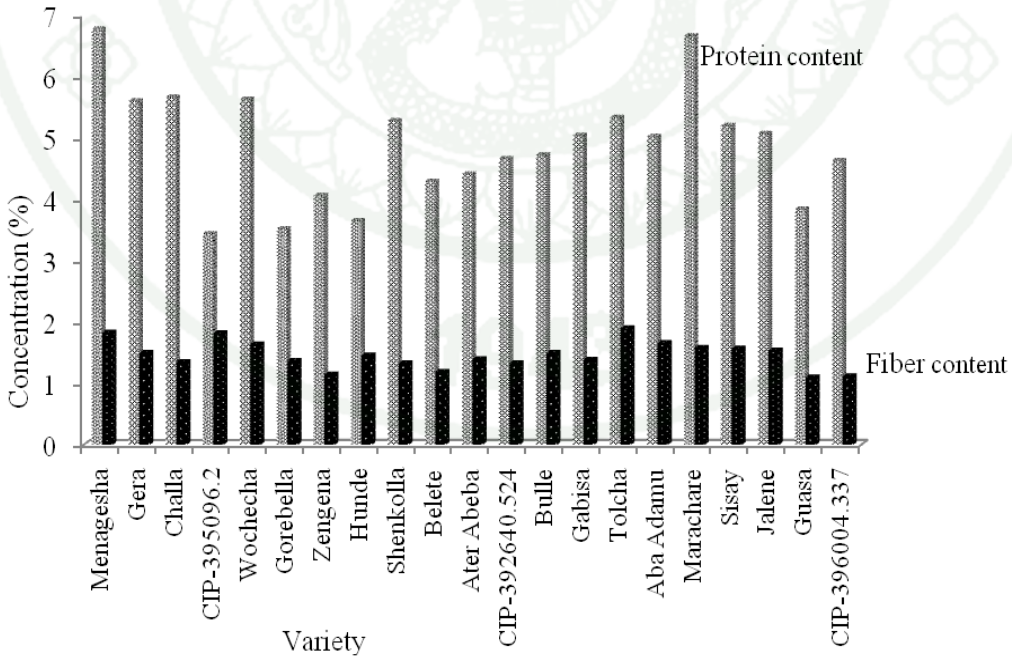

Figure 10 Protein and fiber concentrations distribution of varieties at Debretabor site.

Phosphorus

Similar to the other mineral concentration, varieties also showed differences in their P concentration and this ranged between 145.7 and 469 mg.kg^{-1}at Merawi and from 49 to 362 mg.kg^{-1} at Debretabor (Table 10 and 11).

Table 11 Mean protein, fiber and mineral nutrient concentration and dry matter content of potato varieties tested at Debretabor site, 2011.

Varieties	Protein Content, (%)	Fiber Content, (%)	Fe Conc., mg/kg	Zn, Conc., mg/kg	P Conc., mg/kg	DMC, %
Menagesha	6.77^{a}	1.83^{ab}	39.78^{f}	16.30^{a}	223.75^{f}	17.05^{i}
Gera	5.60^{b}	1.50^{cde}	19.65^{i}	11.85^{bcd}	153.67^{l}	23.80^{fgh}
Challa	5.65^{b}	1.35^{defg}	16.85^{j}	12.05^{bc}	85.48^{r}	27.83^{abc}
CIP-395096.2	3.44^{f}	1.82^{abc}	23.70^{h}	8.40^{fghi}	129.35^{o}	24.58^{efgh}
Wochecha	5.63^{b}	1.64^{abcd}	50.89^{d}	8.35^{fghi}	49.45^{s}	26.55^{bcdef}
Gorebella	3.52^{f}	1.37^{defg}	45.00^{e}	8.70^{efghi}	84.46^{r}	29.18^{ab}
Zengena	4.06^{def}	1.15^{fg}	17.85^{ij}	10.25^{cdef}	114.62^{p}	23.25^{h}
Hunde	3.65^{f}	1.46^{def}	57.50^{c}	6.05^{j}	96.83^{q}	23.75^{fgh}
Shenkolla	5.28^{bc}	1.33^{defg}	33.75^{g}	10.55^{cde}	180.32^{h}	26.10^{cdefg}
Belete	4.29^{cdef}	1.19^{efg}	22.85^{h}	6.90^{ij}	141.61^{n}	29.00^{ab}
Ater Abeba	4.41^{cdef}	1.40^{defg}	44.94^{e}	8.75^{efghi}	162.70^{k}	27.68^{abcd}
CIP-392640.524	4.65^{bcde}	1.33^{defg}	17.83^{ij}	9.95^{defg}	148.82^{m}	26.00^{cdefgh}
Bulle	4.72^{bcde}	1.50^{cde}	9.62^{k}	8.65^{efghi}	171.01^{i}	27.33^{abcde}
Gabisa	5.04^{bcd}	1.39^{defg}	5.12^{l}	8.15^{ghi}	167.28^{j}	23.65^{gh}
Tolcha	5.33^{bc}	1.90^{a}	18.00^{ij}	8.80^{efghi}	166.10^{j}	24.93^{defgh}
Aba Adamu	5.02^{bcd}	1.65^{abcd}	23.81^{h}	9.05^{efgh}	256.39^{e}	25.88^{cdefgh}
Marachare	6.65^{a}	1.58^{bcd}	9.35^{k}	11.05^{bcd}	301.77^{c}	25.10^{cdefgh}
Sisay	5.20^{bc}	1.57^{bcd}	65.20^{b}	13.00^{b}	362.07^{a}	26.15^{cdefg}
Jalene	5.07^{bcd}	1.54^{bcd}	41.14^{f}	11.70^{bcd}	267.02^{d}	26.68^{bcde}
Guassa	3.84^{ef}	1.10^{g}	9.28^{k}	7.24^{hij}	201.31^{g}	29.95^{a}
CIP-396004.337	4.63^{bcde}	1.12^{g}	112.82^{a}	7.05^{hij}	309.55^{b}	25.95^{cdefgh}
Mean	4.88	1.46	32.62	9.66	179.69	25.73
C.V.%	6.91	6.97	1.89	6.51	0.41	3.36
LSD	0.85	0.26	1.56	1.59	1.84	2.59

Means are separated using Duncan's multiple range test at $P < 0.01$ level of probability. Means in the same column that are followed by the same letter/s are not significantly different.

CV = Coefficient of variation; LSD = Least significant difference; DMC = Dry-matter content.

At Merawi, the lowest value was obtained from the improved variety Belete while the highest was from Menagesha (Table 11). The lowest and the highest P concentration at Debretabor site were obtained from the improved variety Wochecha (49.45 $mg.kg^{-1}$) and farmer's cultivar Sisay (362.07 $mg.kg^{-1}$), respectively (Table 11). In addition, 10 (48%) varieties at Merawi and 9 (43%) varieties at Debretabor exceeded the average phosphorus concentration recorded at respective locations (Table 10 and 11). Interestingly, varieties showed similar distribution trend in all these three mineral concentration at both locations but with quantitative differences (Figures 11 and 12).

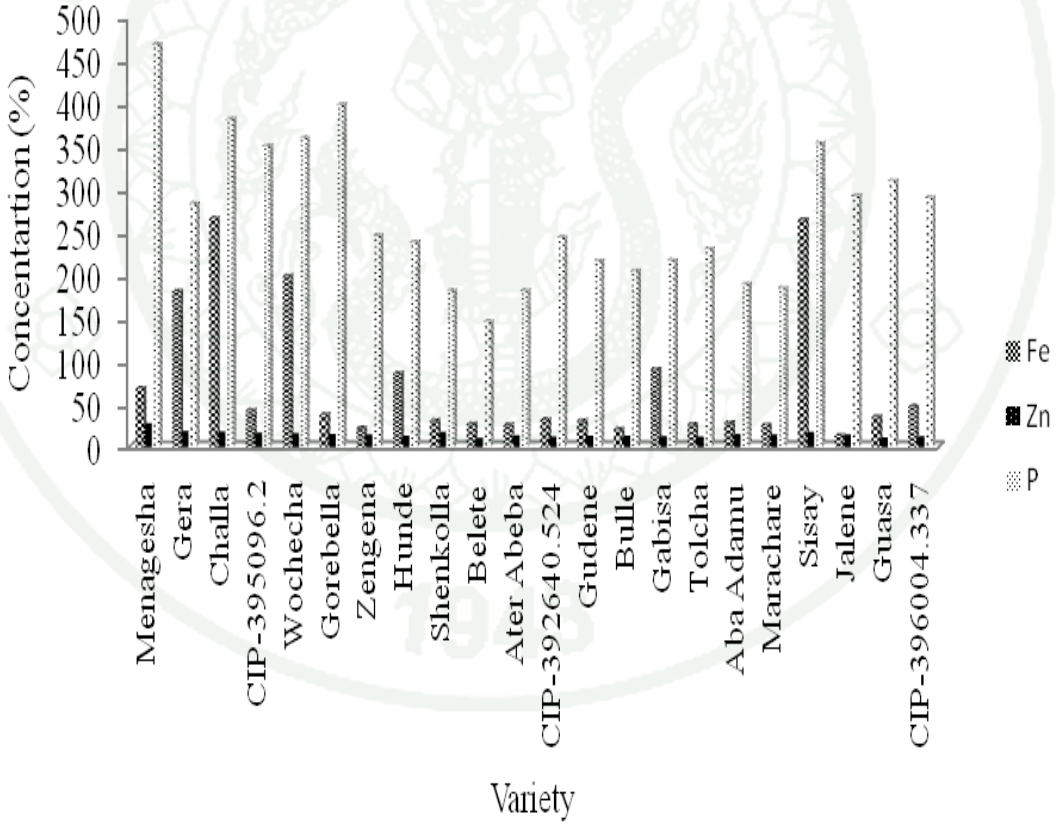

Figure 11 Fe, Zn and P concentration distribution of varieties at Merawi site.

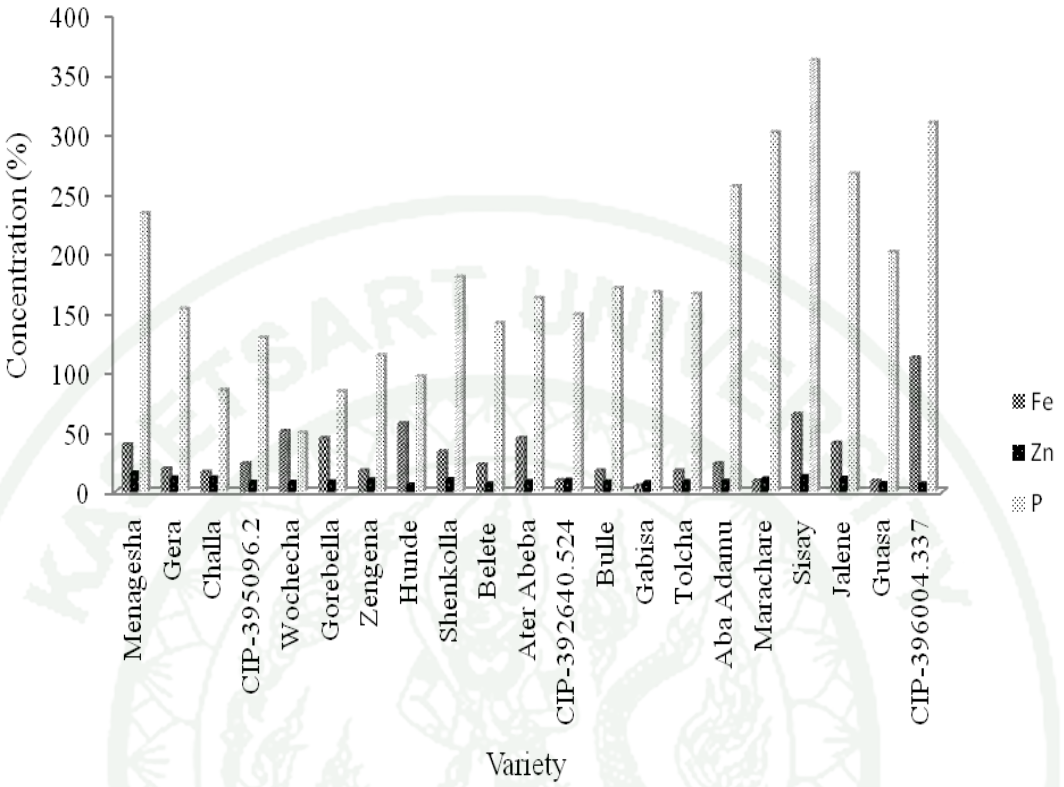

Figure 12 Fe, Zn and P concentration distribution of varieties at Debretabor site.

Combined ANOVA

The results of across locations ANOVA indicated significant ($P < 0.001$) variation due to genotype, locations and environment x location interaction. Accordingly, the protein and fiber contents, and the Fe, Zn and P mean concentrations across the two locations ranged from 3.77 to 7.36% and from 1.18 to 2.07%, and from 17.13 to 164.83, 7.07 to 20.21 and 143.68 to 357.76 $mg.kg^{-1}$, respectively (Table 12).

Table 12 Combined ANOVA mean protein, fiber and mineral nutrient concentration and dry matter content of potato varieties tested at Merawi and Debretabor site, 2011.

Varieties	Protein content, %	Fiber content, %	Fe concent., mg/kg	Zn, concent., mg/kg	P concent., mg/kg	DMC, %
Menagesha	7.36^{a}	2.07^{a}	53.79^{g}	20.21^{a}	346.48^{b}	17.25^{i}
Gera	4.96^{hi}	1.62^{bc}	100.38^{d}	13.68^{b}	218.35^{k}	21.89^{gh}
Challa	5.55^{defg}	1.49^{cd}	141.43^{b}	13.31^{bc}	233.81^{i}	25.54^{bc}
CIP-395096.2	5.10^{ghi}	1.80^{b}	32.98^{k}	10.80^{de}	239.92^{h}	22.71^{efg}
Wochecha	6.24^{bc}	2.06^{a}	124.90^{c}	10.66^{de}	204.74^{l}	22.60^{fg}
Gorebella	4.25^{jkl}	1.60^{bc}	41.10^{i}	10.26^{efg}	241.39^{g}	25.75^{bc}
Zengena	5.10^{ghi}	1.58^{bc}	19.93^{op}	10.78^{de}	180.42^{q}	20.88^{h}
Hunde	4.71^{ij}	1.53^{c}	71.55^{f}	7.83^{jkl}	167.73^{s}	21.05^{h}
Shenkolla	6.45^{b}	1.45^{cde}	31.98^{k}	12.42^{c}	181.14^{q}	23.76^{def}
Belete	3.93^{kl}	1.25^{def}	24.63^{m}	7.07^{l}	143.68^{t}	26.03^{b}
Ater Abeba	4.65^{ij}	1.55^{bc}	35.17^{j}	9.59^{fgh}	172.19^{r}	26.59^{b}
CIP-392640.524	4.73^{ij}	1.57^{bc}	20.59^{o}	9.32^{gh}	196.38^{n}	22.86^{efg}
Bulle	4.64^{ij}	1.56^{bc}	19.17^{p}	9.14^{h}	188.05^{p}	24.10^{d}
Gabisa	5.30^{fgh}	1.55^{bc}	47.51^{h}	8.70^{hij}	192.20^{o}	21.38^{h}
Tolcha	5.82^{cdef}	2.20^{a}	22.03^{n}	8.91^{hi}	198.37^{m}	22.61^{fg}
Aba Adamu	5.93^{bcde}	1.59^{bc}	25.88^{l}	10.52^{def}	222.97^{j}	22.81^{efg}
Marachare	6.07^{bcd}	1.51^{c}	17.13^{q}	11.06^{de}	243.24^{f}	23.84^{de}
Sisay	6.05^{bcd}	1.48^{cd}	164.83^{a}	13.62^{b}	357.76^{a}	23.65^{def}
Jalene	5.45^{efgh}	1.62^{bc}	27.00^{l}	11.42^{d}	279.66^{d}	25.43^{bc}
Guassa	3.77^{l}	1.21^{ef}	22.14^{n}	7.59^{kl}	255.64^{e}	27.90^{a}
CIP-396004.337	4.37^{jk}	1.18^{f}	79.96^{e}	8.10^{ijk}	299.94^{c}	24.61^{cd}
Mean	5.26	1.59	53.52	10.71	226.86	23.49
C.V.%	4.74	7.08	1.13	4.42	0.23	2.31
LSD	0.43	0.18	0.94	0.90	0.91	1.63

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

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

CV = Coefficient of variation; LSD = Least Significant difference; DMC = Dry-matter content.

The highest protein (7.36%) and fiber (2.07%) contents and Zn (20.21 $mg.kg^{-1}$) concentrations were obtained from the improved variety Menagesha. The highest Fe concentration value of 164.83 $mg.ka^{-1}$ and P concentration of 357.76 $mg.kg^{-1}$ were recorded for the farmer's cultivar Sisay (Table 12). The mineral concentrations index of Merawi site was higher for all mineral types. Clearly, this was a clear manifestation of the effects of environment on the mineral concentration of varieties. The genotype x environment interaction also displayed varietal performance differences across environments. Overall, 48 and 33% of varieties had a protein and fiber contents, respectively, above their respective across-location mean values. Likewise, while 33% of the varieties had above average Fe concentration values, 43% had above average concentration values of both Zn and P (Table 12; Figure 10 and 11). Thus, there existed a potential to complement biofortification as one of a sustainable strategy of controlling mineral malnutrition to the effort already in progress by way of dietary diversification, supplementation and fortification.

Correlation analysis

Correlation analysis among the essential nutrients and that of DMC and TY is indicated in Table 13. Accordingly, tuber protein and fiber contents and the Zn and P concentrations had a significant ($P < 0.01$) positive association. However, all of them had significant ($P < 0.01$) and negative relationships with DMC (Table 13). The association between tuber protein, fiber and Fe concentration was positive but weak and statistically insignificant. Tuber protein and fiber had significant ($P < 0.01$) negative relationship with TY as expected. Tuber Fe and Zn had insignificant negative association with TY. Conversely, tuber P concentration and TY had insignificant and very weak positive association. As expected tuber DMC had significant ($P < 0.05$) relationship with TY (Table 13).

Table 13 Correlation among protein, fiber, and mineral nutrient concentration and dry matter content of potato varieties tested at Merawi and Debretabor sites, 2011.

Characters	PC	FC	Fe	Zn	P	DMC	TY
PC	1.00	0.54**	0.21^{ns}	0.69**	0.43**	-0.56**	-0.41**
FC		1.00	0.17^{ns}	0.46***	0.39**	-0.60**	-0.49**
Fe			1.00	0.36**	0.49**	-0.29**	-0.05^{ns}
Zn				1.00	0.58**	-0.52**	-0.16^{ns}
P					1.00	-0.41**	0.06^{ns}
DMC						1.00	0.22*
MTY							1.00

Fe = Iron; Zn = Zinc; P = Phosphorus; PC = Protein content; FC = Fiber content; DMC = Dry-matter content, TY = Tuber yield.

ns = not significant; * = significant ($p < 0.05$); ** = highly significant ($p < 0.01$)

Discussion

Varietal differences in protein content of potatoes have been reported at different times by various authors; Schwimmer and Burr (1976) reported potato protein levels ranging from 3.5% to 23%, Kaldy and Markakis (1972) from 8.1% to 12% on six cultivars, Meidema *et al.* (1976) from 4.8% to 10.1% from examining 34 cultivars, Tekaligne and Hammes (2005) from 5.6% to 10.1% from four advanced genotypes and Ekin (2011) from 10.9% to 13.8% from a study conducted on eight varieties. Despite the variability of the genetic materials, diversified agroecologies and fertilizer management under in these studies, the protein content range obtained in the current study – namely, 3.58 to 7.94% at Merawi and 3.44 to 6.77% at Debretrabor site – generally corroborate with the earlier reports except for some downwards

deviation. Presumably, these differences is attributed among other factors to the varieties differential ability in mineral mining or uptake and use efficiency (White and Broadly, 2005; Hirel *et al*., 2007). The nitrogen fertilizer level used could also be a factor as it has a positive correlation with the total nitrogen content of tubers (Augustin, 1975).

Fiber (soluble and insoluble) is part of plant-based foods that cannot be digested by enzymes in the intestines. It helps to promote a healthy digestive tract and prevents constipation and hemorrhoids, and prevents heart diseases through reduction in blood cholesterol levels (Champ *et al*., 2003). Potatoes are high in dietary fiber, especially when eaten unpeeled with their skins (Bradshaw and Bonierbale, 2010). The result recorded in the current study of 1.8 g fiber per 100 dry weights corroborates the literature reporting an average of 2 g (Dale and Mackay, 1994) and total fiber of 1.49 to 1.98% reported for eight varieties by Rivero *et al*., (2009).

Smith (1968) reported that the concentration of Fe, Zn and P in potato tubers could range from 30 to185, 17 to 22 and 430 to 605 $mg.kg^{-1}$, respectively, on dry-weight basis. Ekin (2011) reported Fe and Zn concentration ranging from75.03 to 122.69 and 15.21 to 18.96 $mg.kg^{-1}$ among eight varieties. Similarly, Burgos *et al.* (2007) reported Fe and Zn concentrations ranging from 9.4 to 36.7 and 8.3 to 20.2 $mg.kg^{-1}$ among 49 potato genotypes from varying backgrounds. The range in Fe concentration of the 21 varieties in the current study (from 12.85 to 266 $mg.kg^{-1}$at Merawi and from 5.12 to 112.81 $mg.kg^{-1}$ at Debretabor) and in Zn (ranging from 7.24 to 24.12 $mg.kg^{-1}$ at Merawi and from 6.05 to 16.30 $mg.kg^{-1}$ at Debretabor) are in agreement with these earlier reports. In all these reports, substantial genetic variation in concentrations of Fe, Zn and P were obtained. Moreover, these data indicate that breeding for increased bioavailable Fe and Zn concentrations is, in principle, feasible as heritability of Fe concentration in potato is moderately high (Bradshaw and Bonierbale 2010).

The significant environments and genotype x environment interaction mean squares observed in the current study agree with the reports of Burgos *et al.* (2007) for two locations and that of Ekin (2011) for the same location but different years. Clearly, this is a common observation for many characters as environmental factors do differ in different years and do crop variety performance differently pertaining to the prevailing set of environmental conditions in each set of sampled years. The Nitosol type, which is normally considered a good agricultural soil in the Food and Agricultural Organization soil classification system, may have contributed to the better concentration observed at Merawi site as contrasted to the Luvisol at Debretabor site which is classified as an infertile soil (Waithaka *et al*., 2007). This fertility differences between the two trial sites has clearly been reflected in the mineral concentrations of plants which is determined by the phytoavailability of nutrients within the soil and the varieties nutrient uptake and use efficiency (White and Brown, 2010).

The negative association between crude protein and dry-matter content observed here agrees with the earlier works of Tekaligne and Hammes (2005) and Gary and Hughes (1978). Likewise, the negative correlation between tuber yield and mineral concentration is in agreement with Tekaligne and Hammes (2007) and many others as reviewed by White *et al*. (2009). This negative correlation association in both cases is attributed to "dilution effect" caused by high plant growth rates that excel the ability of plants to acquire these elements (Jarelle and Beverly, 1981). The most interesting aspect noted in the correlation analysis of current study is the positive association among minerals with the exception of the weak and insignificant positive correlation between protein, fiber and Fe. Clearly, this indicates the possibility of a simultaneous improvement in these mineral concentrations as they are controlled by common genetic factors. Thus, there is a possibility of improving the per capita consumption of protein in the country where there is low calorie intake and a lack of protein caused by the low economic capacity for alternative sources of protein. A similar association of Fe and Zn was reported by Graham and Welch (2004) in wheat,

by Burgos *et al*. (2007) in potato, and by Velu *et al*. (2011) in wheat. Likewise, a positive association between Fe, Zn and protein was reported by Velu *et al*. (2011) in wheat and by Ortiz-Manasterio *et al*. (2007) in wheat and maize.

Conclusion

This study has revealed the presence of sizeable variations in mineral concentrations among potato varieties in Ethiopia. The significant effect of location and association among minerals were also observed. The improved variety Menagesha, farmer's cultivar Sisay and elite clone CIP-396004.337 were found to be better than the other varieties and could be good parents for a genetic enhancement program. Considering the 10% bioavailability of Fe and 21% bioavailability of Zn in developing countries, the Food and Agricultural Organization/World Health Organization recommended 27.4, 58.8 and 12 $mg.day^{-1}$ of Fe for men, women and children, respectively. Additionally, the Food and Agricultural Organization/World Health Organization recommended 6, 4.9 and 4.1 $mg.day^{-1}$ of Zn for men, women and children, respectively. Consequently, men, women and children, respectively can get 29%, 13.3%, and 65% of their daily RNI of Fe from eating 200 g fresh weight (FW) of tubers of the high Fe concentration variety Sisay (7.8 mg) and 12%, 14.3% and 17% of the daily RNI of Zn for men, women and children, respectively, from 200 g of FW tubers of the high Zn variety Menagesha (0.70 mg). Thus, highland inhabitants of Ethiopia who consume potato in large amounts as their staple food could get larger portions of their daily RNI of these two critical minerals. The authors also recommend the continuation of this study backed with detail analysis of soil nutrients.

Experiment- IV

Variation in chemical composition and pasting properties of starches of different potato varieties grown at different locations in amhara region

Results and discussion

One-way analysis of variance

A separate analysis of variance was carried out for both amylose, amylopectin and moisture contents and pasting properties of the starches isolated from the 25 potato varieties evaluated at each location. The results of these analyses at each location showed highly significant ($P < 0.01$) genotypic differences for the amylose, amylopectin and moisture content and starch pasting properties (Tables 14, 15, 16 and 17).

Amylose and amylopectin content

The AMC, APC and MC of starches of the 25 different potato varieties are shown in Table 14. The AMC of the starches at Adet experimental site ranged between 19.40% and 32.22% (mean 24.50%) for Gorebella and farmer's cultivar Ater Abeba, respectively, and varieties showed significant ($P < 0.01$) differences in their AMC. Jalene (19.58%), Sisay (20.34%) and Guasa (20.74%) were among the varieties with the lowest AMC values. Ater Abeba was followed by Shenkolla with 29.84% and Ararsa with 29.02%. In addition, varieties showed highly significant ($P < 0.01$) differences in AMC at Merawi and Debretabor sites (Tables 14). At Merawi, AMC ranged from 19.96% to 33.43% (mean 25.94%) for Zengena and Tolcha, respectively. CIP-396004.337 and Jalene surpassed Zengena with 21.29% and 21.51% AMC. Ararsa with 30.34% and Wochecha with 29.87%, Bulle with 29.63% and Gera with 29.22% followed Tolcha in their order. At Debretabor, AMC ranged from 20.12% to 31.68% (mean 26.24%) for Guasa and Ater Abeba, respectively. Jalene was second

from the last with 21.50% while Aba Adamu and Ararsa followed Ater Abeba with 30.85% and 30.85% (Table 14). Grommers and van der Krogt (2009) reported that potato starch does contain amylose that range from 21% to 25%. Similar study carried by Cottrell *et al.* (1995) documented AMC of 24.4% to 30.9% among four varieties tested under three different sets of temperature ranges. Similarly, while Yusuph *et al*. (2003) reported AMC range of 25.8% to 31.2% among 12 commercial varieties, Liu *et al*. (2007), Kuar *et al.* (2007), Mbougueng *et al.* (2008), Rivero *et al.* (2009) and Alvani *et al.* (2011) reported AMC ranges of 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. According to Noda *et al*. (1998) AMC of normal starches should fell between 10% and 30%. Except for starches isolated from Ater Abeba at Adet (~32%) and Tolcha at Merawi (~31%), AMC of remaining varieties starch in the present study were consistent with this basic fact and earlier literatures. The AMC difference among starches isolated from different potato varieties grown at the same location clearly manifested the significant effect of genetic differences (Kuar *et al*., 2007; Alvani *et al*., 2011).

Starches of the 25 different potato varieties also showed highly significant ($P < 0.01$) differences in APC. At Adet APC value ranged from 67.78% to 80.42% for Ater Abeba and Jalene, respectively. At Merawi it ranged from 66.57% to 80.04%, for Tolcha and Zengena, respectively. At Debretabor APC value ranged between 68.32% and 79.88%, for Ater Abeba and Guasa, respectively. Grommers and van der Krogt (2009) reported that potato starch does contain amylopectin that range from 75% to 79%.Yusuph *et al.* (2003) reported APC values ranging from 68.8% to 74.2% in their study of starch chemical composition of 12 varieties at one location. Similarly, Liu *et al.* (2007), Kuar *et al*. (2007), Mbougueng *et al.* (2008) and Alvani *et al.* (2011) 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 a study made on varying number of varieties in different countries. All these results are in agreement with the ranges observed in the present study. Thus, varieties do have substantial influence in the chemical composition of starches of different varieties.

Starch moisture content

Moisture content of the starches varied significantly ($P < 0.01$) among the different varieties at each location. At Adet, MC of varieties ranged between 13.71% for Ararsa and 17.98% for Tolcha with a location mean value of 16.25%. These same varieties grown at Merawi and Debretabor locations had MC ranging from 14.75% for Tolcha to 15.88% for Belete and 13.00% for Agere and 16.23% for Gorebella, respectively. The overall average MC for Merawi and Debretabor site were 15.33% and 14.98%, respectively (Table 14). These sites had the highest average AMC than that of Adet. Mbougueng *et al.* (2008) reported MC of 10.29% to 18.33% among three potato varieties. Thus, MC values obtained in the current study were in agreement with these authors and the generally acceptable level practiced by European Union for commercial starch (Grommers and van der Krogt, 2009). The difference in MC of starch could be attributed to differences between variety and also the difference in the extent of drying time (Chen *et al*., 2003). Tsakama *et al.* (2010) had reported similar MC difference among starches isolated from 11 sweetpotato varieties in Malawi.

Starch pasting properties

Results of the different varieties starches pasting properties analysis showed significant ($P < 0.01$) differences across genotypes and locations. At Adet PV of the different varieties ranged between 196 for Wochecha and 420 RVU for Jalene (Table 15). At Merawi and Debretabor sites, PV of varieties ranged from 211 (CIP-395096.2) to 430 (Guasa) RVU and 226 (Gera) to 538 RVU for Gabisa, respectively (Table 16 and 17). Mean PV of Adet, Merawi and Debretabor locations ranged from 288, 282 and 326 RVU, respectively indicating the presence of significant substantial differences across the three locations.

The mean PV at each location also showed substantial differences (Tables 15, 16, and 17). All varieties with the highest PV value at each location had the lowest amylose and highest amylopectin content (Tables 15, 16, and 17). This result is in agreement with earlier studies that reported the presence of strong positive relationship between

PV and amylopectin content (Yusuph *et al*., 2003; Liu *et al*., 2007; Kuar *et al.*,2007). BDV value at Adet ranged from 54.21 RVU for Shenkolla to 256.83 RVU for Jalene (Table 15). Guasa and Sisay followed the highest RVU variety Jalene. Similarly, BDV value 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 16). At Debretabor site this same value ranged from 61.92 RVU for Ararsa to 363.38 RVU for Gabisa (Table 17). The highest BDV variety Gabisa is followed by the variety Guasa (309.33). BD is regarded as a measure of the degree of disintegration of granules or paste stability. It is a measure of cooked starch to withstand shears induced disintegration. As such though sometimes different across locations, the highest BDV varieties were all had the lowest amylose content while 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 value had the highest PV values. This is in agreement with the earlier report that stated starches with low amylose or high amylopectin and high phosphorus swell more freely because starch swelling is mainly a property of amylopectin (Tsakama *et al*., 2010). As the relationship between phosphorus content and PV was reported by Tsakama *et al*. (2010), all varieties that had high PV in the present had relatively high tuber phosphorus content at two of the locations in present study (Tesfaye *et al*., 2012) and thus consistent with other workers. In other words, starches with high amylose content are resistant to breakdown and takes more pasting time and high temperature as noted in the current study too (Table 15, 16, 17 and 18). SR and SBR values obtained were also in consistent agreement with the ratio of these two starch polymers, amyloes and amylopectin contents. The lowest SBR values were recorded from high amylopectin containing varieties (Tabe 15, 16, 17 and 18). Contrarily, the highest SBR value was recorded from varieties containing high proportion of amylose.This is in agreement with the report that high amylose starches reassociate more readily than high amylopectin starches (Shimelis *et al*., 2006; Kuar *et al*., 2007). It is of interest to observe viscograph produced by the RVA that also showed pasting profile differences between starches of different varieties isolated from varieties grown at a location and across locations (Figures 13, 14 and 15).

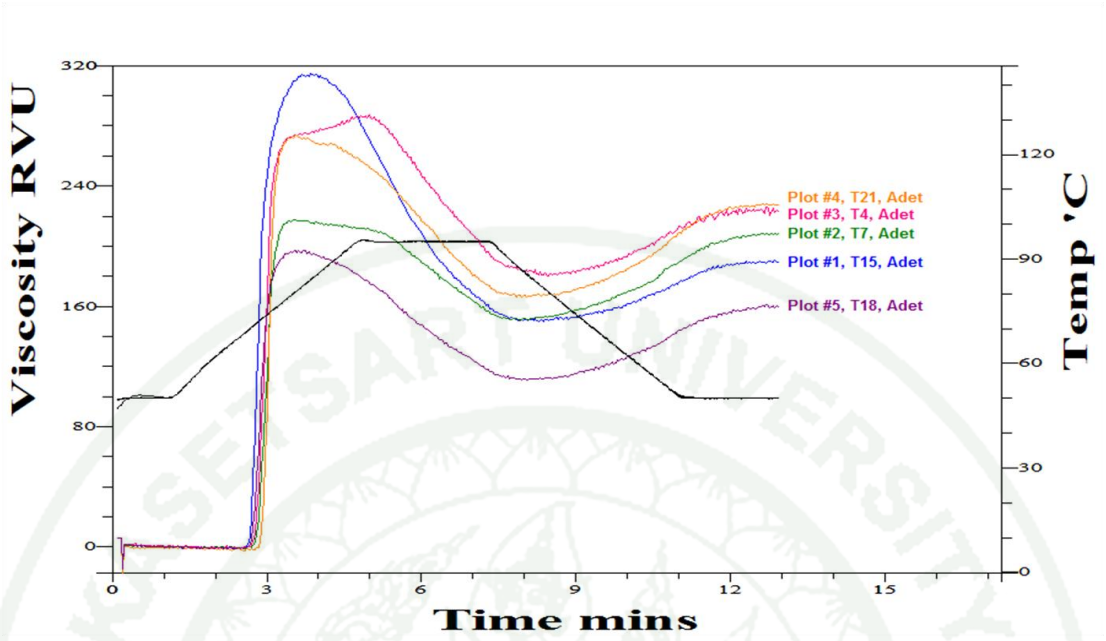

Figure 13 RVA viscosity profiles of the first five varieties starch pastegrown at Adet site.

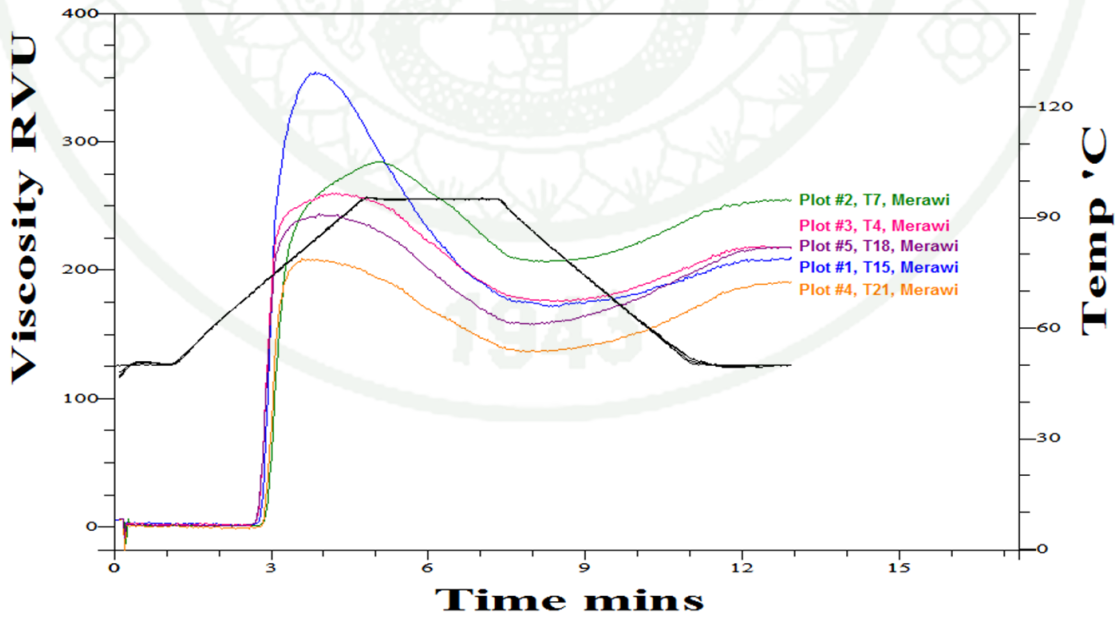

Figure 14 RVA profile of the first five varieties starch paste grown at Merawi site.

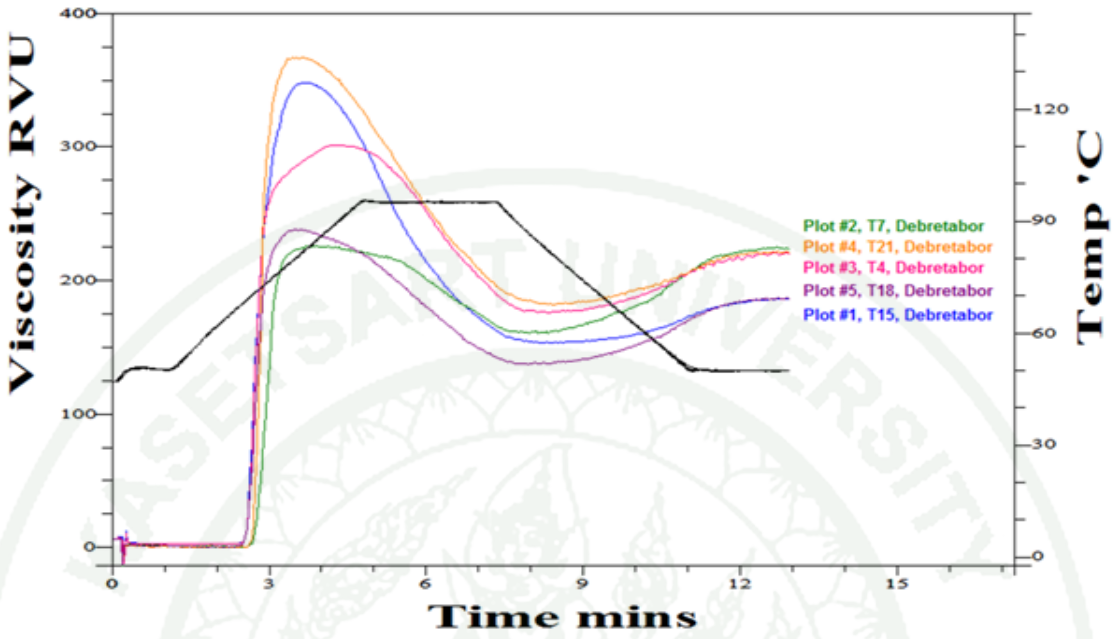

Figure 15 RVA profile of the first five varieties starch paste grown at Debretabor site.

Table 14 Amylose, amylopectin and starch contents of 25 potato varieties tested at three different locations in Amhara region, Ethiopia.

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}	22.15^{jkl}	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	2.22	2.95	2.47	3.06	2.91	2.47	0.16	0.21	0.28

AMC = amylose content; APC = amylopectin content; SMC = starch moisture content; n = 3 for AMC, APC and 2 for MC**;** Mean separation at $P < 0.01$.

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 x location mean square (Tables 18 and 20). AMC of genotypes ranged from 20.86% for Jalene to 30.58% for Ater Abeba (Table 18). Mean AMC at Adet, Merawi and Debretabor was 24.50%, 25.95% and 26.24%, respectively (Table 14). Thus, there were significant differences between genotypes and locations. Kuar *et al*. (2007) had also reported similar variation in AMC across four locations that ranged from 17.41% to 18.90%. The highest AMC value was recorded at Debretabor site where the temperatures are relatively lower than the other two sites. Climatic factors directly influence crops productive potential, regulating its 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 optimum temperature for potato plant varies with crop growth stage, photoperiod, length of exposure and others, a value of 16-24 ^{0}C was reported to be ideal for better potato production (Timlin *et al*., 2006). Furthermore, Mohabir and John (1988) observed 21.5 ^{0}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) had also reported a reduction of enzyme activity in potato plants exposed to elevated temperature and specifically indicated a 59% and 72% reduction of sucrose synthase activity in a heat tolerant and susceptible potato cultivars, respectively. Similarly Keeling *et al.* (1994) reported a temperature of 20 to 25 ^{0}C as maximal for starch synthase activity in cereals. Wang *et al*. (2006) has also noted higher level expression of amylase enzyme – granule bound starch synthase I (GBSSI), enzyme responsible for amylose synthesis, at low temperature in rice crop. Thus, high AMC at the cool Debretabor site of current study clearly agree with these results. Cottrell *et al*. (1995), however, reported observation of high AMC in varieties

grown under high temperature. Genotypes had also exhibited inconsistent AMC value across the three different locations. As a result, the genotype that had highest AMC value at Adet, Merawi and Debretabor were Ater Abeba (32.22%), Tolcha (33.43%) and Ater Abeba (31.68%), respectively (Table 14). Kuar *et al*. (2007) had also found similar genotypic inconsistent AMC value among 21 varieties studied at four locations, a clear manifestation for the presence of genotype x environment interaction.

Mean APC across location also ranged from 69.42% to 79.14% for Ater Abeba and Jalene, respectively (Table 14). Liu *et al.* (2007) and Kuar *et al.* (2007) had reported similar results of locations effect on APC of starches isolated from different potato varieties. Such differences in APC across growing location are attributed to the prevailing differences in climatic conditions especially of optimal temperature during crop growth and development stages. Starch branching enzyme (SBE) that is responsible in amylopectin synthesis 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 pasting properties of starches isolated from the three different locations had highly significant ($P < 0.01$) genotypic, location and genotype x location interaction over all the parameters considered (Table 18 and 21). Mean PV across the three locations (Adet, Merawi and Debretabor) ranged from 235.83 RVU (Ararsa) to 426.72 RVU (Guasa) with average of 298.41 RVU (Table 18). At Adet, Merawi and Debretabor this same value ranged from 195.92 RVU (Wochecha) to 419.71 RVU (Jalene), 211.33 RVU (CIP-395096.2) to 429.54 RVU (Guasa) and 225 RVU(Gera) to 537.58 RVU (Gabisa), respectively (Tables 15, 16 and 17). The mean PV of Adet, Merawi and Debretabor locations were 287.84, 281.90 and 325.48 RVU, respectively. Thus, there were highly significant differences ($P < 0.01$) between genotypes and locations in one hand and significant genotype x

location that was noted from the inconsistent high PV genotypes across the three locations. Growing areas climatic condition had sizeable influence of on this starch pasting property. Similarly, mean BDV, CPV, SBV, PT and Ptemp of the 25 different varieties at Adet ranged from 54 (Shenkolla) to 254 RVU (Jalene), 157 (Wochecha) to 254 RVU (Shenkolla), 24 (Guasa) to 91 RVU (Shenkolla), 3.16 (Ater Abeba) to 4.77 m (CIP-392640.524) and 68.05 (Guasa) to 72.30 ^{o}C (Shenkolla), respectively (Table 15). At Merawi these values ranged from 41 (Ararsa) to 236 RVU (Guasa), 162 (Zengena) to 263 RVU (Ararsa), 28 (Jalene) to 85 RVU (Ararsa), 3.26 (Ater Abeba) to 5.10 m (Gera), 69.30 (Agere) to 72.68 ^{0}C (Hunde), respectively (Table 16). And at Debretabor, BDV, CV, SBV, PT and Ptemp for the 25 differet varieties range from 62 (Ararsa) to 363 RVU (Gabisa), 177 (Gudene) to 271 RVU (Ararsa), 27 (Gudene) to 67 RVU (Gera), 3.14 (Gabisa) to 5.23 m (CIP-392640.524) and 66.28 (Gorebella) to 70.13 ^{0}C (Hunde), respectively (Table 17). Mean BDV, CPV, SBV, PT and Ptemp across the three locations ranged from 70.49 (Gera) to 259.32 RVU (Guasa), 180.17 (Sisay) to 247.51 RVU (Ararsa), 27.17 (Guasa) to 68.15 (Ararsa), 3.35 m (Ater Abeba) to 4.91 m (CIP-392640.524) and 68.16 (Gorebella) to 70.89 RVU (Marachare), respectively (Table 18). Mean PV, HPV, BDV and CPV values at Debretabor site were higher than both Merawi and Adet in one hand and lower Ptemp on the other hand. A study carried by Noda *et al*., (2004) on 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 ^{0}C. In the same way while Kuar *et al*., (2007) reported Ptemp and PT ranges of 64.5 to 69.4 ^{0}C and 3.60 to 5.70 m on 21 different varieties, Liu *et al*., (2003) reported Ptemp ranges of 66.1 to 71.8 ^{0}C on 3 varieties. Although, the genetic materials and growing locations from which the starches were isolated in the present study were different from all the stated workers, results of the pasting properties obtained were within the ranges reported in earlier studies. Kuar *et al*. (2007) reported that temperature during tuber growth affects granule size and pasting temperature and as such lower temperature prevailed during tubers growth resulted into starch with higher granule size and lower pasting

temperatures. Furthermore, Liu *et al.* (2003) reported granule size variability between starches isolated from different varieties and at different growth time. Although, the granule size of the starches of varieties included in the current study was not determined, the results of the pasting properties of starches isolated from varieties grown at the cool highland Debretabor site as contrasted to the relatively warmer Merawi and Adet probably 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 their high AMC at these sites that is responsible for more time needed for the starch to swell and form paste. In general the varieties Guasa, Jalene, Sisay, Gabisa, Gudene and Menagesha had relatively consistent lower AMC, higher APC, PV, HPV, BDV and CPV across all locations. Contrarily, Gera, Wochecha and Ararsa had consistent higher AMC, lower APC, PV, HPV, BDV and CPV. The SR and SBRvalues of across location ranged 0.40 for Guasa to 0.76 for Ararsa and from 1.16 for Guasa to 1.38 for Ararsa. In both case Ararsa, the variety with second highest AM, had the lowest stability ratio and highest setback ratio. The opposite is true with Guasa that has the lowest AM (Table 18). Thus, AM seems to have vital role in the paste consistency and breakdown.

Correlation analysis

Results of Pearson's correlation analysis among pasting properties of starches isolated from the 25 varieties grown at different locations showed non-significant relationship of HPV with CV and HPV with BD and SB. PT revealed significant, positive relationship with AMC ($r = 0.20$; $P < 0.05$) and significant, negative relationship with APC ($r = -0.20$; $P < 0.05$) (Table 19). The remaining pairs of parameters have shown negative and positive relationship based on their differences in the amounts of the two constituent glucose polymers composition and ratios as well as granule size differences emanating from growing environments temperature variability responded differently by the different cultivars in their starch biosynthesis. Highly significant and positive correlation ($r = 0.94$, $P < 0.01$) was observed between

PV and BDV. Kuar *et al*. (2007) on 21 potato varieties and Tsakama *et al* (2010) on starches isolated from 11 sweeetpotato varieties found similar high positive correlation value (r = 0.924, $P < 0.01$) and (r = 0.91, $P < 0.01$). Contrarily, highly significant negative correlation (r = -0.59, $P < 0.01$) between PV and SBV. This result clearly shows the high level disintegration or disruption of starch granules when subject to shear or heat in the first case and starch granule resistance to breakdown when subject to the same shear or heat in the latter case (Singh *et al*., 2006). PV also had negative correlations with PT (r = -0.27, $P < 0.01$), Ptemp (r = -0. 37, $P < 0.01$) and AMC (r = -0.40, $P < 0.01$) and positive association with APC (r = -0.40, $P < 0.01$). This result is in agreement with the results of Kuar *et al*. (2007) and Noda *et al*. (2004) on 21 and six potato varieties. Obviously, high AMC associated with resistance to granule disintegration or breakdown as heat shear applied thus necessitating longer time and high temperature to disintegrate. 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 justify the positive association between PV and APC and negative correlations between PV and PT, Ptemp and AMC. Thus, such result helps to predict the kind of gel, either tough gels and strong film or soft gel and weak film, the starch paste of each variety will be producing. In addition, it will help decide the variety of interest depending on their AMC and APC amounts and proportions they contained in their tubers. Overall, correlation analysis results of current study is in accord with Kuar *et al*. (2007) study on 21 varieties at four different locations except for its difference in values between PV and CV and Noda *et al.* (2004) on six varieties tubers at different growth stage. PV value was negatively associated with AMC and positive associated with APC. This result agreed with Yusuph *et al*. (2003); Liu *et al*. (2007) and Kuar *et al.* (2007) report.

Conclusion

Starch isolated from different potato varieties substantially differed in chemical composition and pasting properties. Pasting properties of varieties also varied owing to their differences in chemical and structural content variability. Growing locations had also substantially influenced chemical composition and pasting properties of starches. Overall, Guasa, Jalene, Sisay, Gabisa, Gudene and Menagesha had relatively consistent lower AMC, higher APC, PV, HPV, BDV and CV across all locations. Perversely, Gera, Wochecha and Ararsa had higher AMC, lower APC, PV, HPV, BDV and CV. Furthermore, mean PV, HPV, BDV and CV values at Debretabor site were higher than both Merawi and Adet in one hand and lower Ptemp on the other hand, which is attributed to low temperature that favored biosynthesis of larger granule size starches at Debretabor than the other two sites. The relationship observed among starch pasting properties had also clearly reflected the overruling influence of the two starch biopolymers, AMC and APC, and granule size on composition and pasting properties. Amylose and amylopectin have different properties and as such while amylose has a high tendency to retrograde produce tough gels and strong films, amylopectin result in opposite. The contribution of genotypic variance to the total variance was higher for AM (50%), APC (52%), CV (52%), SB (77%), PT (53%), SR (64.8%) and SBR (63.8%). Contrarily, the contribution of location variance was greater for pasting parameters AP (59%), HPV (45%), BD (48.4%), and Ptemp (94.3). Thus, the observed significant genetic variability among the evaluated varieties indicates that there is genetic potential for the selection or breeding of genotypes with appropriate amounts of AMC or APC to exploit property of starch desired for intended utility. Inaddition, the correlation result guides the selection of varieties with the desired properties for either industrial or food utility purposes.Based on current one year result, the varieties Guasa, Jalene, Sisay, Gabisa, Gudene and Menagesha could meet the qualities desired for thickening and adhesive while varieties Ararsa, CIP-392640.524, Gera, Shenkolla, Tolcha, Hunde and Marachare could be chosen for bakery and confectionar purposes.

Table 15 Pasting properties of starch isolated from 25 potato varieties grown at Adet site during 2011 cropping season.

Variety	PV (RVU)	HPV (RVU)	BDV (RVU)	CV (RVU)	SBV (RVU)	PT (min.)	Ptemp (^{0}C)	SR	SBR
Menagesha	316.08^{de}	148.46^{gh}	167.63^{d}	186.38^{jk}	37.92^{efgh}	3.83^{bcd}	68.93^{klmn}	0.47^{i}	1.26^{ghij}
Gera	219.38^{lm}	150.50^{gh}	68.88^{m}	209.88^{ef}	59.38^{b}	3.50^{d}	70.55^{cdefgh}	0.69^{b}	1.40^{bcd}
Challa	291.00^{g}	181.63^{a}	109.38^{hij}	223.92^{cd}	42.29^{defg}	4.64^{a}	69.80^{fghijk}	0.63^{cd}	1.23^{hijk}
CIP-395096.2	273.79^{i}	168.96^{bcd}	104.83^{ijk}	223.33^{cd}	54.38^{bc}	3.54^{cd}	71.33^{bc}	0.62^{cd}	1.33^{defg}
Wochecha	195.92^{n}	110.50^{j}	85.42^{l}	156.92^{n}	46.42^{cdef}	3.63^{cd}	69.05^{jklm}	0.57^{ef}	1.42^{bc}
Awash	253.33^{j}	135.53^{i}	117.75^{gh}	173.96^{lm}	38.38^{efgh}	3.76^{bcd}	69.13^{jklm}	0.54^{fg}	1.28^{efghi}
Gorebella	282.33^{h}	142.67^{hi}	139.67^{ef}	189.58^{ijk}	46.92^{cde}	3.58^{cd}	68.83^{lmn}	0.51^{gh}	1.33^{defg}
Zengena	279.00^{hi}	166.21^{cde}	112.79^{ghi}	202.42^{fgh}	36.21^{fghij}	3.76^{bcd}	70.63^{cdefg}	0.60^{de}	1.22^{ijk}
Hunde	233.08^{k}	175.46^{ab}	57.63^{n}	227.42^{bc}	51.96^{bcd}	4.51^{ab}	71.68^{ab}	0.76^{a}	1.30^{efgh}
Agere	274.88^{i}	174.25^{ab}	100.63^{jk}	213.46^{de}	39.21^{efgh}	3.60^{cd}	70.35^{defghi}	0.64^{c}	1.23^{hijk}
Shenkolla	213.25^{m}	159.04^{ef}	54.21^{n}	250.46^{a}	91.42^{a}	3.88^{bcd}	72.30^{a}	0.75^{a}	1.58^{a}
Belete	253.04^{j}	155.54^{fg}	97.50^{k}	201.21^{fgh}	45.67^{cdefg}	3.44^{d}	70.83^{bcde}	0.62^{cd}	1.30^{efgh}
Ater Abeba	274.04^{i}	138.63^{i}	135.42^{f}	200.17^{fgh}	61.54^{b}	3.16^{d}	68.70^{mn}	0.51^{gh}	1.45^{b}
CIP-392640.524	258.13^{j}	176.38^{ab}	81.75^{l}	236.38^{b}	60.00^{b}	4.77^{a}	70.95^{bcd}	0.68^{b}	1.34^{def}
Gudene	319.13^{d}	149.75^{gh}	169.38^{d}	180.00^{kl}	30.25^{hijk}	3.58^{cd}	70.15^{defghi}	0.47^{i}	1.21^{ijk}
Bulle	273.92^{i}	170.29^{bcd}	103.63^{ijk}	217.29^{cde}	47.00^{cde}	4.30^{abc}	70.80^{bcde}	0.62^{cd}	1.28^{efghi}
Gabisa	371.54^{b}	162.63^{def}	208.92^{c}	198.21^{ghi}	35.58^{ghij}	3.52^{cd}	69.73^{ghijk}	0.44^{j}	1.22^{ijk}
Tolcha	303.54^{f}	159.21^{ef}	144.33^{ef}	201.46^{fgh}	42.25^{defg}	3.81^{bcd}	69.93^{efghij}	0.53^{gh}	1.27^{fghij}
Aba Adamu	345.21^{c}	171.17^{bc}	174.04^{d}	214.00^{de}	42.83^{defg}	3.57^{cd}	68.88^{klmn}	0.50^{hi}	1.25^{ghij}
Marachare	276.83^{hi}	155.25^{fg}	121.58^{g}	194.00^{hij}	38.75^{efgh}	3.76^{bcd}	71.38^{bc}	0.56^{f}	1.25^{ghij}
Sisay	366.08^{b}	137.50^{i}	228.58^{b}	164.96^{mn}	27.46^{ijk}	3.44^{d}	69.60^{hijklm}	0.38^{k}	1.20^{jk}
Ararsa	221.25^{l}	154.79^{fg}	66.46^{m}	209.00^{efg}	54.21^{bc}	3.76^{bcd}	70.73^{cdef}	0.70^{b}	1.35^{cde}
Jalene	419.71^{a}	162.88^{def}	256.83^{a}	189.21^{ijk}	26.33^{jk}	3.41^{d}	69.55^{ijklm}	0.39^{k}	1.16^{k}
Guasa	370.83^{b}	137.92^{i}	232.92^{b}	161.54^{n}	23.63^{k}	3.45^{d}	68.05^{n}	0.37^{k}	1.17^{k}
CIP-396004.337	310.63^{e}	162.79^{def}	147.83^{e}	200.08^{fgh}	37.29^{efghi}	3.60^{cd}	70.25^{defghi}	0.53^{gh}	1.22^{hijk}
Mean	287.84	156.32	131.52	201.01	44.69	3.75	70.08	0.56	1.29
CV%	0.81	1.67	2.40	1.72	7.32	6.33	0.43	1.96	1.88
LSD	5.83	6.52	7.85	8.62	8.16	0.59	0.75	0.03	0.06

PV = Peak viscosity; HPV = Hot paste viscosity; BDV = Breakdown viscosity; CPV = Cool paste viscosity; SBV = Set back viscosity; PT = Peak time; Ptemp = Pasting temperature; n = 3 for AMC determination; n = 2 for pasting properties; SR = Stability ratio; SBR = Setback ratio.

CV = Coefficient of variation; LSD = Least significant difference**;** Mean separation at $P < 0.01$; Means followed by the same letter are not different.

Table 16 Pasting properties of starch isolated from 25 potato varieties grown at Merawi site during 2011 cropping season.

Variety	PV (RVU)	HPV (RVU)	BDV (RVU)	CV (RVU)	SBV (RVU)	PT (min.)	Ptemp (^{0}C)	SR	SBR
Menagesha	355.54^{b}	168.79^{e}	186.75^{b}	205.67^{h}	36.88^{hijklm}	3.88^{defgh}	70.35^{ghi}	0.48^{mn}	1.22^{ghijk}
Gera	284.21^{gh}	205.33^{a}	78.88^{lm}	251.67^{b}	46.33^{defgh}	5.10^{a}	71.73^{bcd}	0.73^{b}	1.23^{ghij}
Challa	259.92^{j}	175.96^{d}	83.96^{kl}	219.21^{fg}	43.25^{efghi}	4.17^{cd}	69.80^{ij}	0.68^{cd}	1.25^{fghi}
CIP-395096.2	211.33^{n}	139.33^{jkl}	72.00^{m}	192.50^{jk}	53.17^{cde}	3.62^{ghi}	70.95^{defg}	0.66^{de}	1.39^{bc}
Wochecha	244.79^{k}	158.46^{fg}	86.33^{kl}	214.58^{g}	56.13^{cd}	3.91^{defgh}	69.78^{ij}	0.65^{e}	1.36^{cd}
Awash	241.50^{kl}	131.04^{m}	110.46^{i}	171.33^{m}	40.29^{ghijk}	3.57^{hi}	69.93^{hij}	0.55^{ij}	1.31^{def}
Gorebella	277.79^{hi}	144.71^{ij}	133.08^{ef}	186.08^{kl}	41.38^{fghij}	3.60^{ghi}	69.38^{j}	0.52^{k}	1.29^{defg}
Zengena	229.83^{m}	131.08^{m}	98.75^{j}	162.29^{n}	31.21^{jklm}	3.70^{fgh}	71.25^{cdef}	0.57^{gh}	1.24^{fghi}
Hunde	345.50^{c}	197.21^{b}	148.29^{d}	228.79^{de}	31.58^{jklm}	4.22^{cd}	72.68^{a}	0.57^{gh}	1.16^{jk}
Agere	255.17^{j}	134.63^{lm}	120.54^{h}	164.25^{mn}	29.63^{klm}	3.73^{efgh}	69.30^{j}	0.53^{jk}	1.22^{ghijk}
Shenkolla	235.00^{lm}	137.00^{klm}	98.00^{j}	184.08^{kl}	47.08^{defgh}	3.96^{defg}	70.75^{efgh}	0.59^{g}	1.35^{cde}
Belete	273.88^{i}	141.83^{ijkl}	132.04^{ef}	172.00^{m}	30.17^{klm}	3.57^{hi}	70.98^{defg}	0.51^{lk}	1.21^{ghijk}
Ater Abeba	257.46^{j}	136.17^{klm}	121.29^{gh}	189.92^{jkl}	53.75^{cde}	3.26^{i}	69.58^{ij}	0.53^{jk}	1.40^{bc}
CIP-392640.524	277.21^{hi}	187.25^{c}	89.96^{k}	235.00^{cd}	47.75^{defg}	4.73^{b}	71.88^{abc}	0.68^{cd}	1.26^{fghi}
Gudene	290.58^{g}	161.79^{f}	128.79^{fg}	195.67^{ij}	33.88^{ijklm}	3.75^{efgh}	71.48^{bcde}	0.56^{hi}	1.20^{hijk}
Bulle	320.79^{e}	188.04^{c}	132.75^{ef}	239.38^{c}	51.33^{cdef}	4.11^{cde}	72.18^{ab}	0.59^{g}	1.28^{efgh}
Gabisa	336.50^{d}	152.63^{gh}	183.88^{b}	182.33^{l}	29.71^{klm}	3.73^{efgh}	69.90^{hij}	0.46^{n}	1.19^{ijk}
Tolcha	211.79^{n}	148.08^{hi}	63.71^{n}	215.00^{g}	66.92^{b}	4.17^{cd}	71.13^{cdefg}	0.70^{c}	1.46^{ab}
Aba Adamu	258.63^{j}	159.88^{f}	98.75^{j}	221.50^{efg}	61.63^{bc}	3.60^{ghi}	70.70^{efgh}	0.62^{f}	1.40^{bc}
Marachare	321.58^{e}	187.63^{c}	133.96^{ef}	226.38^{def}	38.75^{ghijkl}	4.40^{bc}	71.85^{abc}	0.58^{gh}	1.20^{hijk}
Sisay	302.83^{f}	143.38^{ijk}	159.46^{c}	171.67^{m}	28.29^{m}	3.65^{gh}	69.45^{j}	0.48^{mn}	1.19^{ijk}
Ararsa	218.75^{n}	177.71^{d}	41.04^{o}	263.04^{a}	85.33^{a}	4.68^{b}	71.40^{bcde}	0.81^{a}	1.48^{a}
Jalene	331.50^{d}	174.50^{de}	157.00^{c}	202.13^{hi}	27.63^{m}	4.07^{cdef}	70.70^{efgh}	0.53^{jk}	1.16^{jk}
Guasa	429.54^{a}	193.83^{bc}	235.71^{a}	222.25^{efg}	28.42^{lm}	3.78^{efgh}	70.88^{defg}	0.46^{n}	1.15^{k}
CIP-396004.337	275.88^{hi}	135.88^{lm}	140.00^{e}	170.63^{mn}	34.75^{ijklm}	3.62^{ghi}	70.43^{fghi}	0.50^{lm}	1.26^{fghi}
Mean	281.90	160.49	121.42	203.49	43.01	3.94	70.74	0.58	1.27
CV%	1.02	1.48	2.33	1.46	7.90	2.98	0.39	1.41	1.84
LSD	7.18	5.93	7.04	7.42	8.46	0.29	0.69	0.02	0.06

PV= Peak viscosity; HPV= Hot paste viscosity; BDV= Breakdown viscosity; CPV= Cool paste viscosity; SBV = Set back viscosity; PT= Peak time; Ptemp= Peak temperature; n = 3 for AMC determination; n = 2 for pasting properties; SR = Stability ratio; SBR = Setback ratio.

CV = Coefficient of variation; LSD = Least significant difference**;** Mean separation at $P < 0.01$; Means followed by the same letter are not different.

Table 17 Pasting properties of starch isolated from 25 potato varieties grown at Debretabor site during 2011 cropping season.

Variety	PV (RVU)	HPV (RVU)	BDV (RVU)	CV (RVU)	SBV (RVU)	PT (min.)	Ptemp (^{0}C)	SR	SBR
Menagesha	348.79^{gh}	151.50ij	197.29^{f}	187.58^{gh}	36.08^{hijk}	3.65^{ef}	67.48^{hi}	0.43^{lm}	1.24^{efg}
Gera	225.63^{q}	161.92^{g}	63.71^{p}	228.79^{c}	66.88^{a}	3.86^{de}	69.30^{b}	0.72^{bc}	1.41^{a}
Challa	300.96^{k}	175.21^{de}	125.75^{kl}	218.50^{d}	43.29^{efgh}	4.29^{c}	67.70^{ghi}	0.58^{efg}	1.25^{defg}
CIP-395096.2	366.96^{e}	181.38^{cd}	185.58^{gh}	219.38^{d}	38.00^{ghi}	3.62^{ef}	68.60^{cdef}	0.50^{hi}	1.21^{gh}
Wochecha	236.79^{p}	136.08^{lm}	100.71^{m}	184.00^{ghij}	47.92^{def}	3.58^{ef}	67.48^{hi}	0.57^{fg}	1.36^{b}
Awash	352.33^{fg}	141.96^{kl}	210.38^{e}	175.75^{j}	33.79^{ijkl}	3.27^{ghi}	66.30^{j}	0.40^{n}	1.24^{efg}
Gorebella	292.88^{l}	140.58^{kl}	152.29^{j}	181.50^{hij}	40.92^{fghi}	3.62^{ef}	66.28^{j}	0.48^{ij}	1.29^{cd}
Zengena	284.29^{m}	206.88^{a}	77.42^{o}	265.29^{a}	58.42^{bc}	4.95^{b}	69.23^{bc}	0.73^{b}	1.28^{cde}
Hunde	291.67^{l}	202.83^{ab}	88.83^{n}	247.29^{b}	44.46^{efg}	4.42^{c}	70.13^{a}	0.70^{c}	1.22^{fgh}
Agere	271.71^{n}	165.38^{fg}	106.33^{m}	201.54^{ef}	36.17^{hijk}	4.53^{c}	66.28^{j}	0.62^{d}	1.22^{fgh}
Shenkolla	317.04^{j}	186.58^{c}	130.46^{k}	231.33^{c}	44.75^{efg}	4.51^{c}	68.30^{efg}	0.59^{def}	1.24^{efg}
Belete	252.21^{o}	151.96^{hij}	100.25^{m}	192.67^{fg}	40.71^{fghi}	3.93^{d}	69.45^{b}	0.61^{de}	1.27^{cdef}
Ater Abeba	324.29^{i}	160.04^{gh}	164.25^{i}	209.42^{e}	48.38^{de}	3.62^{ef}	67.08^{i}	0.50^{hi}	1.31^{c}
CIP-392640.524	268.96^{n}	195.79^{b}	73.17^{o}	254.88^{b}	59.08^{bc}	5.23^{a}	69.10^{bcd}	0.73^{b}	1.31^{c}
Gudene	342.42^{h}	150.58^{ij}	191.83^{fg}	177.46^{ij}	26.88^{l}	3.47^{fgh}	68.10^{fgh}	0.44^{kl}	1.18^{h}
Bulle	302.63^{k}	145.08^{jk}	157.54^{ij}	186.21^{ghi}	41.13^{efghi}	3.83^{de}	67.98^{fgh}	0.48^{ij}	1.28^{cde}
Gabisa	537.58^{a}	174.21^{de}	363.38^{a}	207.88^{e}	33.67^{ijkl}	3.14^{i}	67.33^{i}	0.33^{p}	1.20^{gh}
Tolcha	357.38^{f}	178.58^{cde}	178.79^{h}	231.46^{c}	52.88^{cd}	4.35^{c}	68.53^{def}	0.50^{hi}	1.30^{c}
Aba Adamu	246.67^{o}	128.33^{m}	118.33^{l}	182.63^{hij}	54.29^{cd}	3.24^{hi}	68.10^{fgh}	0.52^{h}	1.43^{a}
Marachare	281.29^{m}	157.58^{ghi}	123.71^{kl}	192.88^{fg}	35.29^{ijk}	3.73^{def}	69.45^{b}	0.56^{g}	1.22^{fgh}
Sisay	423.83^{c}	173.42^{def}	250.42^{c}	203.88^{e}	30.46^{jkl}	3.60^{ef}	68.10^{fgh}	0.41^{mn}	1.18^{h}
Ararsa	267.50^{n}	205.58^{a}	61.92^{p}	270.51^{a}	64.92^{ab}	5.18^{ab}	68.93^{bcde}	0.77^{a}	1.32^{bc}
Jalene	394.21^{d}	172.46^{ef}	221.75^{d}	202.25^{e}	29.79^{kl}	3.50^{fgh}	67.15^{i}	0.43^{lm}	1.18^{h}
Guasa	479.79^{b}	170.46^{ef}	309.33^{b}	199.92^{ef}	29.46^{kl}	3.16^{i}	67.28^{i}	0.36^{o}	1.18^{h}
CIP-396004.337	369.29^{e}	171.42^{ef}	197.88^{f}	209.21^{e}	37.79^{ghij}	3.52^{fg}	68.08^{fgh}	0.47^{jk}	1.22^{fgh}
Mean	325.48	167.43	158.05	210.45	43.02	3.91	68.05	0.54	1.26
CV%	0.71	1.67	1.90	1.44	5.52	2.26	0.31	1.72	1.28
LSD	5.72	6.99	7.48	7.55	5.92	0.22	0.64	0.02	0.04

PV= Peak viscosity; HPV= Hot paste viscosity; BDV= Breakdown viscosity; CPV= Cool paste viscosity; SBV = Set back viscosity; PT= Peak time; Ptemp= Peak temperature; n = 3 for AMC determination; n = 2 for pasting properties; SR = Stability ratio; SBR = Setback ratio.

CV = Coefficient of variation; LSD = Least significant difference**;** Mean separation at $P < 0.01$; Means followed by the same letter are not different.

Table 18 Combined mean results of AMC, APC and pasting properties of starches isolated from 25 potato varieties grown at Adet, Merawi and Debretabor site, 2011 cropping season.

Variety	AMC (%)	APC (%)	PV (RVU)	HPV (RVU)	BD (RVU)	CV (RVU)	SB (RVU)	PT (min.)	Ptemp (^{o}C)	SR	SBR
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}	0.46^{l}	1.24^{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}	0.71^{b}	1.34^{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}	0.63^{d}	1.24^{ghi}
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}	0.59^{ef}	1.31^{de}
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}	0.60^{e}	1.37^{ab}
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}	0.50^{jk}	1.27^{efg}
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}	0.50^{jk}	1.30^{e}
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}	0.63^{d}	1.25^{fgh}
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}	0. 67^{c}	1.23^{hij}
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}	0.59^{efg}	1.2^{2hij}
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}	0.64^{d}	1.39^{a}
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}	0.58^{fgh}	1.26^{fgh}
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}	0.51^{j}	1.38^{a}
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}	0.70^{b}	1.30^{e}
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}	0.49^{k}	1.20^{ijk}
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}	0.56^{h}	1.28^{ef}
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}	0.41^{n}	1.20^{ijk}
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}	0.57^{gh}	1.33^{cd}
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}	0.54^{i}	1.36^{abc}
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}	0.57^{gh}	1.23^{hij}
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}	0.42^{m}	1.19^{jk}
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}	0.76^{a}	1.38^{a}
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}	0.45^{l}	1.17^{kl}
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}	0.40^{n}	1.16^{l}
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}	0.50^{jk}	1.24^{ghi}
Mean	25.56	74.40	298.41	161.41	137.00	204.98	43.57	3.87	69.62	0.56	1.27
CV%	5.11	1.93	0.87	1.56	2.11	1.50	7.26	4.20	0.40	1.68	1.77
LSD	1.45	1.59	3.46	3.58	4.12	4.34	4.19	0.22	0.38	0.01	0.03

AMC= Amylose content; APC= Amylopectin content; PV= Peak viscosity; HPV= Hot paste viscosity; BDV= Breakdown viscosity; CPV= Cool paste viscosity; SBV = Set back viscosity; PT= Peak time; Ptemp= Peak temperature; SR = Stability ratio; SBR = Setback ratio.

CV = Coefficient of variation; LSD = Least significant difference**;** Mean separation at $P < 0.01$; Means followed by the same letter are not different.

Table 19 Correlations among starch pasting properties, amylose and amylopectin content of 25 potato varieties tested at three distinct environments in Amhara region, 2011.

Parameters	PV	HPV	BD	CPV	SB	PT	Ptemp	AMC	APC
PV									
HPV	0.30**								
BD	0.94**	-0.03ns							
CV	-0.06ns	0.87**	-0.36**						
SB	-0.59**	0.14ns	0.66**	0.61**					
PT	-0.27**	0.66**	-0.51**	0.70**	0.35**				
Ptemp	-0.37**	0.22**	-0.46**	0.29**	0.24**	0.29**			
AMC	-0.40**	0.24**	-0.51**	0.51**	0.64**	0.34**	0.20*		
APC	0.40**	-0.24**	0.51**	-0.51**	-0.64**	-0.34**	-0.20*	-1.00**	

PV = peak viscosity; HPV= hot paste viscosity; BD = breakdown; CPV = cool paste viscosity; PT = pasting time; Ptemp = pasting temperature; AMC = amylose content; APC = amylopectin content

ns = not significant; * = significant ($P < 0.05$); ** = highly significant ($P < 0.01$)

Table 20 Results of summary of combined analysis of variance of AM and APC content of the 25 varieties across the three locations in Amhara Region during the year 2011.

AM				
Source of variation	df	SS	MS	Pr > F
Total	224	2672.777		
Loc	2	129.531	64.765	**
Block in Loc	6	5.091	0.848	ns
Genotype	24	1816.882	75.703	**
Genotype by Loc	48	475.848	9.914	**
Error	144	245.425	1.704	
Grand mean	25.51			
CV	5.11			
APC				
Source of variation	df	SS	MS	Pr > F
Total	224	2628.456		
Loc	2	108.576	54.288	**
Block in Loc	6	6.394	1.066	ns
Genotype	24	1740.859	72.536	**
Genotype by Loc	48	475.519	9.907	**
Error	144	297.109	2.063	
Grand mean	74.49			
CV%	1.93			

Table 21 Results of combined analysis of variance of pasting parameters of the 25 varieties across the three locations in Amhara Region during the year 2011.

PV				
Source of variation	df	SS	MS	Pr > F
Total	149	603461.582		
Loc	2	55865.575	27932.787	**
Block in Loc	3	16.160	5.387	ns
Genotype	24	383943.215.	15997.634	**
Genotype by Loc	48	163179.579	3399.575	**
Error	72	257.053	6.348	
Grand mean	298.41			
CV	0.84			
HPV				
Source of variation	df	SS	MS	Pr > F
Total	149	65451.325		
Loc	2	3152.410	1576.205	**
Block in Loc	3	25.047	8.349	ns
Genotype	24	29196.518	1216.522	**
Genotype by Loc	48	32588.624	678.930	**
Error	72	488.726	6.788	
Grand mean	161.41			
CV%	1.61			
BD				
Source of variation	df	SS	MS	Pr > F
Total	149	549958.890		
Loc	2	35805.262	17902.631	**
Block in Loc	3	6.215	2.072	ns
Genotype	24	403428.106	16809.504	**
Genotype by Loc	48	110072.984	2293.187	**
Error	72	646.323	8.977	
Grand mean	137.00			
CV%	2.19			

Table 21 (Continued)

CV				
Source of variation	Df	SS	MS	Pr > F
Total	149	103069.895		
Loc	2	2393.642	1196.821	**
Block in Loc	3	14.855	4.952	ns
Genotype	24	55401.436	2308.393	**
Genotype by Loc	48	44539.830	927.913	**
Error	72	720.133	10.002	
Grand mean	204.98			
CV	1.54			
SB				
Source of variation	Df	SS	MS	Pr > F
Total	149	26213.690		
Loc	2	93.925	46.962	**
Block in Loc	3	7.868	2.623	ns
Genotype	24	17581.763	732.573	**
Genotype by Loc	48	7860.818	163.767	**
Error	72	669.317	9.296	
Grand mean	43.57			
CV%	7.00			
PT				
Source of variation	df	SS	MS	Pr > F
Total	149	37.234		
Loc	2	1.030	0.515	**
Block in Loc	3	0.130	0.043	ns
Genotype	24	22.655	0.944	**
Genotype by Loc	48	11.550	0.241	**
Error	72	1.868	0.026	
Grand mean	3.87			
CV%	4.16			

Table 21 (Continued)

Ptemp				
Source of variation	Df	SS	MS	Pr > F
Total	149	346.594		
Loc	2	192.323	96.162	**
Block in Loc	3	0.658	0.219	ns
Genotype	24	117.399	4.892	**
Genotype by Loc	48	30.588	0.637	**
Error	72	5.626	0.078	
Grand mean	69.63			
CV	0.40			
SR				
Source of variation	Df	SS	MS	Pr > F
Total	149	1.755		
Loc	2	0.047	0.024	**
Block in Loc	3	0.00	0.000	ns
Genotype	24	1.364	0.057	**
Genotype by Loc	48	0.337	0.007	**
Error	72	0.007	0.000	
Grand mean	0.56			
CV%	1.70			
SBR				
Source of variation	df	SS	MS	Pr > F
Total	149	1.130		
Loc	2	0.020	0.010	**
Block in Loc	3	0.001	0.000	ns
Genotype	24	0.717	0.030	**
Genotype by Loc	48	0.358	0.007	**
Error	72	0.033	0.000	
Grand mean	1.27			
CV%	1.69			

Experiment- V

Phenotypic diversity analysis within cultivated potato (*solanum tuberosum* l.) in Ethiopia at three distinct locations based on morphological characteristics

Results and discussion

Analysis of variance of quantitative characteristics

Results of the separate analysis of variance of the 11 quantitative characteristics at each location are indicated in Tables 22, 23and 24. This ANOVA result revealed that the 25 potato varieties differed significantly ($P < 0.01$) in all the characters considered indicating the presence of notable genetic variability among them.

Accordingly, days to flowering at Merawi, Adet and Debretabor ranged from 27 for Awash, Challa and Ater Abeba to 39 days for Agere (Table 22), from 30 days for Hunde to 46 days for Jalene and Guasa (Table 24), and from 30 days for Wochecha to 44 days for Belete, Aba Adamu, Jalene and Guasa (Table 26), respectively. Likewise, days to maturity of these varieties ranged from 88 days for Sisay to 113 days for Menagesha at Merawi, from 84 days for Awash to 104 days for Menagesha at Adet, and from 95 days for Awash to 112 days at Debretabor. The lowest and highest value of leaf length (LL) at Merawi and Adet were recorded from Zengena and Challa, respectively. The lowest length at both sites was recorded from Zengena while the highest length was recorded from Challa (Tables 22 and 23). At Debretabor LL ranged between 21.5 cm for Wochecha and 27 cm for the variety Challa. Leaflet length (LLL) varied from 5.9 cm (Menagesha) to 8.7 cm (Gabisa), from 6.49 cm (Zengena) to 8.92 cm (Gabisa), and from 6.3 cm (Ararsa) to 8.1 cm (Gabisa) at Adet, Merawi and Debretabor, respectively (Tables 22, 24 and 26). The varieties leaflet width (LLW) Merawi, Adet and Debretabor sites ranged from 4 cm (for Agere) to 6.1 cm (Gabisa), 3.68 cm (Zengena) to 5.47 cm (Sisay), and 3.7 cm

(Bulle) to 5.6 cm (Aba Adamu), respectively (Tables 22, 24 and 26). Significant variation in leaflet length to width ratio (LLWR) was also evident among the varieties and it ranged from 1.3 (Hunde) to 1.8 (Agere) at Merawi, 1.47 (Hunde) to 1.96 (Ararsa) at Adet, and 1.3 (Awash) to 1.8 for Agere (Tables 22, 24 and 26). The number of main stem per plant (SN) of varieties fell between 2.5 for Wochecha to 6.8 for gudene at Merawi, 2.5 (for Tolcha, Wochecha and Belete) to 8 (Gudene) at Adet, and 1.5 for Wochecha to 3 for Ater Abeba at Debretabor site (Tables 22, 24 and 26). The tallest plant height (PH) at Merawi (73.2 cm), Adet (92.7 cm), and Debretabor (56.8 cm) was recorded from the same variety Zengena. On the Other hand, the shortest PH value at Merawi (40.5 cm), Adet (42 cm), and Debretabor (27.5 cm) were recorded from the variety Tolcha and Wochecha, respectively (Tables 22, 24 and 26). At Merawi and Debretabor the largest number of tubers per plant (TN) of 19.2 was obtained from the farmer's cultivar Ater Abeba while from Marachare at Adet (Tables 22, 24 and 26). The heaviest tuber weight (TW) at Merawi and Adet was produced by the variety Belete while at Debretabor it was produced by Shenkolla. In contrast the lowest weight tubers at all the three sites were harvested from the farmer's Ater Abeba (Tables 22, 24 and 26). The highest marketable tuber yield (MTY) of 48.03 $t.ha^{-1}$ at Merawi, 38.52 $t.h^{-1}$ at Adet, and 39.96 $t.ha^{-1}$ at Debretabor were obtained from Guasa, Belet and Gorebella, respectively (Tables 22, 24 and 26). On the contrary, the lowest MTY at all the three sites was harvested from the earliest in maturity date and umbrella canopy leaf arrangement having Awash (Tables 22, 23 and 24). Arslanoglu *et al*. (2011) also reported similar genetic variability in plant height, main stem number and maturity among 146 local potato genotypes collected from Turkey in their morphological characterization study paper. Similarly, in a genetic diversity analysis of 30 potato varieties grown Bangladesh based on morphological characteristic Haydar *et al.* (2007) reported variability of genotypes over their morphological traits and noted the significant contribution of plant height, number of leaves per plant, tuber number per plant, tuber weight per plant (tuber yield), and fresh weight per plant towards total divergence among the genotypes. Mondal *et al.* (2007) in their genetic diversity study of potato genotypes based on morphological characteristics reported

observation of significant variation among 31 potato genotypes over days to emergence, plant height, number stems per plant, number of tubers per plant, tuber weight per plant and dry-matter content. Tairo *et al*. (2008) reported significant differences in number of roots per plant, weight of roots, fresh weight per plant and dry matter content of 136 sweet potato germplasm collection evaluated in Tanzania for two season using morphological characteristics. Similar phenotypic variability was reported in pepper (Yayeh and Zeven, 1997), sorghum (Amsalu and Endashaw, 2000), sweet potato (Tairo *et al*., 2008), hazelnut (Ferreira *et al*., 2010). Results of the current study are in agreement with reports of these studies carried on different crops including potato by different authors. Moreover, the inherent problem of the morphological characters related to their high genotype × environment variability was noted in the current study from low consistency of these polygenically controlled quantitative characteristics and thus corroborates with the earlier reports that quantitative characteristic are poor descriptors to typifying varieties. The effects of climatic factors on these traits was clearly noted from sites mean index for overall days to flowering, days to maturity, stem number, plant height, tuber weight and marketable tuber yield. Early flowering and maturity dates were observed in warmer sites that the cool Debretabor site. Merawi and Debretabor sites with even a week and more day extension of maturity time varieties resulted in higher marketable tuber yield as expected. Hawkes (1990) described potato as a phenotypically plastic plant, a phenomenon in which a given genotype may develop different states for a character or group of characters in different environments due to genotype-environment interaction. The different values that a given variety hold for most of the quantitative characters considered in the diversity analysis when evaluated under different environemt clearly corroborates with the above report. Thus, such environmentally inconsistent characteritics are inappropriate to be used in genetic diversity analysis making morphological characterization procedure inefficient. Genetic diatance and dendrogram produced based on these 11 quantitative and 18 qualitative morphological characteristics recorded at each of the three locations have resulted in distinct genetic distance values and and cluster numbers and variety groups (Tables 23, 25 and 27 and

Figures 16, 17 and 18) specific to each locations. This pronounces the inefficiency of using all possible recorded morphological characteristics as some of them manifest different state under different set of environments. Thus, cautious selection of morphological description charactersistics that are consistent under any set of environmental conditions of test is vital.

Table 22 Mean results of 11 quantitative data of 25 varieties at Merawi experiment station, 2011.

Variety	DF(day)	DM(day)	LL (cm)	LLL(cm)	LLW(cm)	LLWR	SN(no.)	SH(cm)	TN(no.)	TW(g)	MTY(t.ha^{-1})
Menagesha	28.5^{ghij}	113.0^{a}	16.6^{fg}	5.9^{i}	4.2^{hij}	1.4^{bc}	3.7^{cdef}	53.0^{cdef}	8.7^{defgh}	76.5^{cdefg}	26.45^{fgh}
Gera	30.8^{defgh}	98.0^{fg}	21.2^{abc}	7.0^{defg}	5.0^{defg}	1.4^{bc}	3.8^{cdef}	64.0^{b}	12.2^{bcd}	61.5^{ghijk}	32.83^{def}
Challa	27.2^{ij}	102.0^{bcdefg}	23.1^{a}	8.2^{ab}	5.6^{abc}	1.5^{bc}	3.5^{cdef}	66.0^{ab}	12.3^{bc}	74.0^{cdefgh}	37.96^{bcde}
CIP-395096.2	30.8^{defgh}	106.3^{abcde}	17.8^{def}	6.6^{efghi}	4.8^{efgh}	1.4^{bc}	3.8^{cdef}	54.1^{cdef}	10.5^{bcdef}	65.7^{fghij}	28.06^{fg}
Wochecha	30.5^{defgh}	105.2^{bcdef}	19.1^{cde}	7.1^{def}	4.9^{defg}	1.4^{bc}	2.5^{f}	40.5^{h}	6.3^{gh}	84.3^{bcde}	20.39^{ghi}
Awash	28.3^{ghij}	88.8^{i}	16.9^{ef}	6.7^{efghi}	4.9^{defg}	1.4^{bc}	3.3^{cdef}	41.5^{gh}	7.8^{fgh}	52.2^{jkl}	17.16^{hi}
Gorebella	27.0^{j}	104.5^{bcdef}	18.5^{def}	6.7^{efghi}	4.8^{efgh}	1.4^{bc}	4.3^{bc}	67.6^{ab}	11.0^{bcdef}	95.5^{b}	42.76^{abc}
Zengena	31.0^{defg}	95.8^{gh}	14.6^{g}	6.2^{hi}	4.5^{fghij}	1.4^{bc}	4.2^{cd}	73.2^{a}	11.2^{bcdef}	65.8^{fghij}	29.84^{defg}
Hunde	27.5^{ij}	104.0^{bcdef}	20.0^{bcd}	7.3^{cde}	5.5^{bcd}	1.3^{c}	3.3^{cdef}	55.9^{cde}	13.3^{b}	71.2^{defghi}	39.47^{abcd}
Agere	39.2^{a}	109.3^{ab}	18.7^{def}	7.1^{def}	4.0^{j}	1.8^{a}	4.0^{cde}	53.7^{cdef}	12.8^{bc}	57.0^{hijkl}	24.95^{fgh}
Shenkolla	32.8^{cde}	100.0^{efg}	21.6^{ab}	7.2^{cde}	4.6^{efghi}	1.6^{b}	3.0^{cdef}	61.1^{bc}	8.0^{fgh}	90.3^{bc}	30.82^{def}
Belete	32.3^{cdef}	105.5^{bcde}	22.4^{a}	7.9^{bc}	5.1^{cdef}	1.6^{b}	3.0^{cdef}	60.2^{bcd}	10.3^{bcdef}	113.0^{a}	48.03^{a}
Ater Abeba	27.3^{ij}	102.2^{bcdefg}	18.6^{def}	6.0^{hi}	4.2^{hij}	1.4^{bc}	5.5^{b}	52.5^{def}	19.2^{a}	44.2^{l}	33.55^{cdef}
CIP-392640.524	31.8^{def}	100.5^{defg}	19.2^{bcde}	7.1^{def}	4.9^{defg}	1.4^{bc}	3.5^{cdef}	51.4^{ef}	7.8^{fgh}	83.8^{bcde}	27.92^{fg}
Gudene	33.3^{cd}	91.3^{hi}	18.2^{def}	6.8^{efgh}	5.1^{cdef}	1.3^{c}	6.8^{a}	60.9^{bc}	10.5^{bcdef}	61.5^{ghijk}	26.57^{fgh}
Bulle	31.2^{defg}	107.0^{abcde}	18.5^{def}	6.4^{fghi}	4.4^{ghij}	1.5^{bc}	4.0^{cde}	54.8^{cdef}	10.3^{bcdef}	61.5^{ghijk}	24.56^{fgh}
Gabisa	33.0^{cd}	88.8^{i}	19.4^{bcd}	8.7^{a}	6.1^{a}	1.4^{bc}	3.2^{cdef}	51.5^{ef}	11.7^{bcde}	62.5^{ghijk}	31.68^{def}
Tolcha	30.0^{efghi}	106.3^{abcde}	19.9^{bcd}	7.2^{cde}	4.9^{defg}	1.5^{bc}	2.7^{ef}	41.6^{gh}	5.7^{h}	76.5^{cdefg}	14.83^{i}
Aba Adamu	35.0^{bc}	100.8^{cdefg}	19.6^{bcd}	8.2^{ab}	6.0^{ab}	1.4^{bc}	2.8^{def}	48.2^{efg}	8.5^{efgh}	82.8^{bcde}	29.14^{efg}
Marachare	28.0^{hij}	106.3^{abcde}	19.9^{bcd}	7.7^{bcd}	5.5^{bcd}	1.4^{bc}	3.3^{cdef}	51.0^{ef}	13.3^{b}	69.2^{efghij}	38.50^{bcde}
Sisay	29.7^{fghij}	87.7^{i}	18.4^{def}	7.2^{cde}	5.2^{cde}	1.4^{bc}	3.2^{cdef}	50.3^{ef}	12.3^{bc}	48.5^{kl}	25.62^{fgh}
Ararsa	28.8^{ghij}	89.3^{hi}	22.4^{a}	6.3^{ghi}	4.1^{ij}	1.5^{bc}	4.3^{bc}	54.6^{cdef}	13.2^{b}	54.7^{ijkl}	28.90^{efg}
Jalene	36.8^{ab}	106.7^{abcde}	17.9^{def}	7.1^{def}	4.7^{efgh}	1.5^{bc}	4.0^{cde}	53.7^{cdef}	13.0^{b}	68.2^{efghij}	38.14^{bcde}
Guasa	36.0^{b}	108.2^{abc}	19.4^{bcd}	7.3^{cde}	5.0^{defg}	1.5^{bc}	3.5^{cdef}	53.3^{cdef}	12.5^{bc}	81.7^{bcdef}	43.25^{ab}
CIP-396004.337	31.0^{defg}	107.5^{abcd}	19.8^{bcd}	7.2^{cde}	5.2^{cde}	1.4^{bc}	3.5^{cdef}	47.3^{fgh}	9.3^{cdefg}	87.7^{bcd}	32.76^{def}
CV%	5.27	4.11	7.07	6.41	7.25	6.21	20.43	8.52	18.73	13.59	18.13
LSD	2.23	5.67	1.85	0.62	0.49	0.12	1.03	6.32	2.77	13.24	7.63

Table 23 Genetic distance between the 25 potato genotypes grown at Merawi based on 29 morphological characteristics.

Variety	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Menagesha																								
Gera	0.77																							
Challa	0.77	0.70																						
CIP-395096.2	0.52	0.77	0.77																					
Wochecha	0.77	0.76	0.76	0.77																				
Awash	0.78	0.78	0.78	0.78	0.78																			
Gorebella	0.67	0.77	0.77	0.67	0.77	0.78																		
Zengena	0.67	0.77	0.77	0.67	0.77	0.78	0.65																	
Hunde	0.77	0.60	0.70	0.77	0.76	0.78	0.77	0.77																
Agere	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87															
Shenkolla	0.77	0.67	0.70	0.77	0.76	0.78	0.77	0.77	0.67	0.87														
Belete	0.77	0.70	0.62	0.77	0.76	0.78	0.77	0.77	0.70	0.87	0.70													
Ater Abeba	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90												
CIP-392640.524	0.77	0.67	0.70	0.77	0.76	0.78	0.77	0.77	0.67	0.87	0.60	0.70	0.90											
Gudene	0.78	0.78	0.78	0.78	0.78	0.76	0.78	0.78	0.78	0.87	0.78	0.78	0.90	0.78										
Bulle	0.61	0.77	0.77	0.61	0.77	0.78	0.67	0.67	0.77	0.87	0.77	0.77	0.90	0.77	0.78									
Gabisa	0.77	0.66	0.70	0.77	0.76	0.78	0.77	0.77	0.66	0.87	0.67	0.70	0.90	0.67	0.78	0.77								
Tolcha	0.77	0.76	0.76	0.77	0.30	0.78	0.77	0.77	0.76	0.87	0.76	0.76	0.90	0.76	0.78	0.77	0.76							
Aba Adamu	0.77	0.66	0.70	0.77	0.76	0.78	0.77	0.77	0.66	0.87	0.67	0.70	0.90	0.67	0.78	0.77	0.57	0.76						
Marachare	0.77	0.60	0.70	0.77	0.76	0.78	0.77	0.77	0.47	0.87	0.67	0.70	0.90	0.67	0.78	0.77	0.66	0.76	0.66					
Sisay	0.78	0.78	0.78	0.78	0.78	0.63	0.78	0.78	0.78	0.87	0.78	0.78	0.90	0.78	0.76	0.78	0.78	0.78	0.78	0.78				
Ararsa	0.78	0.78	0.78	0.78	0.78	0.72	0.78	0.78	0.78	0.87	0.78	0.78	0.90	0.78	0.76	0.78	0.78	0.78	0.78	0.78	0.72			
Jalene	0.77	0.66	0.70	0.77	0.76	0.78	0.77	0.77	0.66	0.87	0.67	0.70	0.90	0.67	0.78	0.77	0.63	0.76	0.63	0.66	0.78	0.78		
Guasa	0.77	0.66	0.70	0.77	0.76	0.78	0.77	0.77	0.66	0.87	0.67	0.70	0.90	0.67	0.78	0.77	0.63	0.76	0.63	0.66	0.78	0.78	0.39	
CIP-396004.337	0.77	0.66	0.70	0.77	0.76	0.78	0.77	0.77	0.66	0.87	0.67	0.70	0.90	0.67	0.78	0.77	0.57	0.76	0.50	0.66	0.78	0.78	0.63	0.63

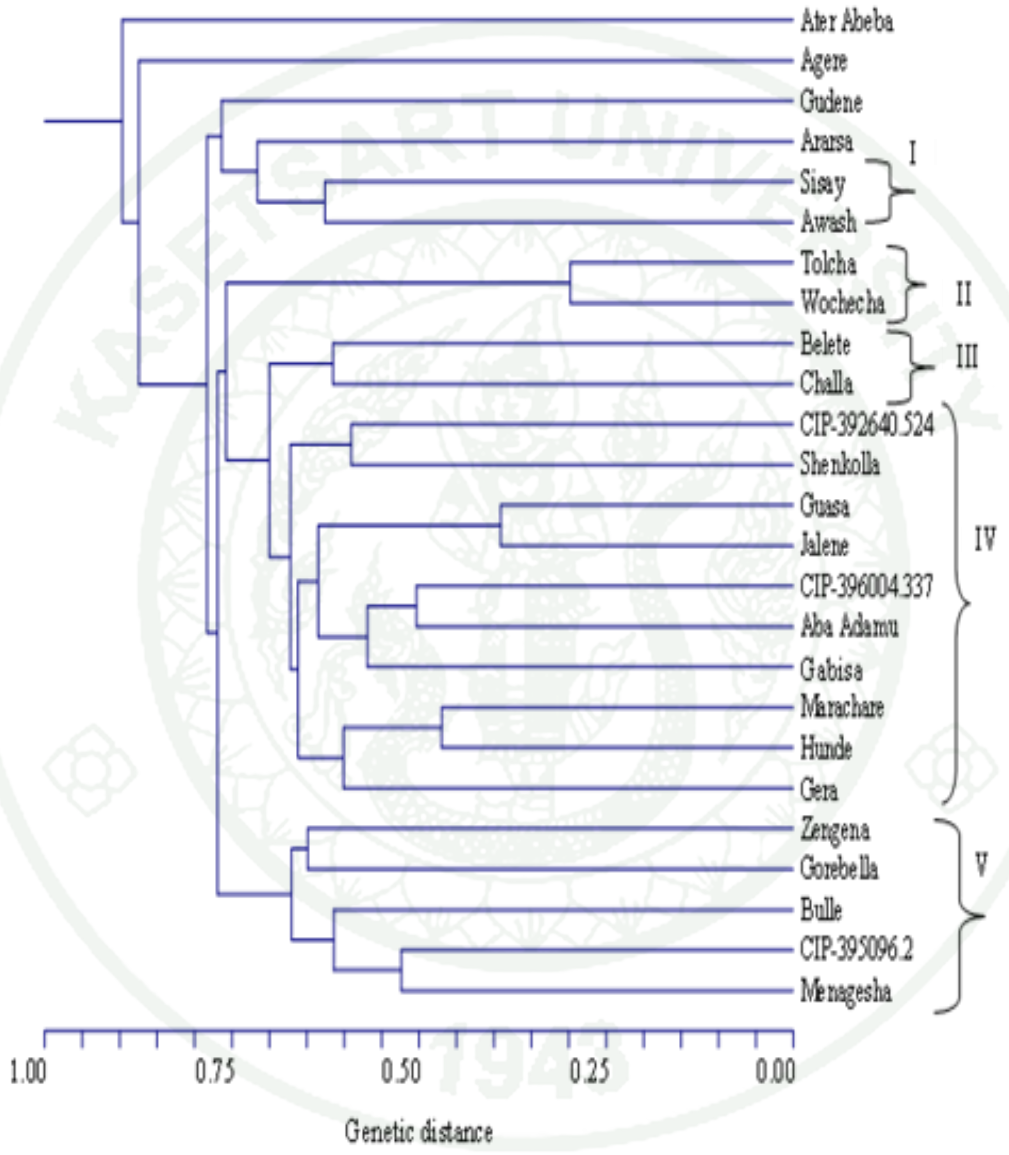

Figure 16 Dendrogram depicting the interrelationship between 25 potato genotypes grown at Merawi constructed based on 11 quantitative and 18 quantitative morphological characters using UPGMA using a 0.70 genetic distance as a cut-off point.

Table 24 Mean results of 11 quantitative data of 25 varieties at Adet experiment station, 2011.

Variety	DF(day)	DM(day)	LL (cm)	LLL(cm)	LLW(cm)	LLWR	SN(no.)	SH(cm)	TN(no.)	TW(g)	MTY(t.ha^{-1})
Menagesha	32.17^{gh}	104.00^{a}	22.65^{defg}	7.31^{ef}	4.21^{efgh}	1.75^{bcd}	3.8^{cdefg}	60.6^{efgh}	8.0^{i}	73.8^{abc}	24.49^{def}
Gera	33.67^{efg}	88.83^{ef}	24.99^{abcde}	7.89^{bcde}	4.64^{bcdef}	1.73^{bcd}	4.2^{cde}	64.5^{cdefg}	13.3^{cdef}	48.3^{fghi}	27.68^{cdef}
Challa	31.67^{hi}	98.33^{bc}	27.06^{a}	8.60^{abc}	5.10^{abcd}	1.69^{bcdef}	3.8^{cdefg}	71.6^{bcd}	12.8^{defg}	60.3^{bcdefgh}	32.41^{abc}
CIP-395096.2	35.50^{de}	100.33^{ab}	23.32^{bcdefg}	7.77^{bcde}	4.68^{bcdef}	1.66^{bcdef}	3.2^{efgh}	65.1^{cdef}	11.3^{efghi}	61.6^{bcdefg}	28.38^{cde}
Wochecha	33.83^{efg}	99.17^{b}	22.83^{defg}	7.51^{de}	4.50^{defg}	1.68^{bcdef}	2.5^{h}	44.9^{ij}	8.3^{hi}	58.3^{cdefgh}	20.32^{fg}
Awash	34.00^{efg}	83.67^{g}	21.67^{efg}	7.82^{bcde}	5.21^{abc}	1.50^{ef}	4.0^{cdef}	45.8^{ij}	9.7^{fghi}	48.9^{fghi}	16.81^{g}
Gorebella	31.67^{hi}	100.50^{ab}	22.57^{efg}	7.44^{ef}	4.83^{abcde}	1.54^{def}	4.7^{c}	72.3^{bc}	11.2^{efghi}	69.0^{bcd}	31.44^{abcd}
Zengena	35.67^{cde}	93.50^{d}	20.47^{g}	6.49^{f}	3.68^{h}	1.77^{abcd}	4.2^{cde}	92.7^{a}	11.7^{efghi}	56.8^{defgh}	26.23^{cdef}
Hunde	30.17^{i}	98.00^{bc}	23.02^{cdefg}	7.31^{ef}	4.98^{abcd}	1.47^{f}	3.0^{fgh}	56.4^{fgh}	14.3^{bcde}	45.6^{ghi}	25.86^{cdef}
Agere	40.17^{b}	104.17^{a}	21.35^{fg}	7.28^{ef}	3.89^{gh}	1.88^{ab}	4.3^{cd}	70.6^{bcd}	13.5^{bcdef}	45.8^{ghi}	22.50^{efg}
Shenkolla	33.67^{efg}	94.00^{cd}	26.26^{abc}	7.84^{bcde}	4.60^{cdef}	1.71^{bcde}	3.0^{fgh}	76.9^{b}	9.2^{ghi}	75.6^{ab}	27.08^{cdef}
Belete	34.33^{ef}	101.50^{ab}	25.96^{abcd}	8.01^{abcde}	4.82^{abcde}	1.66^{bcdef}	2.5^{h}	66.0^{cde}	11.0^{efghi}	85.1^{a}	36.00^{ab}
Ater Abeba	31.00^{hi}	99.33^{b}	22.27^{efg}	7.26^{ef}	4.47^{defg}	1.64^{def}	6.3^{b}	55.8^{gh}	16.8^{abc}	40.2^{i}	26.99^{cdef}
CIP-392640.524	34.33^{ef}	93.17^{de}	26.38^{ab}	7.51^{de}	4.08^{fgh}	1.69^{bcdef}	5.8^{b}	57.9^{efgh}	11.7^{efghi}	56.1^{defghi}	25.99^{cdef}
Gudene	36.33^{cd}	87.67^{f}	22.31^{efg}	7.63^{cde}	4.67^{bcdef}	1.64^{def}	8.0^{a}	66.7^{cde}	12.2^{efgh}	57.9^{defgh}	26.32^{cdef}
Bulle	32.83^{fgh}	101.50^{ab}	24.72^{abcdef}	7.59^{cde}	4.46^{defg}	1.86^{abc}	4.0^{cdef}	57.6^{efgh}	11.2^{efghi}	49.8^{efghi}	22.73^{efg}
Gabisa	34.00^{efg}	90.00^{def}	23.76^{abcdefg}	8.92^{a}	5.24^{abc}	1.71^{bcde}	3.2^{efgh}	52.3^{hi}	11.5^{efghi}	54.2^{defghi}	25.23^{cdef}
Tolcha	33.67^{efg}	98.33^{bc}	21.66^{efg}	7.49^{e}	4.59^{cdef}	1.64^{def}	2.5^{h}	42.0^{j}	8.0^{i}	64.0^{bcdef}	20.63^{fg}
Aba Adamu	37.50^{c}	99.17^{b}	22.77^{defg}	8.71^{ab}	5.35^{ab}	1.64^{def}	3.2^{efgh}	51.9^{hi}	10.2^{fghi}	65.6^{bcde}	27.8^{cdef}
Marachare	31.33^{hi}	99.50^{b}	24.31^{abcdef}	7.61^{cde}	4.82^{abcde}	1.59^{def}	3.5^{defgh}	51.8^{hi}	19.3^{a}	44.2^{hi}	32.43^{abc}
Sisay	35.67^{cde}	91.33^{def}	24.21^{abcdef}	8.55^{abcd}	5.47^{a}	1.57^{def}	2.8^{gh}	56.8^{fgh}	13.7^{bcdef}	48.3^{fghi}	26.22^{cdef}
Ararsa	32.33^{gh}	91.17^{def}	26.46^{ab}	7.82^{bcde}	4.04^{fgh}	1.96^{a}	4.5^{cd}	60.6^{efgh}	10.5^{efghi}	58.6^{cdefgh}	25.72^{cdef}
Jalene	45.67^{a}	98.17^{bc}	22.22^{efg}	7.68^{bcde}	4.57^{cdef}	1.68^{bcdef}	5.8^{b}	61.6^{efg}	16.7^{abcd}	49.2^{fghi}	31.14^{bcd}
Guasa	45.67^{a}	99.00^{b}	22.23^{efg}	7.79^{bcde}	4.41^{defg}	1.77^{abcd}	4.7^{c}	63.2^{defg}	17.3^{ab}	55.8^{defghi}	38.52^{a}
CIP-396004.337	34.50^{def}	98.00^{bc}	24.84^{abcde}	8.06^{abcde}	4.72^{bcdef}	1.71^{bcde}	4.7^{c}	60.2^{efgh}	12.0^{efghi}	67.5^{bcd}	31.76^{abcd}
CV%	3.27	2.74	8.00	7.55	8.57	7.44	15.54	8.51	18.88	15.70	15.61
LSD	1.55	3.60	2.57	0.80	0.54	0.17	0.91	7.07	3.14	12.28	5.79

Table 25 Genetic distance between the 25 potato genotypes grown at Adet based on 29 morphological characteristics.

Variety	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Menagesha																								
Gera	0.72																							
Challa	0.72	0.62																						
CIP-395096.2	0.64	0.72	0.72																					
Wochecha	0.74	0.74	0.74	0.74																				
Awash	0.83	0.83	0.83	0.83	0.83																			
Gorebella	0.64	0.72	0.72	0.45	0.74	0.83																		
Zengena	0.90	0.90	0.90	0.90	0.90	0.90	0.90																	
Hunde	0.79	0.79	0.79	0.79	0.79	0.83	0.79	0.90																
Agere	0.81	0.81	0.81	0.81	0.81	0.83	0.81	0.90	0.81															
Shenkolla	0.69	0.72	0.72	0.69	0.74	0.83	0.69	0.90	0.79	0.81														
Belete	0.64	0.72	0.72	0.59	0.74	0.83	0.59	0.90	0.79	0.81	0.69													
Ater Abeba	0.79	0.79	0.79	0.79	0.79	0.83	0.79	0.90	0.70	0.81	0.79	0.79												
CIP-392640.524	0.72	0.67	0.67	0.72	0.74	0.83	0.72	0.90	0.79	0.81	0.72	0.72	0.79											
Gudene	0.72	0.56	0.62	0.72	0.74	0.83	0.72	0.90	0.79	0.81	0.72	0.72	0.79	0.67										
Bulle	0.72	0.67	0.67	0.72	0.74	0.83	0.72	0.90	0.79	0.81	0.72	0.72	0.79	0.60	0.67									
Gabisa	0.74	0.74	0.74	0.74	0.63	0.83	0.74	0.90	0.79	0.81	0.74	0.74	0.79	0.74	0.74	0.74								
Tolcha	0.74	0.74	0.74	0.74	0.35	0.83	0.74	0.90	0.79	0.81	0.74	0.74	0.79	0.74	0.74	0.74	0.63							
Aba Adamu	0.74	0.74	0.74	0.74	0.63	0.83	0.74	0.90	0.79	0.81	0.74	0.74	0.79	0.74	0.74	0.74	0.55	0.63						
Marachare	0.79	0.79	0.79	0.79	0.79	0.83	0.79	0.90	0.55	0.81	0.79	0.79	0.67	0.79	0.79	0.79	0.79	0.79	0.79					
Sisay	0.72	0.62	0.60	0.72	0.74	0.83	0.72	0.90	0.79	0.81	0.72	0.72	0.79	0.67	0.62	0.67	0.74	0.74	0.74	0.79				
Ararsa	0.72	0.67	0.67	0.72	0.74	0.83	0.72	0.90	0.79	0.81	0.72	0.72	0.79	0.64	0.67	0.64	0.74	0.74	0.74	0.79	0.67			
Jalene	0.81	0.81	0.81	0.81	0.81	0.83	0.81	0.90	0.81	0.72	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81		
Guasa	0.81	0.81	0.81	0.81	0.81	0.83	0.81	0.90	0.81	0.72	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.47	
CIP-396004.337	0.72	0.62	0.56	0.72	0.74	0.83	0.72	0.90	0.79	0.81	0.72	0.72	0.79	0.67	0.62	0.67	0.74	0.74	0.74	0.79	0.60	0.67	0.81	0.81

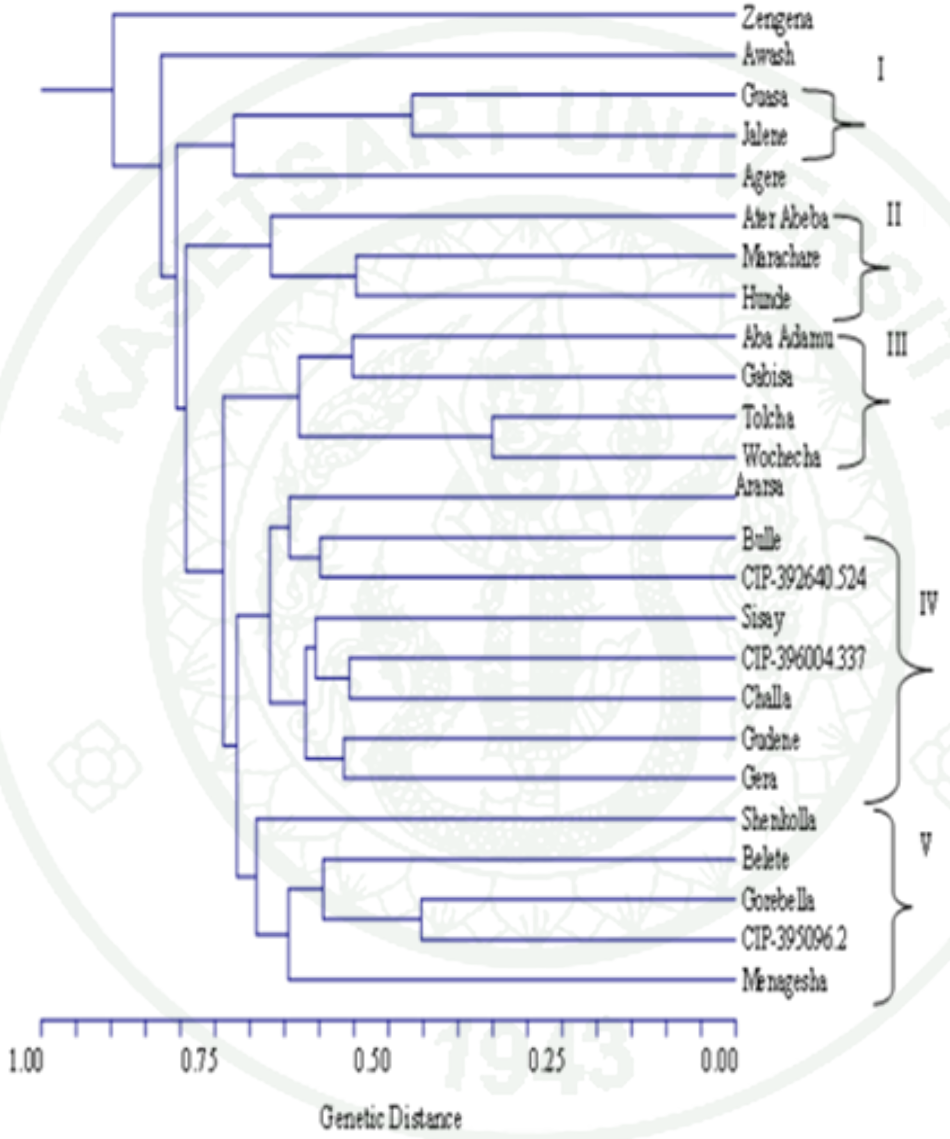

Figure 17 Dendrogram depicting the interrelationship between 25 potato genotypes grown at Adet constructed based on 11 quantitative and 18 quantitative morphological characters using UPGMA using a 0.70 genetic distance as a cut-off point.

Table 26 Mean results of 11 quantitative data of 25 varieties at Debretabor experiment station, 2011.

Variety	DF(day)	DM(day)	LL (cm)	LLL(cm)	LLW(cm)	LLWR	SN(no.)	SH(cm)	TN(no.)	TW(g)	MTY(t.ha^{-1})
Menagesha	34.7^{fgh}	106.5^{abc}	22.8^{cde}	6.7^{hij}	4.4^{fg}	1.5^{cd}	2.3^{abcd}	47.8^{bcd}	7.3^{ef}	82.7b^{cde}	25.69^{defg}
Gera	38.7^{cdef}	104.3^{abc}	23.7^{bcde}	6.9^{ghij}	4.6^{defg}	1.5^{cd}	2.3^{abcd}	49.7^{abc}	10.3^{de}	70.4^{defgh}	31.69^{abcde}
Challa	37.5^{def}	104.5^{abc}	27.0^{a}	7.7^{abcde}	4.6^{defg}	1.7^{ab}	2.3^{abcd}	45.4^{bcdefg}	10.0^{de}	71.9^{defg}	31.80^{abcde}
CIP-395096.2	40.2^{abcde}	101.0^{abc}	22.2^{ed}	7.0^{efghi}	4.9^{cdef}	1.4^{de}	2.5^{abc}	46.8^{bcdef}	12.5^{abcd}	57.7^{fghij}	30.85^{bcde}
Wochecha	30.2^{h}	110.7^{a}	21.5^{e}	7.0^{efghi}	4.5^{efg}	1.6^{bc}	1.5^{d}	27.5^{j}	6.0^{f}	69.3^{efgh}	17.71^{g}
Awash	38.3^{cdef}	95.0^{c}	23.5^{bcde}	7.4^{bcdef}	5.5^{ab}	1.3^{e}	2.2^{abcd}	31.8^{ij}	9.2^{def}	61.3^{fghij}	17.53^{g}
Gorebella	42^{abcd}	106.3^{abc}	23.7^{bcde}	6.4^{ij}	4.6^{defg}	1.4^{de}	2.3^{abcd}	51.3^{abc}	10.5^{de}	93.5^{b}	39.96^{a}
Zengena	41.0^{abcd}	109.2^{a}	21.8^{e}	7.1^{defghi}	5.1^{abcd}	1.4^{de}	2.5^{abc}	56.8^{a}	10.7^{cde}	67.2^{efgh}	31.85^{abcde}
Hunde	37.3^{def}	106.0^{abc}	24.6^{bcd}	7.0^{efghi}	5.0^{bcde}	1.4^{de}	2.3^{abcd}	44.0^{cdefg}	15.0^{ab}	48.1^{ij}	30.29^{bcde}
Agere	41.2^{abcd}	110.0^{a}	23.4^{bcde}	7.7^{abcde}	4.2^{gh}	18^{a}	2.2^{abcd}	47.0^{bcdef}	15.7^{a}	47.5^{j}	26.95^{cdef}
Shenkolla	40.0^{abcde}	100.2^{abc}	27.0^{a}	7.3^{cdefg}	4.6^{defg}	1.6^{bc}	1.8^{bcd}	52.3^{ab}	6.3^{f}	111.5^{a}	32.07^{abcde}
Belete	44.2^{a}	107.0^{ab}	24.9^{abc}	7.9^{abc}	4.9^{cdef}	1.6^{bc}	2.3^{abcd}	52.8^{ab}	10.3^{de}	90.2^{bc}	37.52^{ab}
Ater Abeba	37.3^{def}	109.2^{a}	22.5^{ed}	6.4^{ij}	3.8^{h}	1.7^{ab}	3.0^{a}	43.7^{cdefg}	15.5^{a}	46.9^{j}	30.79^{bcde}
CIP-392640.524	38.5^{cdef}	107.5^{ab}	23.5^{bcde}	7.2^{cdefgh}	4.8^{cdef}	1.5^{cd}	1.7^{cd}	39.7^{efgh}	7.5^{ef}	74.2^{cdef}	23.36^{efg}
Gudene	43.0^{abc}	103.2^{abc}	22.2^{ed}	7.0^{efghi}	4.9^{cdef}	1.4^{de}	2.7^{ab}	49.3^{abc}	11.0^{cd}	60.6^{fghij}	27.18^{cdef}
Bulle	35.5^{efg}	100.5^{abc}	23.4^{bcde}	6.4^{ij}	3.7^{h}	1.7^{ab}	2.2^{abcd}	38.2^{ghi}	11.0^{cd}	53.3^{ghij}	24.27^{efg}
Gabisa	40.8^{abcd}	106.3^{abc}	24.5^{bcd}	8.1^{a}	5.5^{ab}	1.5^{cd}	2.0^{bcd}	43.9^{cdefg}	10.3^{de}	81.6^{bcde}	34.63^{abcd}
Tolcha	31.3^{gh}	109.2^{a}	23.6^{bcde}	7.0^{efghi}	4.5^{efg}	1.5^{cd}	1.7^{cd}	33.7^{hij}	6.7^{f}	82.2^{bcde}	20.16^{fg}
Aba Adamu	44.2^{a}	107.5^{ab}	23.8^{bcde}	8.1^{a}	5.6^{a}	1.5^{cd}	1.7^{cd}	40.4^{defgh}	10.3^{de}	70.1^{defgh}	26.95^{cdef}
Marachare	35.5^{efg}	102.8^{abc}	24.4^{bcd}	7.0^{efghi}	4.9^{cdef}	1.4^{de}	2.2^{abcd}	39.3^{fgh}	14.0^{abc}	52.8^{hij}	30.89^{bcde}
Sisay	38.8^{bcdef}	97.0^{bc}	25.4^{ab}	8.0^{ab}	5.5^{ab}	1.5^{cd}	2.0^{bcd}	40.5^{defgh}	12.5^{abcd}	60.6^{fghij}	30.74^{bcde}
Ararsa	38.8^{bcdef}	104.7^{abc}	25.2^{abc}	6.3^{j}	3.8^{h}	1.7^{ab}	2.3^{abcd}	46.4^{bcdef}	10.7^{cde}	60.9^{fghij}	26.92^{cdef}
Jalene	44.4^{a}	111.5^{a}	22.8^{cde}	7.9^{abc}	5.5^{abc}	1.5^{cd}	2.3^{abcd}	47.5^{bcde}	11.8^{bcd}	66.5^{efghi}	36.77^{ab}
Guasa	43.8^{ab}	109.5^{a}	21.6^{e}	7.8^{abcd}	5.1^{abcd}	1.5^{cd}	2.3^{abcd}	46.1^{bcdefg}	11.7^{cd}	68.1^{efgh}	35.11^{abc}
CIP-396004.337	35.5^{efg}	106.7^{abc}	23.7^{bcde}	6.9^{ghij}	4.7^{defg}	1.5^{cd}	2.0^{bcd}	45.6^{bcdefg}	9.2^{def}	88.4^{bcd}	34.43^{abcd}
Mean	38.92	105.45	23.70	7.20	4.75	1.53	2.19	44.29	10.64	69.43	29.44
CV%	7.44	6.23	5.55	5.60	6.64	5.69	22.88	10.11	18.49	15.42	17.15
LSD	3.94	8.95	1.79	0.55	0.43	0.12	0.68	6.32	2.68	14.60	6.88

Table 27 Genetic distance between the 25 potato genotypes grown at Debretabor based on 29 morphological characteristics.

Variety	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Menagesha																								
Gera	0.72																							
Challa	0.72	0.69																						
CIP-395096.2	0.72	0.61	0.69																					
Wochecha	0.88	0.88	0.88	0.88																				
Awash	0.82	0.82	0.82	0.82	0.88																			
Gorebella	0.72	0.61	0.69	0.56	0.88	0.82																		
Zengena	0.72	0.55	0.69	0.61	0.88	0.82	0.61																	
Hunde	0.72	0.69	0.65	0.69	0.88	0.82	0.69	0.69																
Agere	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95															
Shenkolla	0.77	0.77	0.77	0.77	0.88	0.82	0.77	0.77	0.77	0.95														
Belete	0.72	0.65	0.69	0.65	0.88	0.82	0.65	0.65	0.69	0.95	0.77													
Ater Abeba	0.79	0.79	0.79	0.79	0.88	0.82	0.79	0.79	0.79	0.95	0.79	0.79												
CIP-392640.524	0.69	0.72	0.72	0.72	0.88	0.82	0.72	0.72	0.72	0.95	0.77	0.72	0.79											
Gudene	0.72	0.50	0.69	0.61	0.88	0.82	0.61	0.55	0.69	0.95	0.77	0.65	0.79	0.72										
Bulle	0.79	0.79	0.79	0.79	0.88	0.82	0.79	0.79	0.79	0.95	0.79	0.79	0.69	0.79	0.79									
Gabisa	0.72	0.65	0.69	0.65	0.88	0.82	0.65	0.65	0.69	0.95	0.77	0.59	0.79	0.72	0.65	0.79								
Tolcha	0.88	0.88	0.88	0.88	0.36	0.88	0.88	0.88	0.88	0.95	0.88	0.88	0.88	0.88	0.88	0.88	0.88							
Aba Adamu	0.72	0.65	0.69	0.65	0.88	0.82	0.65	0.65	0.69	0.95	0.77	0.59	0.79	0.72	0.65	0.79	0.49	0.88						
Marachare	0.72	0.69	0.65	0.69	0.88	0.82	0.69	0.69	0.46	0.95	0.77	0.69	0.79	0.72	0.69	0.79	0.69	0.88	0.69					
Sisay	0.72	0.69	0.58	0.69	0.88	0.82	0.69	0.69	0.65	0.95	0.77	0.69	0.79	0.72	0.69	0.79	0.69	0.88	0.69	0.65				
Ararsa	0.79	0.79	0.79	0.79	0.88	0.82	0.79	0.79	0.79	0.95	0.79	0.79	0.69	0.79	0.79	0.62	0.79	0.88	0.79	0.79	0.79			
Jalene	0.72	0.65	0.69	0.65	0.88	0.82	0.65	0.65	0.69	0.95	0.77	0.55	0.79	0.72	0.65	0.79	0.59	0.88	0.59	0.69	0.69	0.79		
Guasa	0.72	0.65	0.69	0.65	0.88	0.82	0.65	0.65	0.69	0.95	0.77	0.55	0.79	0.72	0.65	0.79	0.59	0.88	0.59	0.69	0.69	0.79	0.37	
CIP-396004.337	0.72	0.65	0.69	0.65	0.88	0.82	0.65	0.65	0.69	0.95	0.77	0.59	0.79	0.72	0.65	0.79	0.55	0.88	0.55	0.69	0.69	0.79	0.59	0.59

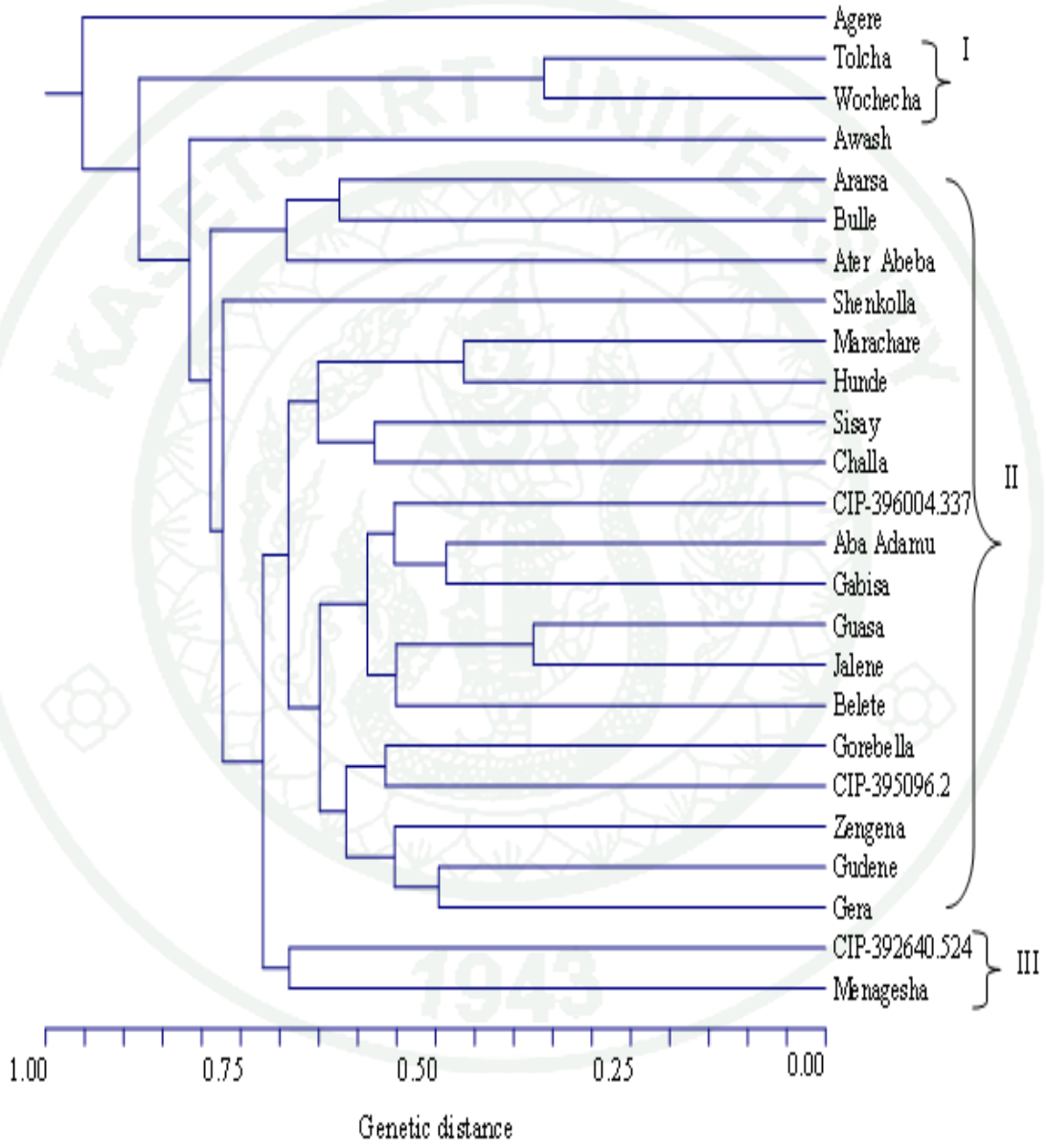

Figure 18 Dendrogram depicting the interrelationship between 25 potato genotypes grown at Debretabor constructed based on 11 quantitative and 18 quantitative morphological characters using UPGMA using a 0.70 genetic distance as a cut-off point.

Alternatively, carefully chosen stable phenotypic characteristics across environments will make this system of diversity analysis more reliable. Thus, only those 18 morphological characteristics that have consistent state under different set of environments were chosen as a common dta appoint for use across any set of environments and hence the genetic distance and cluster analysis results computed based on these characteristics were discussed in the current study.

Genetic distance analysis

The qualitative characteristics numeral data converted into binary matrix was subjected to computation of genetic distance using Euclidian distance analysis procedure. This distance matrix in turn used to construct a dendrogram which presents graphical association and divergence of the evaluated varieties. The lowest genetic distance of 0.27 or the highest similarity distance 0.73 was observed between Tolcha and Wochecha (Table 28). These varieties were commercial varieties introduced to Ethiopia in the 1980 following the poor cereal crop harvest period due to poor rainfall pattern as a rescue short cycled crop to be grown under irrigation. These varieties do display very similar growth habit, flower color, maturity days, leaf length, leaflet length, leaflet width and leaflet length to width ratios as shown in Tables 22, 23 and 24. Thus, these two varieties probably have closely related parents or sports. In the same way the second lowest genetic distance was observed between the two improved varieties Guasa and Jalene. These varieties are progenies of the same parental line and thus have common genetic background. They have very similar growth habit, flower color, leaf characteristics as a whole, flowering and maturity periods. This however is not the rule to the tetrasomic potato in which alleles occur in four dosage of allele and highly heterozygous crop unlike the diploids where only two alleles occur at a locus (Gebhardt, 2007). A practical evidence for this fact is clearly observed from the genetic distance of the variety Awash and Sisay that have common parent but differ in flower color, plant height, and tuber yield among others as seen in Tables 22, 23 and 24. Conversely, the highest genetic distance value of 0.72 was observed between the

farmer's cultivar Ater Abeba and improved variety Gorebella. Gorebella also had the next highest genetic distance value of 0.64 with the other farmer's cultivar Agere (Table 28).

Cluster analysis

The dendrogram produced from the distance matrix clustered the 25 varieties into three main clusters and one singleton (Figure 16). The first cluster (cluster I) contained only two varieties, Bulle and Challa. The second cluster (cluster II) the largest number of varieties, i.e. 18 varieties. And the third cluster (cluster III) contained four varieties, viz., Menagesha, CIP-395096.2, Gorebella and Belete. The separately placed singleton was Ater Abeba. Cluster II has four sub-clusters each containing different number of varieties. The first sub-cluster contained five varieties, viz., CIP-392640.524, Zengena, Marachare, Hunde and Awash. The second sub-cluster contained two varieties, i.e., Ararsa and Sisay. The third sub-cluster contained six varieties, namely, Guasa, Jalene, CIP-396004.337, Gabisa, Tolcha and Wochecha. The fourth sub-cluster possesses fourt varieties, viz., Agere, Aba Adamu, Gudene, Shenkolla and Gera.

Cluster I varieties characteristics

The two varieties in this cluster are identified by profuse flowering nature, medium duration of flowering, strongly dissected leaves, semi-stellate corolla shape, erect growth habit, obtuse leaf insertion and red-brown pigment midribs leaves, predominantly yellow tuber skin, purplish-black secondary tuber skin confined to their eyes.

Cluster II varieties characteristics

Sub-cluster I

The five varieties in the first sub-cluster are typified by erect growth habit, light green colored leaves and light purple flower color in all varieties, white acumen secondary flower color distribution on both surface, strongly dissected leaf, with brown pigment midribs, predominantly white colored tuber flesh and shallow eye in three of the four varieties in the group, Zengen missing the group in the leaf dissection, Awash in midribs pigmented group, and CIP-392640.524 deviating from the rest in eye depth and flesh color. As seen in the sub-cluster, these five varieties have two mini-clusters within the sub cluster. Phenotypically it is quite difficult to distinguish between Hunde and Marachare despite their registration by the National Variety Registration Office based on the different code number provided for these two varieties. On the other hand the variety Marachare and Awash have pedigree linkage to each other. Thus, the mini-sub grouping among these three varieties might probably be attributed to these underlying facts.

Sub-cluster II

The two varieties under this sub-cluster are characterized by erect growth habit, semi-stellate corolla shape, short flowering duration, obtuse leaf insertion, light green leaf color, oblong tuber shape, smooth skin type, tuber skin with secondary color confined to their eyes and predominantly of white fleshed tuber.

Sub-cluster III

The six varieties of this sub-cluster are identified with their medium leaf dissection, equal obtuse and acute leaf insertion and green and light green leaf color, semi-stellate corolla shape, white flower color, moderate degree of flowering except

CIP-396006.337 that is profuse, erect growth habit, and four with predominant white flesh color while two with white flesh color characteristics. The linkage within this sub-cluster clearly follows both pedigree proximity and phenotypic proximity as Guasa and Jalene are sister line varieties derived from the same parents. The closeness between Tolcha and Wochecha as described under the genetic distance part follows their phenotypic resemblance which sheds the light of doubt on their origin from either common parent or one is a sport of the other thus necessitating further investigation at DNA level with primers covering wide area of the genome. This condition observed between Tolcha and Wochecha and Marachare and Hunde in sub-cluster I of this same cluster II clearly follows the description made to the method of morphological characterization by Sneath and Sokal. These authors describe morphological characterization system as a method of classification that generally relies upon the overall phenotypic resemblance or differences judged from the phenotype of the organism without any implication as to their relationship by ancestry (Sneath and Sokal, 1973). In the same line van Eck (2007) emphasized the importance of realizing that phenotypic variation may not have a heritable basis at all for in many cases severe phenotypic differences are observed despite lacking any genetic variation. On the contrary we have noticed close linkage among some of genetically distant varieties which is against the hypothesis of van Eck (2007) but in favor of Sneath and Sokal (1973) morphological method of characterization. Presumably, the linkage observed between such genetically distant varieties might be results of breeder's favor for certain phenotypic of such as erect growth habit, smooth skin type and intermediate maturity classes.

Sub-cluster IV

Varieties in this sub-cluster are characterized by erect growth habit except the semi-erect Agere, obtuse leaf insertion in all of them, Agre and Shenkolla with light green color leaf while Gera, Aba Adamu and Gudene with green color leaf, white tuber skin color except Gudene with yellow color, flaky skin type except Agere with

heavy netted skin type and white tuber flesh color in all varieties of the group. Like in the earlier groups, Agere linked at distance pertaining to the differences it exhibited in growth habit, leaf color and tuber skin type among others.

Cluster III varieties characteristics

These varieties have erect growth habit plants with intense green color leaves, semi-stellate corolla shape, predominantly white flesh tubers, and purplish secondary skin color and equally divided obtuse and acute leaf inserted plants. Menagesha and CIP-395096.2 further associates more to each other by their scattered type secondary tuber skin color distribution.

The singleton Ater Abeba is characterized by its strongly dissected leaves, pentagonal corolla shape, light purple flower color, profuse flower with medium duration of stay, erect growth habit, obtuse leaf insertion, green leaf color, round tubers with purplish red tuber skin spectacled with white-cream secondary color, partially netted skin type, yellow-cream flesh and deep eye tubers.

Conclusion

The environmentally stable qualitative characteristics employed in this study grouped the studied 25 varieties into three main and one. Thus, morphological characterization could be efficiently used to characterize varieties if characteristics that are consistent across varying environments are carefully recorded. As most of these characteristics are controlled by simply heritable genetic factors, those varieties with desirable flesh color, tuber shape and eye depth could be used further in the potato improvement program of the country. The difference observed between Marachare and Hunde and between Tolcha and Wochecha implied the relevance of complementing phenotypic based diversity analysis with DNA fingerprinting techniques could help solve doubts emanating from phenotypic evaluation system.

Table 28 Genetic distance between the 25 potato genotypes grown at all the three sites based on 18 qualitative morphological characteristics.

Variety	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Menagesha																								
Gera	0.56																							
Challa	0.62	0.58																						
CIP-395096.2	0.49	0.58	0.61																					
Wochecha	0.60	0.49	0.56	0.53																				
Awash	0.67	0.53	0.59	0.53	0.51																			
Gorebella	0.59	0.64	0.51	0.43	0.56	0.49																		
Zengena	0.62	0.51	0.58	0.54	0.56	0.53	0.51																	
Hunde	0.62	0.61	0.61	0.54	0.56	0.41	0.58	0.58																
Agere	0.65	0.51	0.64	0.61	0.56	0.59	0.67	0.64	0.54															
Shenkolla	0.64	0.45	0.62	0.56	0.54	0.47	0.65	0.53	0.56	0.49														
Belete	0.61	0.56	0.53	0.49	0.54	0.64	0.45	0.59	0.65	0.56	0.58													
Ater Abeba	0.65	0.64	0.61	0.67	0.65	0.65	0.64	0.72	0.61	0.64	0.68	0.65												
CIP-392640.524	0.67	0.53	0.59	0.56	0.58	0.54	0.59	0.41	0.59	0.65	0.51	0.61	0.68											
Gudene	0.68	0.47	0.54	0.64	0.53	0.53	0.58	0.51	0.58	0.51	0.45	0.56	0.64	0.56										
Bulle	0.61	0.59	0.49	0.59	0.61	0.61	0.59	0.59	0.62	0.68	0.64	0.64	0.56	0.54	0.62									
Gabisa	0.68	0.58	0.61	0.67	0.45	0.56	0.61	0.54	0.58	0.51	0.49	0.53	0.69	0.59	0.47	0.62								
Tolcha	0.62	0.51	0.61	0.54	0.24	0.49	0.54	0.58	0.58	0.54	0.56	0.56	0.67	0.62	0.51	0.62	0.47							
Aba Adamu	0.59	0.43	0.61	0.54	0.45	0.53	0.58	0.54	0.61	0.43	0.41	0.53	0.67	0.59	0.38	0.65	0.47	0.43						
Marachare	0.54	0.49	0.56	0.62	0.54	0.51	0.65	0.53	0.45	0.59	0.54	0.67	0.65	0.54	0.53	0.54	0.59	0.56	0.56					
Sisay	0.64	0.53	0.49	0.59	0.58	0.54	0.62	0.65	0.56	0.56	0.47	0.51	0.62	0.58	0.56	0.61	0.56	0.62	0.53	0.58				
Ararsa	0.59	0.58	0.51	0.61	0.56	0.56	0.51	0.54	0.64	0.61	0.62	0.49	0.67	0.56	0.58	0.62	0.51	0.61	0.58	0.62	0.49			
Jalene	0.64	0.53	0.53	0.59	0.47	0.51	0.53	0.49	0.59	0.49	0.51	0.51	0.68	0.58	0.49	0.64	0.41	0.49	0.49	0.54	0.58	0.49		
Guasa	0.61	0.56	0.45	0.49	0.47	0.51	0.45	0.59	0.59	0.53	0.54	0.47	0.65	0.67	0.59	0.61	0.53	0.49	0.53	0.61	0.51	0.49	0.38	
CIP-396004.337	0.62	0.51	0.54	0.61	0.36	0.53	0.61	0.58	0.54	0.51	0.53	0.56	0.64	0.59	0.51	0.62	0.38	0.43	0.43	0.56	0.45	0.51	0.49	0.53

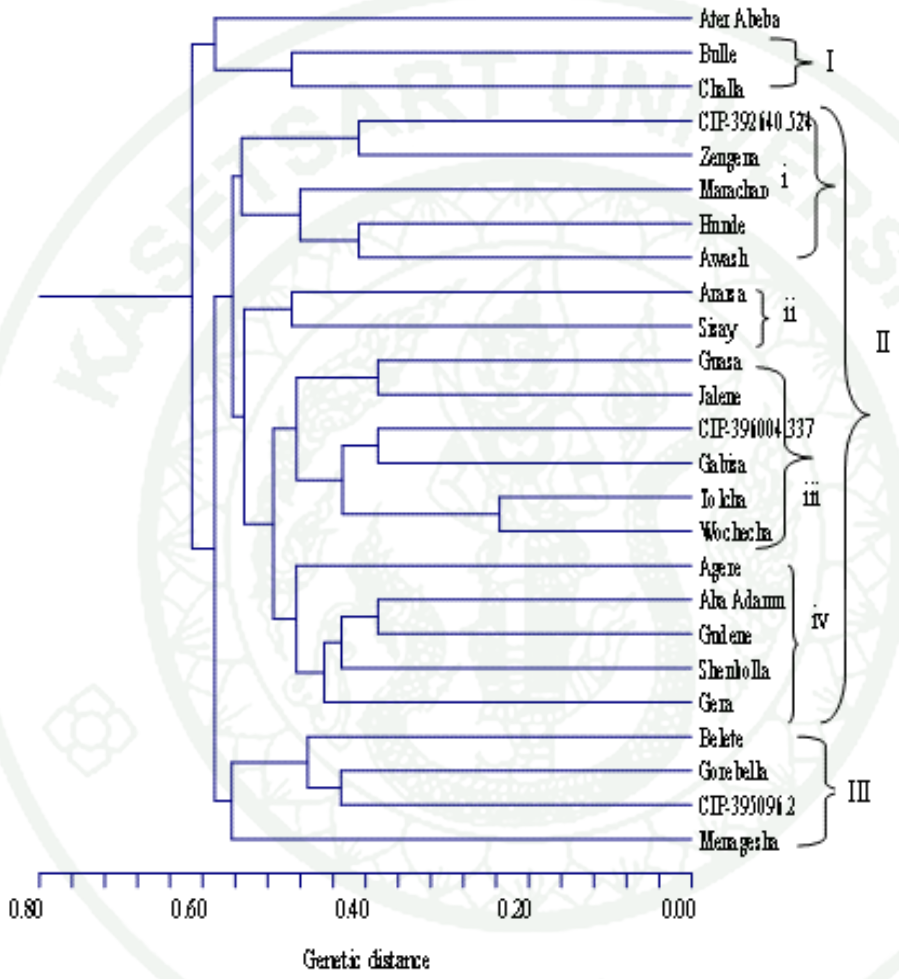

Figure 19 Dendrogram depicting the interrelationship between 25 potato genotypes constructed based on 18 qualitative morphological characteristics using UPGMA using a 0.58 genetic distance as a cut-off point.

Experiment- VI

Microsatellite analysis of genetic diversity within cultivated potato (*solanum tuberosum* l.) varieties in Ethiopia

Result and discussion

All the 11 set of primers chosen and designed from preliminary research report successfully amplified products. And as a result one and three amplified DNA products were observed at the various loci of any individual cultivar and a total of 17 amplified DNA different type products were observed in the 25 cultivars examined (Table 29). Only 17 of the total number of amplified products showed varying degree of polymorphism within the varieties, while the other 300 of them were present in all the varieties. PIC values varied from 0 to 0.34. The primer STCPKIN3 had the highest PIC value of 0.34, revealing 3 different alleles in our varieties (Table 30). As a rule because of the tetraploid nature of the widely cultivated potato varieties including all evaluated in present study, each cultivar can have any number from one to four different alleles for each of the single locus SSRs (McGregor *et al*., 1999; Kawchuk *et al*., 1996). Nevertheless, of the 11 microsatellite primers used in the current study, STS 1_2, STS 1_3, STGBSS, and STWIN12G, STRBCS3 and TF11 were single locus primers and amplified single locus microsatellites (Figure 20), while STIIKA, STINHWI, STCPKIN3 and STSNRA10 were multilocus primers and amplified multiple microsatellite (Figure 21) containing loci (Provan *et. al*., 1996; McGregor *et al*., 1999). Accordingly, STS1_3, STWIN12G, STGBSS, STRBCS3 and TF11 microsatellite primers in this study gave monomorphic bands in all the 25 varieties tested. Although this result is different from earlier research reports made by MacGregor *et al*., (1999) and Yi *et al.*, (2010) for the same primer pairs amplicon, it is in agreement with contrasting result observed by Schneider and Douches (1997) who found only two alleles for the GBSS gene in 39 tetraploid potato cultivars and one *S. phureja* breeding lines, while Provan *et al*. (1996a) found 6 alleles in 18 cultivars for the same primer. Likewise, Eduard (1997) found monomorphic bands for the most

polymorphic locus reported by Provan *et al*. (1996a) to producing 19 alleles in 18 cultivars. Presumably, this could result from the nature of the variability of working population that the different authors with contrasting reports had examined in their respective studies. Ghislain *et al*. (2004) have also reported similar result of low frequency of polymorphism by SSRs primer pairs which have their repeat sequence within the coding regions as contrasted with those in untranscribed regions. The other worthy of noting results observed in the current study is the relatively better number DNA amplification products from multiple locus microsatellite containing loci primers such as STIIKA, STINHWI, STSNRA10 and STCPKIN3. Though their number are still lower than reported by Provan *et al*. (1996a), MacGregor *et al*. (1999) and that of Yi *et al*. (2010), these primer pairs amplified one to three different bands. It seems that these authors worked with a much more variable population than the current study as also noted by Schneider and Douches (1997) and Eduard (1997). This result looks more justifiable when we thoroughly look into the sources of 21 of these varieties, i.e., the International Potato Center (CIP), which distributes advanced breeding populations and tuber families of their crossing programs products to most developing countries as a way of strengthening national research systems (Amoros *et al*., 2000). Since improving post-harvest qualities of potato is one of the main objectives of CIP breeding program, observation of common banding pattern for primers STS1_2, STS1_3, SGBSS and STRBCS3 that targeted at scanning the areas of these varieties genome especially related to starch biosynthesis could be attributed to the high probability of common parental background of these varieties as they all were obtained from CIP.

Table 29 Polymorphism in 25 potato varieties from Ethiopia detected by 11 microsatellite markers.

SSR marker name	No, of SSR fragments detected	No. of polymorphic SSR fragments detected	PIC
STS1_2	1	1	0.00
STS1_3	1	1	0.00
STIIKA	2	2	0.22
STWIN12G	1	1	0.00
STGBSS	1	1	0.00
STINHWI	2	2	0.24
STSNRNA10	2	2	0.24
PII	1	1	0.00
STRBCS3	1	1	0.00
STCPKIN3	3	3	0.34
STPATP1/TF11	1	1	0.00
Total	17	17	

All varieties had one and common banding pattern for primer pairs STS1_2, STS1_3, SGBSS, STRBCS3, STWIN12G, PII and STPATP1/TF11. Among the 25 varieties that had monomorphic banding pattern for the above six different primer pairs, the varieties Menagesha, Gera, Challa, and CIP-395096.2 had a different common banding pattern amplified by STIIKA, STINHWI, STSNRA10 and STCPKIN3. Zengena, Belete and Aba Adamu join the special sub groups amplified by STIIKA and STINHWI. Furthermore, while Belete associates with Menagesha, Gera, Challa and CIP-395096.2 subgroup by sharing similar band amplified by STSNRA10, Zengena join them by common banding pattern amplified by STCPKIN3 primer pair. Also while Ater Abeba joined the groups of STINHWI, Jalene and Guasa merged with the groups of STSPKIN 3. Although, these varieties were officially released over a period of 30 years, the similarity shared among them could probably be attributed to their common source origin as indicated above that virtually all (over 84%) the varieties released in Ethiopia is obtained from CIP advanced breeding populations

distributed across different national research systems. For this same reason some of the varieties that are officially released to be widely grown by potato growers are also found being recommended in neighboring country Kenya and Uganda and South American countries such as Peru, Bolivia due to their desired quality attribute.

Conclusion

Obviously, the results of current study shade two different remarkable thought or light to the potato researchers in Ethiopia. One of important observations of this study result is confirmation of the presence of genes responsible for the biosynthesis of starch and thus the possibility of using those varieties having other desirable or special features for further breeding purpose in a reliable manner. The second observation from this study is the relevance of further work on the diversity analysis of potato varieties in Ethiopia by using primer pairs that can scan over an extensive area of the genome.

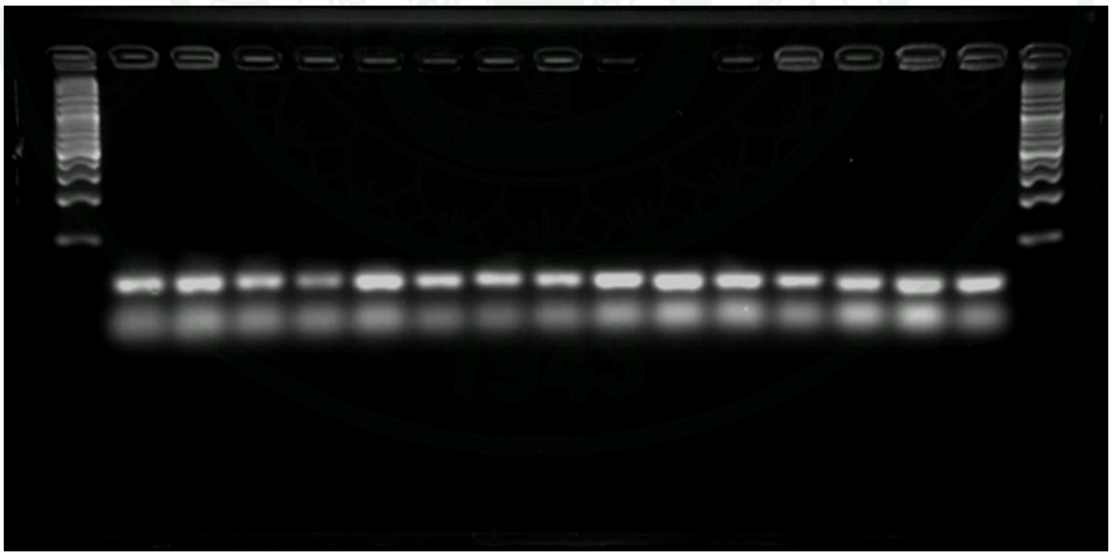

Figure 20 PCR amplified products of the first 15 varieties by single locus STS1_2 primer.

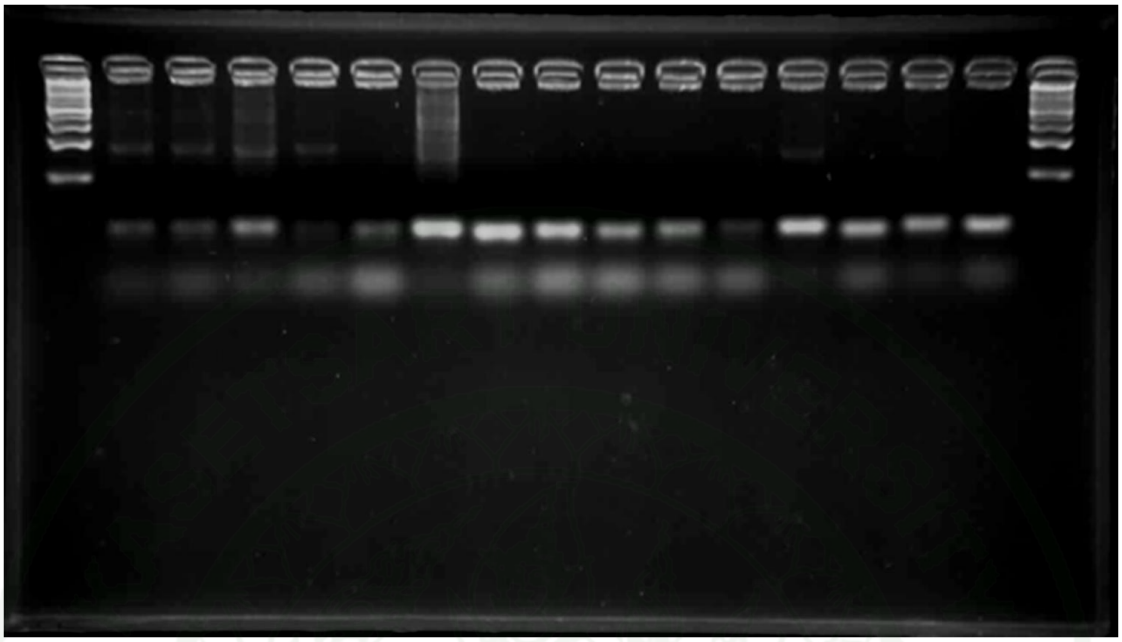

Figure 21 PCR amplified DNA products of the first 15 varieties by multi-locus STSNRA10 primer.

General Disscussion

Genetic diversity is the state of all the variety of genes existing in a particular variety or species. And as such presence of sufficient genetic diversity or variety of desirable genes among both cultivated crop varieties and their close wild relative is fundamental for a sustainable agricultural development that can respond to growing human demands for both food and non-food products. For this reason analysis of genetic diversity has been and will continue to be an integral part of any crop or animal improvement activity. In this thesis a total of 25 potato varieties composed of 18 improved varieties, three elite clones and four farmer's cultivars in Ethiopia were evaluated to analyze the variability present between them in their dry matter and starch content, starch yield, essential mineral nutrient concentration, starch chemical composition and pasting properties, and ultimately the morphological and molecular basis of their differences across three distinct environments in Amhara Region of Ethiopia.

The results of analysis have shown the presence of significant variation among varieties in Ethiopia over their dry matter and starch content, starch yield, mineral concentrations within their tubers, the starches chemical composition and pasting properties. The significant ($P < 0.01$) genotypic variation observed among the varieties over dry matter and starch content agreed with earlier reports (Benesi *et al.*, 2004; Rivero *et al*, 2009; Elfnesh *et al.* 2011; Ekin, 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. High heritability estimates of maturity dates, growth habit, leaf area, number of main stems, and tuber size were also reported by different authors at different times (Killick, 1977; Brown and Caligari, 1989; Moris, 1989; Neele *et al.*, 1991). Such fundamental differences among varieties regarding these characteristics could account for the observed DMC and SC differences among the studied varieties as clearly noted from the differences in their maturity time, tuber size, plant growth habit, leaf area cover and number of main stems. Gray and Hughes (1978) also reported that tubers from late-maturing potato varieties usually have high DMC than tubers of early-maturing varieties. Grommers and van der Krogt (2009) described the importance the dry matter content of potato for processors and its depends on variety and genetical determination. The present study result corroborates with this report. Consistent with this existing research reports, Belete, Gorebella, Challa and Shenkolla, varieties with upright growth habit, were all had larger size tubers than others. Moreover, their tubers had high dry matter content and long eliiptical shape which is suitable for French fries processing product. Similarly, the farmer's cultivar Ater Abeba which also had an erect growth habit, high dry matter content and almost round type tuber shape was preferable for processing purposes maily of crisp products. The mineral concentar variability observed among the varieties presumably is attributed among other factors to the varieties differential ability in mineral mining or uptake and use efficiency (White and Broadly, 2005;

Hirel *et al*., 2007). The fertilizer level used could also be a factor as it has a positive correlation with the total nitrogen content of tubers (Augustin, 1975).

Significant environments and genotype x environment interaction was also observed for tubers mineral concentration. This significant environments and genotype x environment interaction mean squares observed in the current study agree with the reports of Burgos *et al.* (2007) for two locations and that of Ekin (2011) for the same location but different years. Clearly, this is a common observation for many characters as environmental factors do differ in different years and do crop variety performance differently pertaining to the prevailing set of environmental conditions in each set of sampled years. The Nitosol type, which is normally considered a good agricultural soil in the Food and Agricultural Organization soil classification system, may have contributed to the better concentration observed at Merawi site as contrasted to the Luvisol at Debretabor site which is classified as an infertile soil (Waithaka *et al*., 2007). This fertility differences between the two trial sites has clearly been reflected in the mineral concentrations of plants which is determined by the phytoavailability of nutrients within the soil and the varieties nutrient uptake and use efficiency (White and Brown, 2010).

Amylose content variability has been seen among the varieties. This among starches isolated from different potato varieties grown at the same location clearly manifested the significant effect of genetic differences (Kuar *et al*., 2007; Alvani *et al*., 2010). Furthermore, AMC values varied across the three locations and this clearly conforms that climatic factors could directly influence crop's potential productivities, regulating its transpiration, photosynthesis, and respiration processes in such a way as to control the growth and development of the plants throughout their physiological cycle at a given site. Though optimum temperature for potato plant varies with crop growth stage, photoperiod, length of exposure among others, a value of 16-24 ^{0}C was reported to be ideal for better potato production (Timlin *et al*., 2006). Furthermore, Mohabir and John (1988) observed 21.5 ^{0}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) had also reported a reduction of enzyme activity in potato plants exposed to elevated temperature and specifically indicated a 59% and 72% reduction of sucrose synthase activity in a heat tolerant and susceptible potato cultivars, respectively. Similarly, Keeling *et al.* (1994) reported a temperature of 20 to 25 ^{0}C as maximal for starch synthase activity in cereals. Wang *et al*. (2006) has also noted higher level expression of amylase enzyme – granule bound starch synthase I (GBSSI), enzyme responsible for amylose synthesis, at low temperature in rice crop. Thus, high AMC at the cool Debretabor site of current study clearly agree with these results. Cottrell *et al*. (1995), however, reported observation of high AMC in varieties grown under high temperature. The pasting properties profiles variability is the resultant effects of the amylose and amylopectin content variability manifested among the starches isolated from both different varieties grown under similar location and across different location. Potatoes starch has been reported to contain high level of phosphate concentration (Lim *et al*., 1994) that contributed for potato's starch higher viscosities, water binding abilities, lower pasting temperature, highest consistency on pasting than cereals (Galliard and Bowler, 1987), and binding characteristics (Alexander, 1995). Owing to their relative higher phosphorus concentration in their tubres, all varieties tested at Merawi and Debretabor locations had high PV, BD, low Ptemp and PT. Thus, the results obtained in present study related to paste viscosity profile vs phosphorus concentration agreed with the reports of previous workers.

Microsatellite analysis of these varieties with major emphasis to starch synthase markers has shown narrow variability among these varieties. Certainly, this has been clearly reflected by the performance of all varieties grown under ideal Debretabor condition at which almost all varieties with the exception of Menagesha were observed to be suitable for processing purposes. Thus, genotypes possing the desired genetic make up or genes responsible for traits of interest could express their maximum potential provided they are grown under the right environment (Akeley and

Stevenson, 1944; Mondal and Hosain, 2006). These claimed a larger effect was due to genetic make-up and inherent differences of varieties commonly manifested in their mean differences.

The phenotypic diversity analysis carried out using both quantitative and qualitative characteristics collected from the experiment at each location resulted in a genetic distance values and dendrogram of location specific. This has revealed the inefficiency of morphological characterization or description procedure was evidenced in present study. Hawkes (1990) attributed this phenomenon to the phenotypic plasticity of quantitative charactersistics or a state in which character or group of characteristics manifest different state under different set environments. Thus, the selective use of environmentally stable or consistent characteristics was found useful to improve the efficiency of morphological description techniques. Accordingly, the 18 stable environmentally stable or consistent qualitative characteristics were used to compute the genetic distance matrix and construct a dendrogram pictorially depicting the relationship and grouping of studied 25 varieties. And this has revealed the differences among these varieties by grouping them into three main clusters and one singleton. The growth habit, leaf insertion, skin type, corolla shape, skin and flesh color, general tuber shape and eye depth were among the characters that distinctly separated them. Some of these morphological characersitic were also responsible for the differences observed among them in their dry matter accumulation as varieties with up-right growth habit and acute leaf insertion could enable the variety with these kind of feature to trap maximum amount of ratdiation and also reduce shadding each other for maximal photosynthesis of leaves.

CONCLUSION AND RECOMMENDATIONS

Conclusion

Despite the fact that this tudy was conducted only for one season, the overall result obtained across the different experiments could help us safely arrive at the following conclusions.

1) The varieties exisiting in Ethiopia possess sufficient genetic variability in their dry matter content, starch content and starch yield. These varieties also showed significant differences in their stability of performance across locations. Considering their consistent dry matter content, starch content and starch yield across the major potato growing areas of this part of the country, Gorebella, Belete, Guasa, Challa, CIP-396004.337 and Ater Abeba were found ideal for processing purposes, especially for high starch production pertaining to their high dry matter content, extractable starch and high tuber yield responsible for their high starch yield. Conversely, Menagesha, Awash, Ararsa and Bulle were found to be most suitable for home consumption or table use purposes due to their elatively low dry matter content. Likewise, while Debretabor site is appropriate for high DMC, SC and SY processing type varieties, Merawi was invariably suitable for table-type potato production owing to its climatic conditions.

2) Specific garavity of varieties is the most common ad an easiest criterion used by processing fims to decide the suitability of a give potato variety for processing purpose. Accordingly varieties with a specific gravity value of 1.077 (19.5 % DMC) and 1.079(20% DMC) were set as a cut off point for suitability for French fries and crisp processing purposes. Thus, all those below these values are unacceptable for processing puroses. The evaluated varieties had shown significant variability at a locations and across locations and thus in their performance stability. Menagesha, CIP-392650.96.2, Wochcecha and Awash are totally suitable for table purpose while the remaining could be used for processing purpose depending on

growing areas. Considering size, stability and shape Belete, CIP-3960004.337, Challa, Ater Abeba, Gorebella, Jalene and Guasa are recommended for processing purpose. Debretabor followed by Adet are appropriate for processing while Merawi for table purpse production.

3) Malnutrition is one of the critical diet related health problem in the region in particular and the country at large. Biofortification or elevating the concentration of essential nutrients within the staple food crops is chosen as a sustainable strategy of circumventing this global and country issue. Potato has a special feature to address this issue due to the high content of chemicals that promot and low concentrations of those chemicals that inhibit the absorption of critical nutrients such as iron and zinc. Results of mineral concentrations variability study revealed the presence of significant variability among the varieties in the country. The mineral concentrations in tubers of improved variety Menagesha, farmer's cultivar Sisay and elite clone CIP-396004.337 were found to be higher than the other varieties and could be good parents for genetic enhancement program. Considering the 10% bioavailability of Fe and 21% bioavailability of Zn in developing countries, the FAO/WHrecommended 27.4, 58.8 and 12 $mg.day^{-1}$ of Fe for men, women and children, respectively. Additionally, the FAO/WHO recommended 6, 4.9 and 4.1 $mg.day^{-1}$ of Zn for men, women and children, respectively. Consequently, men, women and children, respectively can get 29%, 13.3% and 65% of their daily RNI of Fe from eating 200 g fresh weight (FW) of tubers of the high Fe concentration variety Sisay (7.8 mg) and 12%, 14.3% and 17% of the daily RNI of Zn for men, women and children, respectively, from 200 g of FW tubers of the high Zn variety Menagesha (0.70 mg). Thus, highland inhabitants that consume large amounts potato in their daily diet could get substantial amounts of their daily RNI of these two critical minerals.

4) There was significant genetic variability among the 25 potato varieties in their chemical composition, especially of amylose and amlopectin content and starch pasting properties. Amylose content of starch is considered to be one of the

most important factors influencing the cooking and texture quality of whole tuber and potato starch based foods. Similarly starch psting properties do influence eating quality and ultimately determines the industrial utility of starch. Varieties Jalene, Guasa, CIP-396004.337, Gabisa and Sisay displayed consistently high peak viscosity value across all the three distinct locations, and thus these varieties could be ideal for processing industries that use starch to preserve food state, food thickining and for glue industries.

5) Results of the phenotypic diversity analysis had also shown significant variability over their phenotypic attributes. Overall, the varieties Belete, Gorebella, Shenkolla and Challa had large sized tubers with long axis to width ratio making them more preferrable for French fries processing product. On the other hand the varieties Guasa, Jallene, Ater Abeba and Gudene good for crisp making due to their tuber shape.

6) The microsatellite analysis study using locus specific marker had revealed the narrow variability among these varieties over the selected specific genome areas. The most interesting result was the confirmation of starch synthase gene in all varieties thus making future breeding work targeted at improving the post harvest quality of potato in Ethiopia feasible.

Recommendations

1. All post harvest quality characteristics addressed in the current studies, dry matter and starch content, starch yield, tuber mineral concentration, starch chemical composition and pasting properties, are considerably influenced by environments, i.e., seasons and years and location. Yet, all the different studies in this thesis were carried for only one season due to the tight training schedule of the sponsoring instituition. Thus, it is strongly recommended that all the current research

experiments be continued for more years over wider areas of the country to allow firm recommendations to be made at national level.

2. It is also reasonable to recommend at this moment the relevance of a carrying out tuber mineral concentration studies with detail analysis of soil nutrients under varying major potato production areas so that the contribution of potato in addressing the prevalent mineral malnutrition or hidden hunger both in the Amhara Region and the country at large is enhanced.

3. The food science research department in the region is also adviced to developing various products that can diversify the utility of potato in significant and sizeable level. Thus, the undertaking multifaceted efforts of producing nutritionally balanced fortified potato based products by this research groups is highly recommended.

4. Finally, the improvement of the industrial utility of potato in both food and non-food processing enterprises is crucial if the potato sector is to contribute to alleviation of poverty, enhancement of employment opportunity and ultimately saving/generation of foreign hard currency. This can be realized if the work on the chemical and functional properties of potato varieties grown under different environment is studied in detail. We do also strongly recommend the continuation of this part of the thesis in a comprehensive manner so that relevant starch attributes not addressed in the current study, starch granule size, size distribution, molecular chain length and length distribution, phosphorus and lipd contents, be done with special emphasis to agronomic and growing areas soil characteristics.

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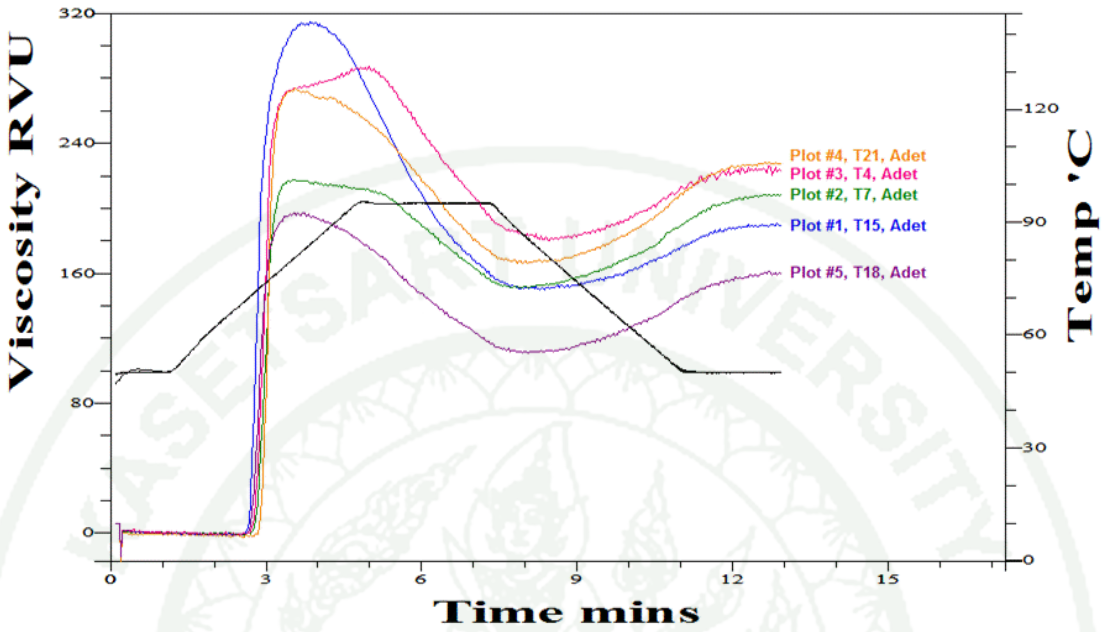
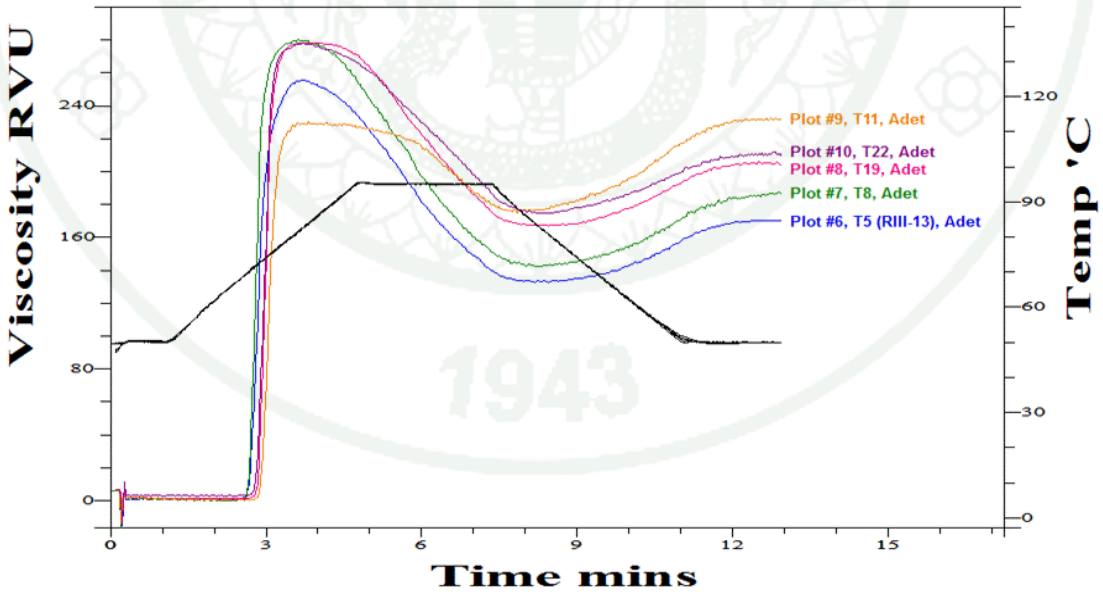
APPENDICES

Appedix A

RVA profile of starches of the 25 varieties grown at the three locations.

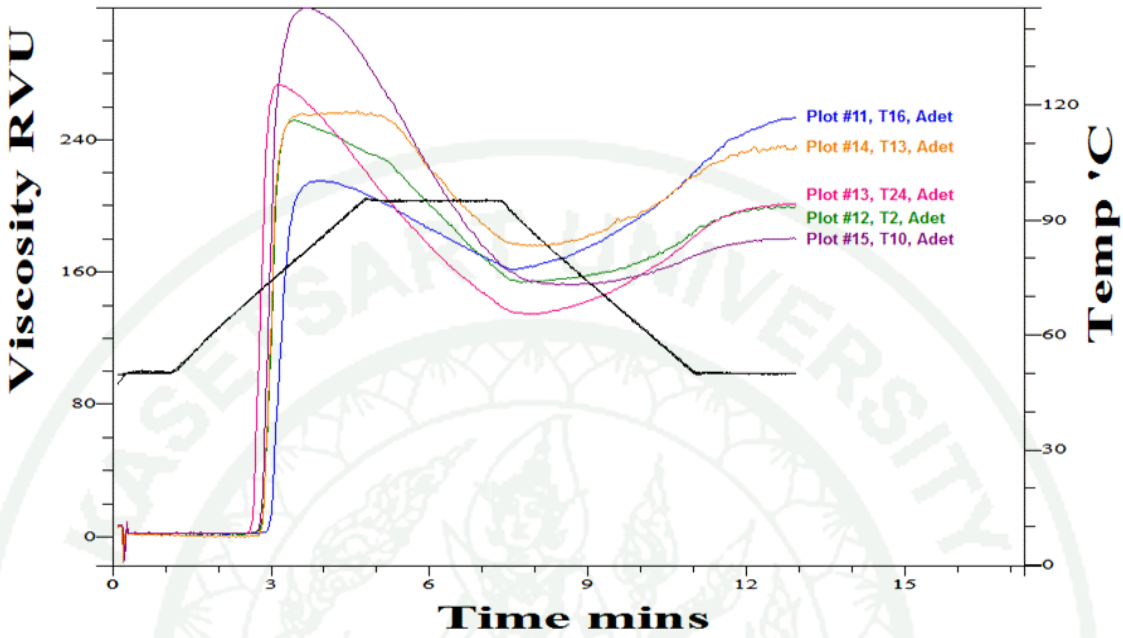


(a) The RVA profile of starches isolated from varieties 1 to 5 grown at Adet.

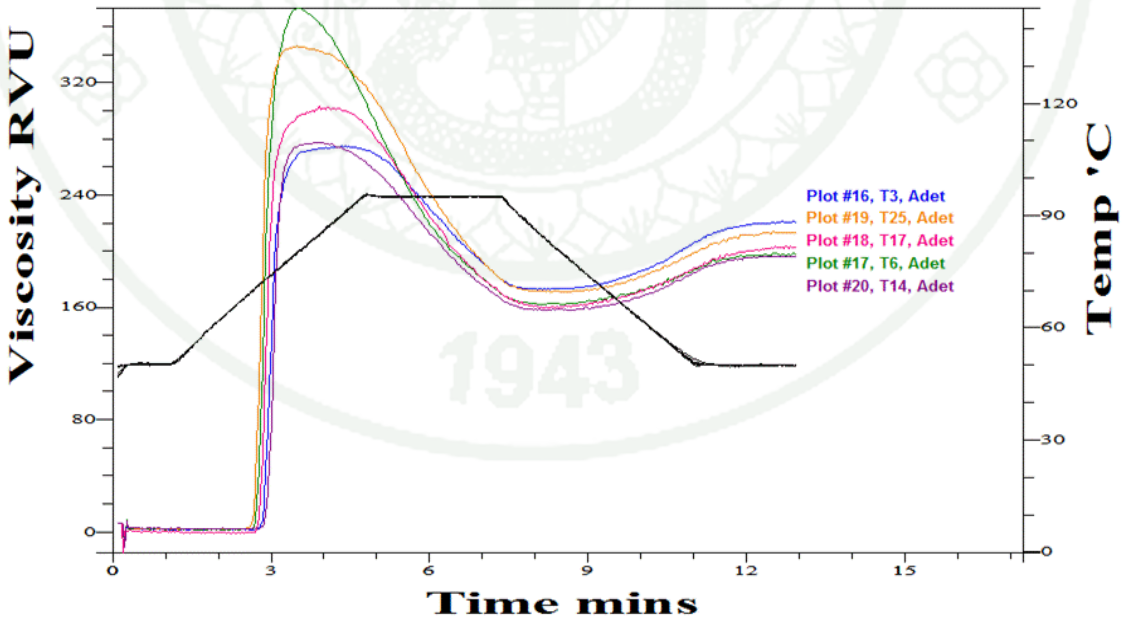


(b) The RVA profile of starches isolated from varieties 6 to 10 grown at Adet.

Appendix Figure A1 RVA profile of starches of the 25 varieties grown at the three locations.

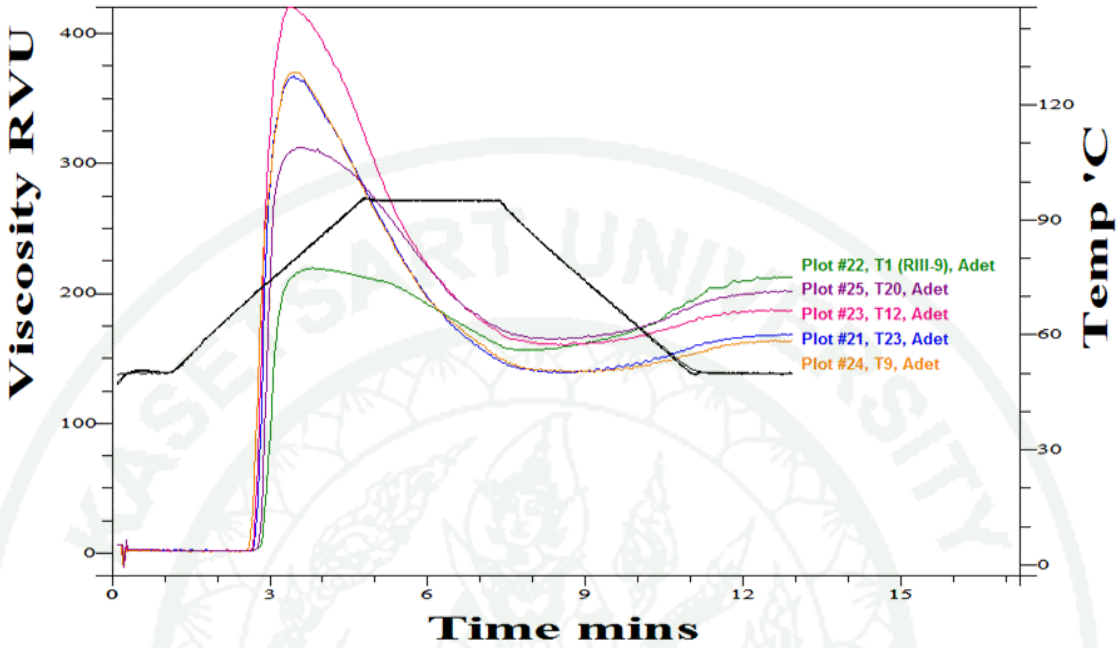


(c) The RVA profile of starches isolated from five varieties 11 to 15 grown Adet.

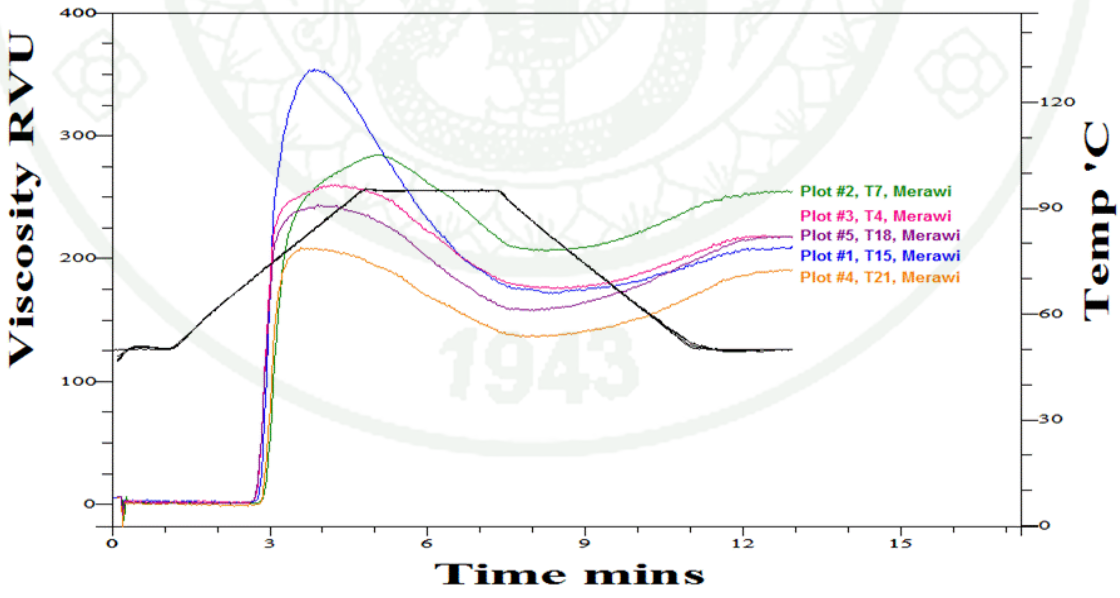


(d) The RVA profile of starches isolated from varieties 16 to 20 grown at Adet.

Appendix Figure A1 (Continued)

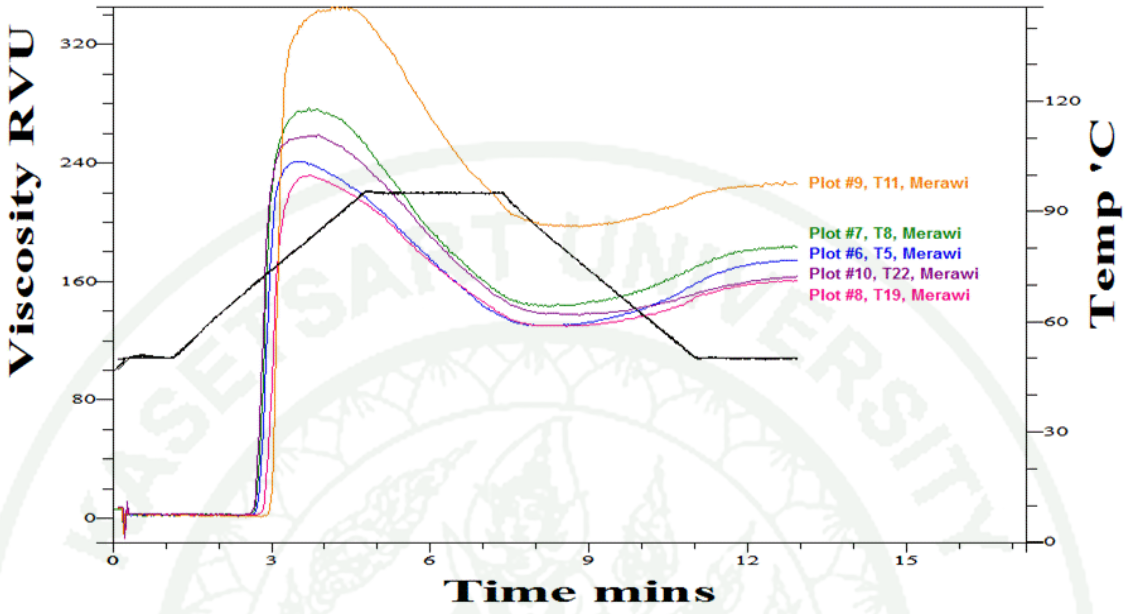


(e) The RVA profile of starches isolated from varieties 21 to 25 grown at Adet.

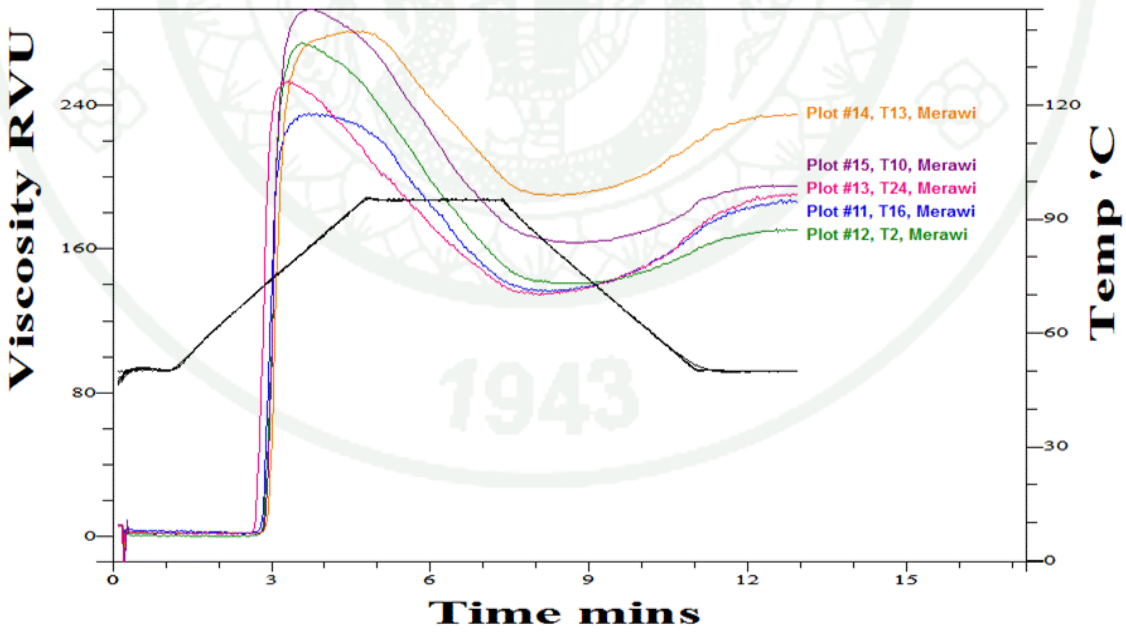


(f) The RVA profile of starches isolated from varieties 1 to 5 grown at Merawi.

Appendix Figure A1 (Continued)

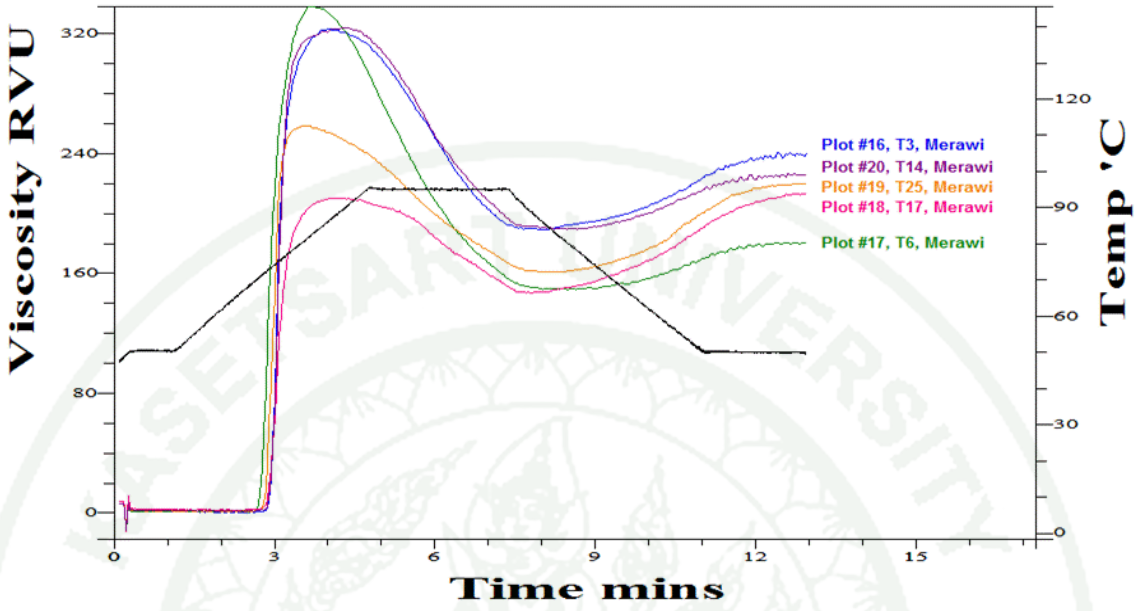


(g) The RVA profile of starches isolated from varieties 6 to 10 grown at Merawi.

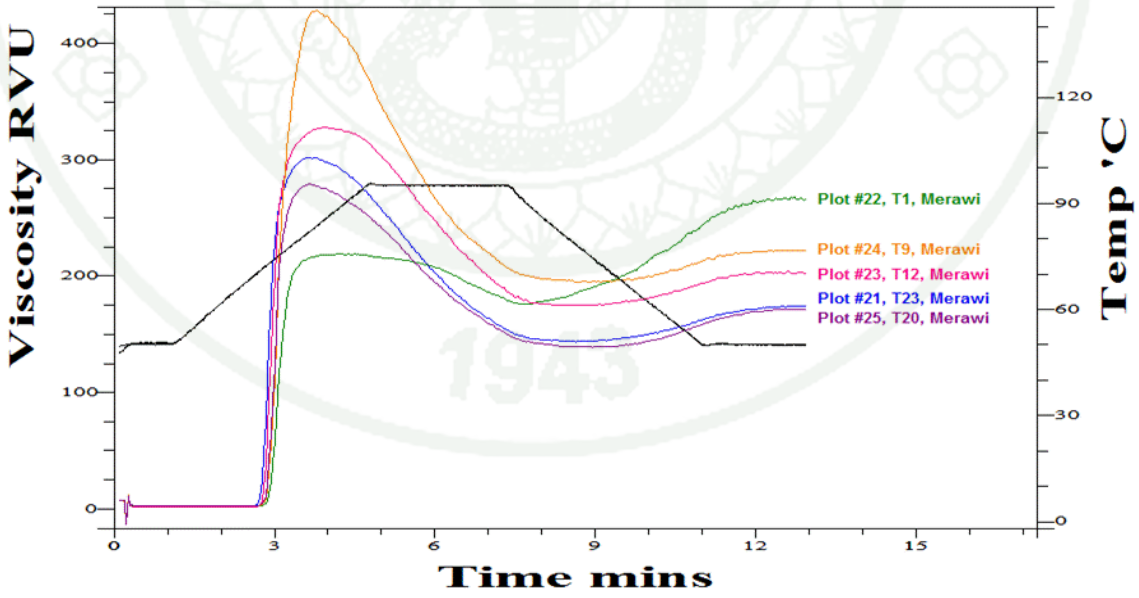


(h) The RVA profile of starches isolated from varieties 11 to 15 grown at Merawi.

Appendix Figure A1 (Continued)

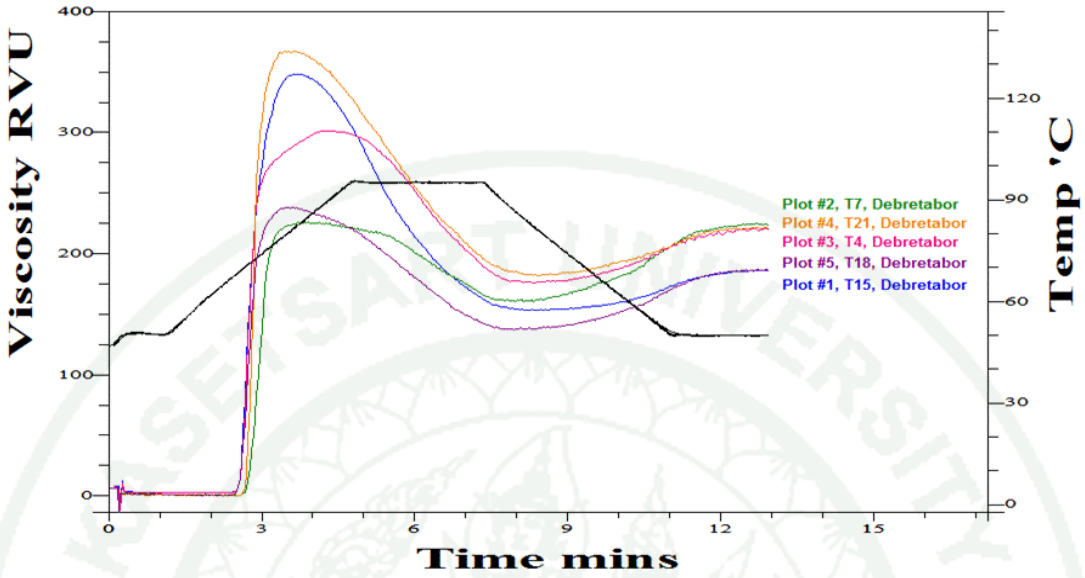


(i) The RVA profile of starches isolated from varieties 16 to 20 grown at Merawi.

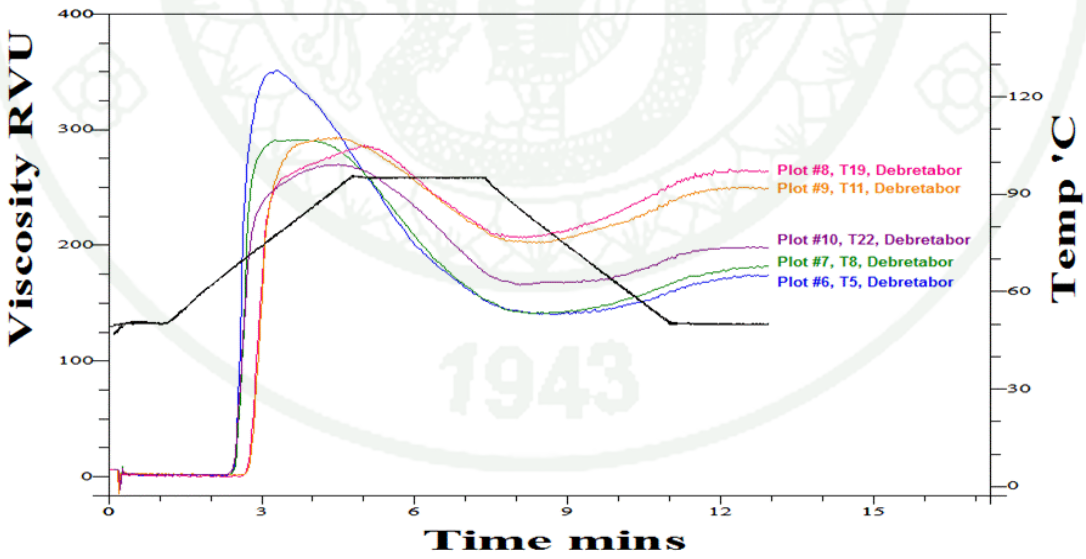


(j) The RVA profile of starches isolated from varieties 21 to 25 grown Merawi.

Appendix Figure A1 (Continued)

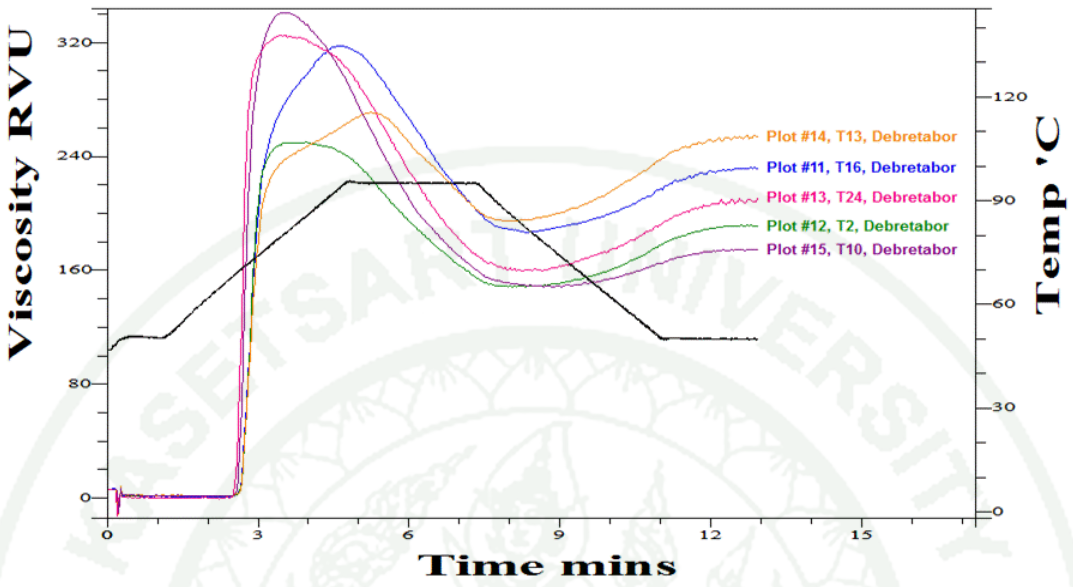


(k) The RVA profile of starches isolated from varieties 1 to 5 grown at Debretabor.

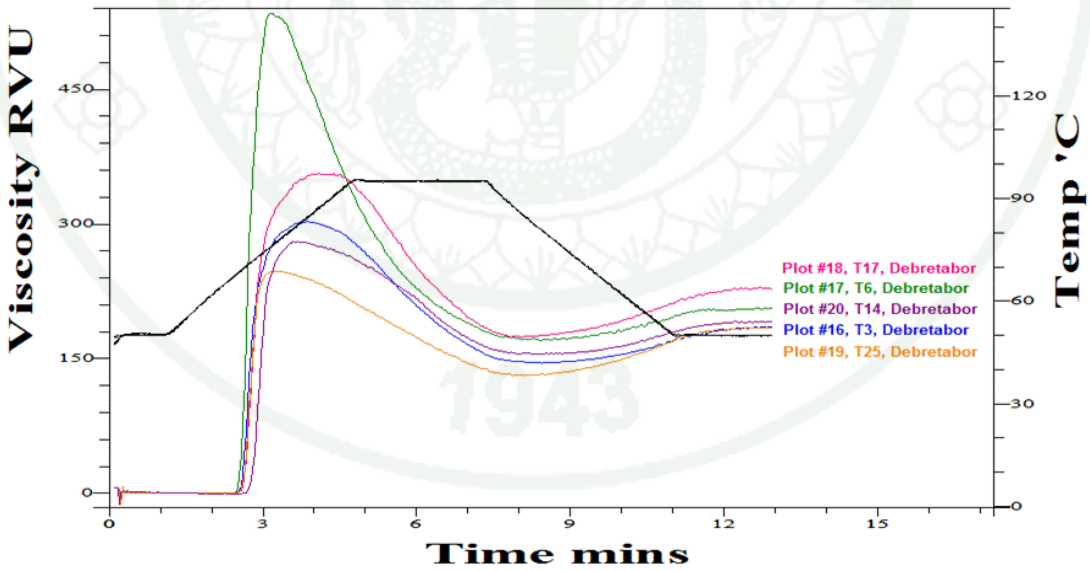


(l) The RVA profile of starches isolated from varieties 6 to 10 grown at Debretabor.

Appendix Figure A1 (Continued)

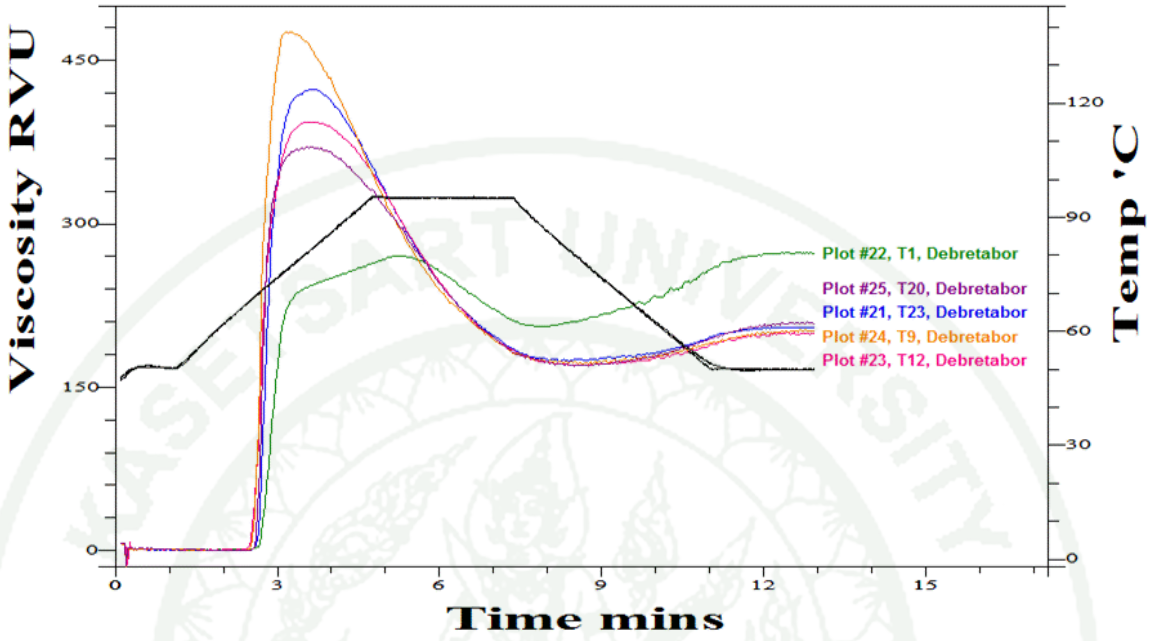


(m)The profile of starches isolated from varieties 11 to 15 grown at Debretabor.



(n) The RVA profile of starches isolated from varieties 16 to 20 grown at Debretabor.

Appendix Figure A1 (Continued)



(o) The RVA profile of starches isolated from varieties 21 to 25 grown at Debretabor.

Appendix Figure A1 (Continued)

Appedix B

List of morphological descriptors of potato used in the study.

Appendix Table B1 List of morphological descriptors of potato used in the study.

No.	Characteristics and abbreviation	Description categories
1	Leaf dissection (LD)	Undissected entire leaves =1 Pinnatilobed- leaves with lobes extending to midribs =2 Scarcely dissected =3 Weakly dissected =4 Medium dissected =5 Strongly dissected =6 Very strongly dissected =7 Others =8
2	Leaf insertion (LI)	Acute (upper angle between stem and leaf $\leq 45^0$ =1 Obtuse (upper angel between stem and leaf $\geq 45^0$ =2
3	Leaf midrib color (LMC)	Unpigmented =0 Axillary pigmentation =1 Whole midrib pigmented =2
4	Leaf length (LL)	Length from the tip of the terminal leaflet to the end of petiole measured in cm
5	Leaflets length (LLL)	Leaflets measured from their tip to the end of petiolule in cm
6	Leaflet width (LLW)	Narrow (<0.60) =1 Average width (0.60-0.67) =2 Broad (>0.67) =3
7	Leaflet length to width ratio (LLWR)	Measured as the ratio of LLL to LLW
8	Leaf green color intensity (LGCI)	Green =1 Light green =2
9	Growth habit	Erect =1 Semi-erect =2 Decumbent –stem trail on the ground but rise at the apex =3 Prostrate- stem trail on the ground =4 Semi-rosette =5 Rosette- when all or most leaves arranged at the base of the stem close to the soil =6

Appendix Table B1 (Continued)

No.	Characteristics and abbreviation	Description categories	
10	Number of the primary stem (SN)	Single	=1
		Few (1 to 3)	=2
		Medium	=3
		Many	=4
11	Plant height at flowering (PH)	Measurement of the distance between the top point of the plant and the ground surface in cm	
12	Days to flowering (DF)	Counted as the number of days from emergence to flowering of 50% of the plants of an Accession	
13	Days to maturity (DM)	Recorded when 50% of the plants of an accession are ready for harvest as indicated by the senescence of vines	
14	Corolla shape (CS)	Very rotate	=1
		Rotate	=3
		Pentagonal	=5
		Semi-stellate	=7
		Stallate	=9
15	Predominant flower color (PFC)	White	=1
		Light red	=2
		Intense red	=3
		Light blue	=4
		Intense blue	=5
		Light purple	=6
		Intense purple	=7
		Yellow	=8
16	Secondary flower color (SFC)	Absent	=0
		White	=1
		Light red	=2
		Intense red	=3
		Light blue	=4
		Intense blue	=5
		Light purple	=6
		Intense purple	=7

Appendix Table B1 (Continued)

No.	Characteristics and abbreviation	Description categories
17	Distribution of secondary flower color (DSFC)	Absent = 0 White acumen adaxial surface=1 White acumen abaxial surfac=2 White acumen both surface =3 Star- adaxial surface =4 Stripe- adaxial surface =5 Stripe on both surface =6 Stippled =7 Other =8
18	Degree of flowering (DFL)	No bud =0 Bud abortion =1 Flowering scarce =3 Flowering moderate =5 Flowering profuse =7
20	Number of tubers per plant (TN)	Counted in number
21	Average weight of a tuber (TW)	Measured as the ratio of marketable tuber yield per plot to the number of marketable tuber in gm
22	Marketable yield (MTY)	Weight of total marketable tubers per plot converted into hectare, t/ha
23	Predominant tuber skin color (PTSC)	White-cream =1 Yellow =2 Orange =3 Brownish =4 Pink =5 Red =6 Purplish-red =7 Purple =8 Dark purple-black =9
24	Secondary tuber skin color (STSC)	Absent =0 and all stated for PTSC

Appendix Table B1 (Continued)

No.	Characteristics and abbreviation	Description categories	
25	Distribution of secondary tuber skin color (STSCD)	Absent	=0
		Eye1	=1
		Eyebrows	=2
		Splashed	=3
		Scattered	=4
		Spectacled	=5
		Stippled	=6
		Other	=7
26	Tuber skin type	Smooth	=1
		Rough(flaky)	=2
		Partially netted	=3
		Totally netted	=4
		Very heavily netted	=5
		Other	=6
27	Predominant tuber flesh color (PTFC);	White	=1
		Cream	=2
		Yellow-cream	=3
		Yellow	=4
		Red	=5
		Violet	=6
		Purple	=7
		Other	=8
28	General tuber shape (GTS)	Compressed	=1
		Round	=2
		Ovate	=3
		Obovate	=4
		Elliptic	=5
		Oblong	=6
		Long-oblong	=7
		Elongate	=8
29	Tuber eye depth (TED)	Protruding	=1
		Shallow	=2
		Medium	=3
		Deep	=4
		Very deep	=5

Appendix C

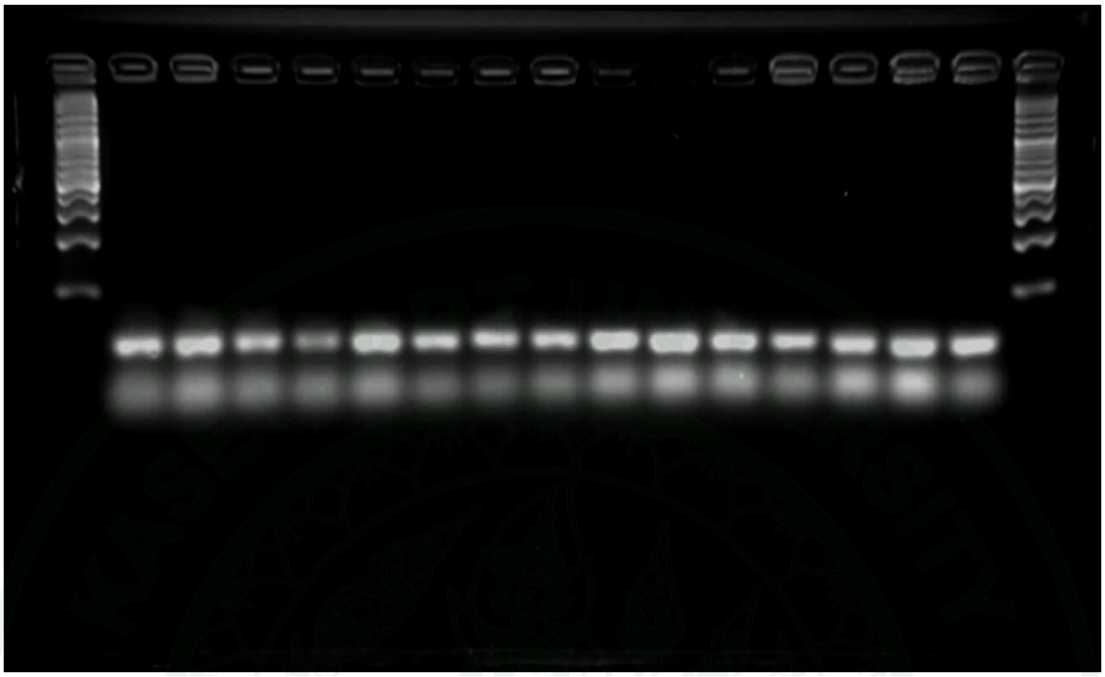
Primer names, simple sequence repeat, associated gene and melting temperature [Tm].

Appedix Table C1 Primer names, simple sequence repeat, associated gene and melting temperature [Tm].

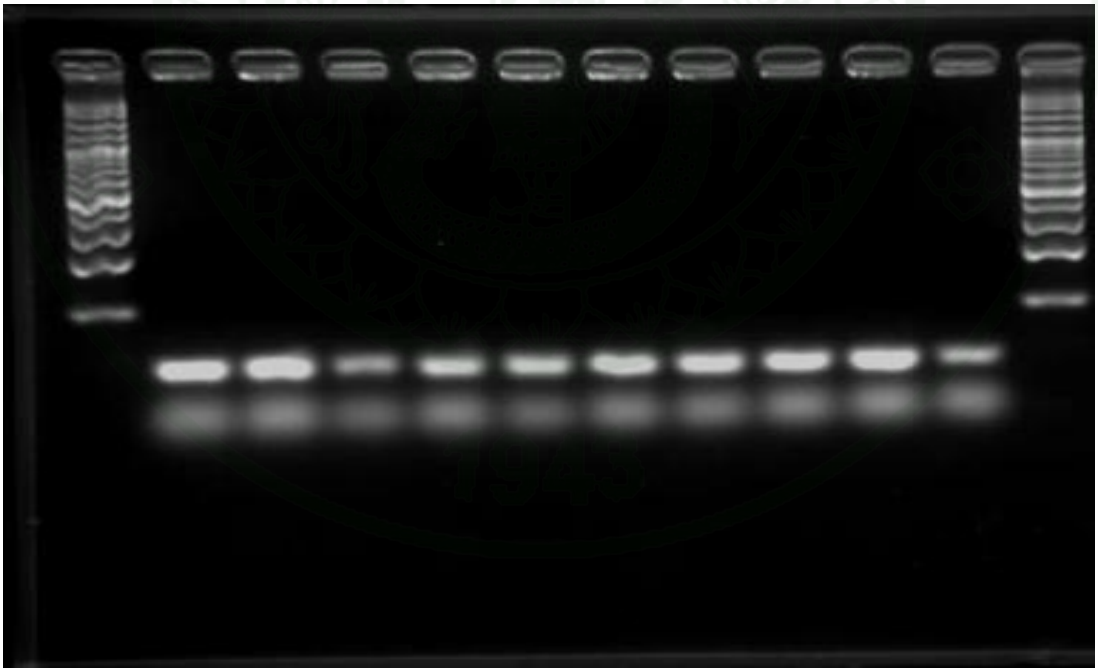
Name	Associated Gene	Simple Sequence Repeat	Primer (5′→3′)	Tm (^{0}C)
STS1_2	Starch synthase	$(TCAC)_m$	5′-TCTCTTGACACGTGTCACTGAAAC-3′ 5′-TCACCGATTACAGTAGGCAAGAGA-3′	55
STS1_3	Starch synthase	$(TCAC)_m . (CTT)_n$	5′-TCTCTTGACACGTGTCACTGAAAC-3′ 5′-TTGCCATGTGATGTGTGGTCTACAA-3′	55
STIIKA	Potato inhibitor IIK	$(T)_{12}(A)_9ATTCTTGTT(TA)_2CA(TA)_7$	5′-TTCGTTGCTTACCTAACTA-3′ 5′-CCCAAGATTACCACATTC-3′	50
STWIN12G	Potato wound-induced genes W1N1and W1W2	$(TGAAA)_2(ATA)_6$	5′-TGTTGATTGTGGTGATAA-3′ 5′-TGTTGGACGTGACTTGTA-3′	48
STGBSS	Potato granule-bound starch synthase	$(TCT)_9$	5′-AATCGGTGATAAATGTGAATGC-3′ 5′-ATGCTTGCCATGTGATGTGT-3′	58
STINHWI	Potato wound inducible proteinase inhibitor I	$(CT)_3TT(CT)_8(AT)_9$	5′-GGAGTCAAAGTTTGCTCACATC-3′ 5′-CACCCTCAACCCCCATATC-3′	60
STSNRNA10	Potato U1sn RNA gene U1-10	$(A)_{19}$	5′-AGTACTCAGTCAATCAAAG-3′ 5′-AGGTAAGTATGTTCTCCAG-3′	52
PII	Proteinase inhibitor I	$(C)_{p.}(CT)_{q.}(AT)_{r.}(G)_s$	5′-CATGTGGTTGTTAGACACCACTAGT-3′ 5′-TTTGGCACAAAGCAAGGGTAGAAGG-3′	55
STRBCS3	Potato rbcS3 gene for RUBISCO small subunit	$(A)_{15}$	5′-CCACAGTGTAATAAGCAT-3′ 5′-TAGTAACGGGGAAAGACG-3′	50
STCPKIN3	Potato cystolic pyruvate kinase patatin pseudiogene (SB6B)	$(AT)_{13}$	5′-AAGGAGAGAAGAACATAA-3′ 5′-CATTGAATAACACCAT-3′	50
STPATP1/ TF11	Potato patatin pseudogene (SB6B)	$(AT)_{22}$	5′-TGCAATGTGTCGAACAATCA-3′ 5′-TAATTGGATAGGTCGGCCTG-3′	56

Appendix D

Gel image of electrophoretic product of the 25 varieties in the study.

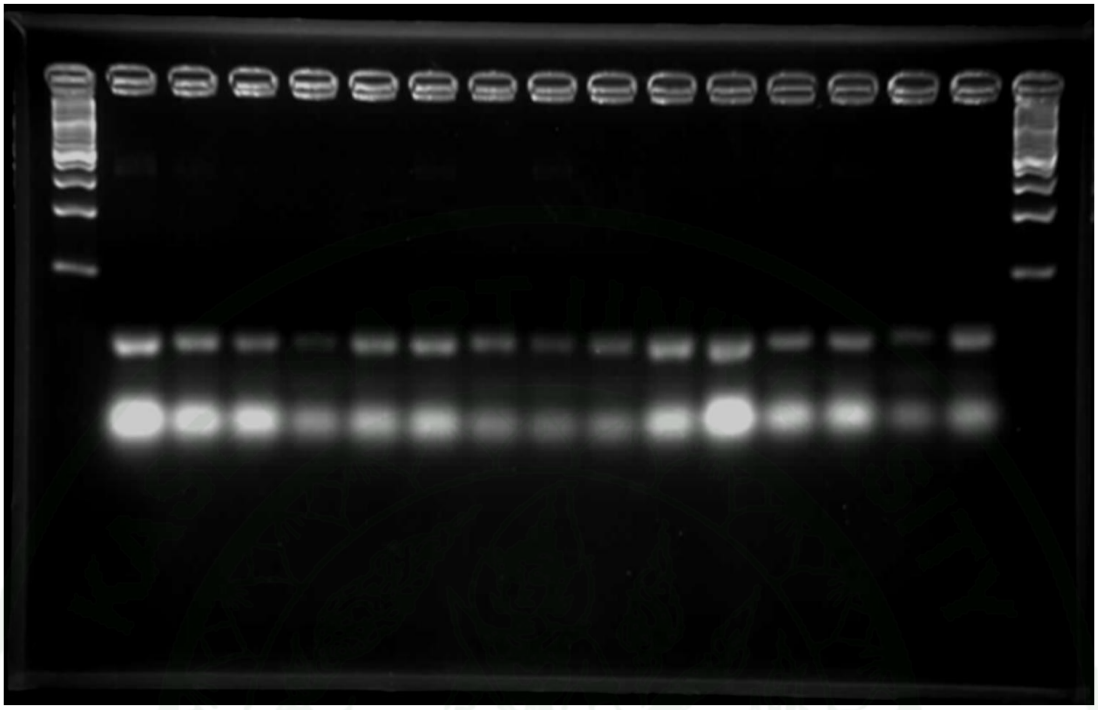


PCR amplified DNA products of varieties 1 to 15 by primer pair **STS1_2**.

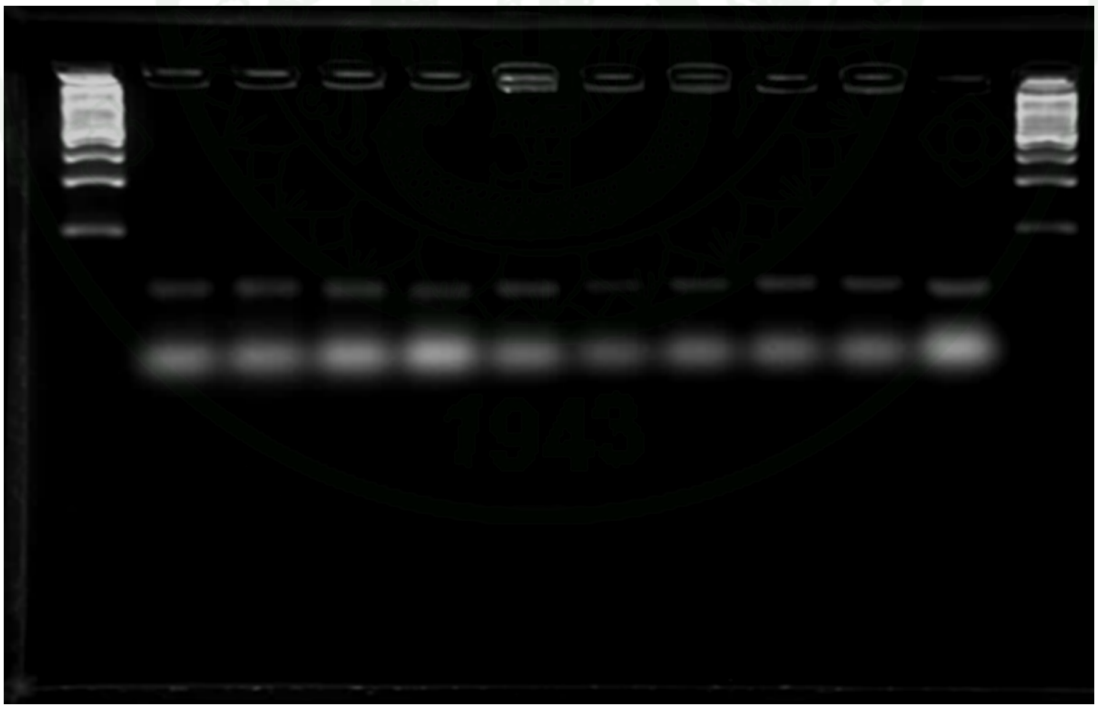


PCR amplified DNA products of varieties 16 to 25 by primer pair **STS1_2.**

Appendix Figure D1 Gel image of electrophoretic product of the 25 varieties in the study.

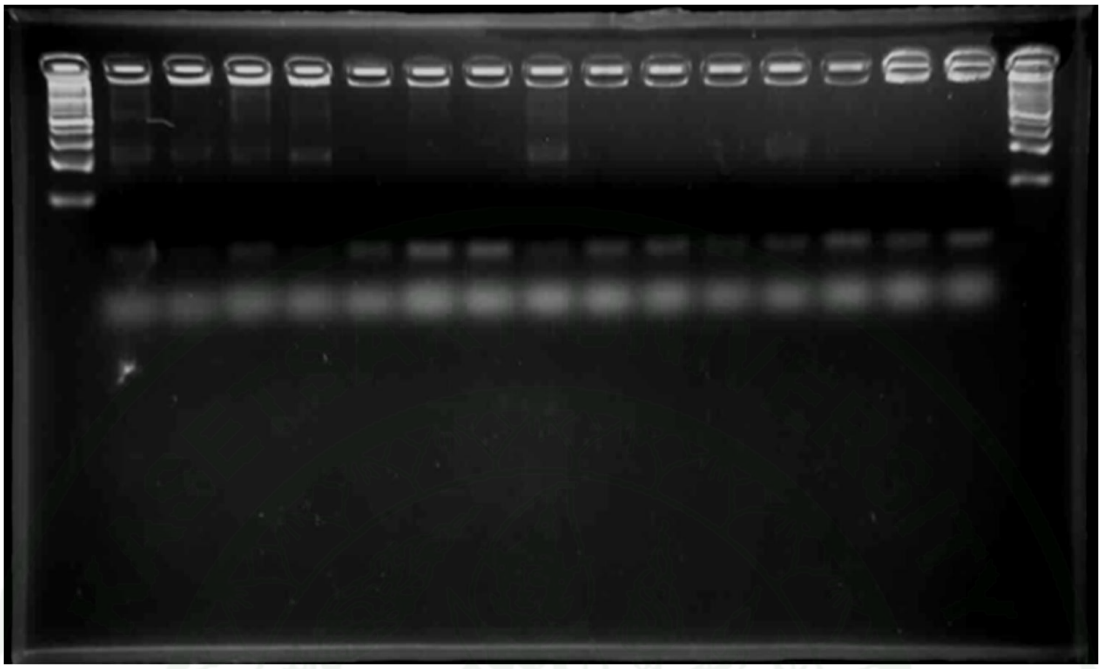


PCR amplified DNA products of varieties 1 to 15 by primer pair **STS1_3**.

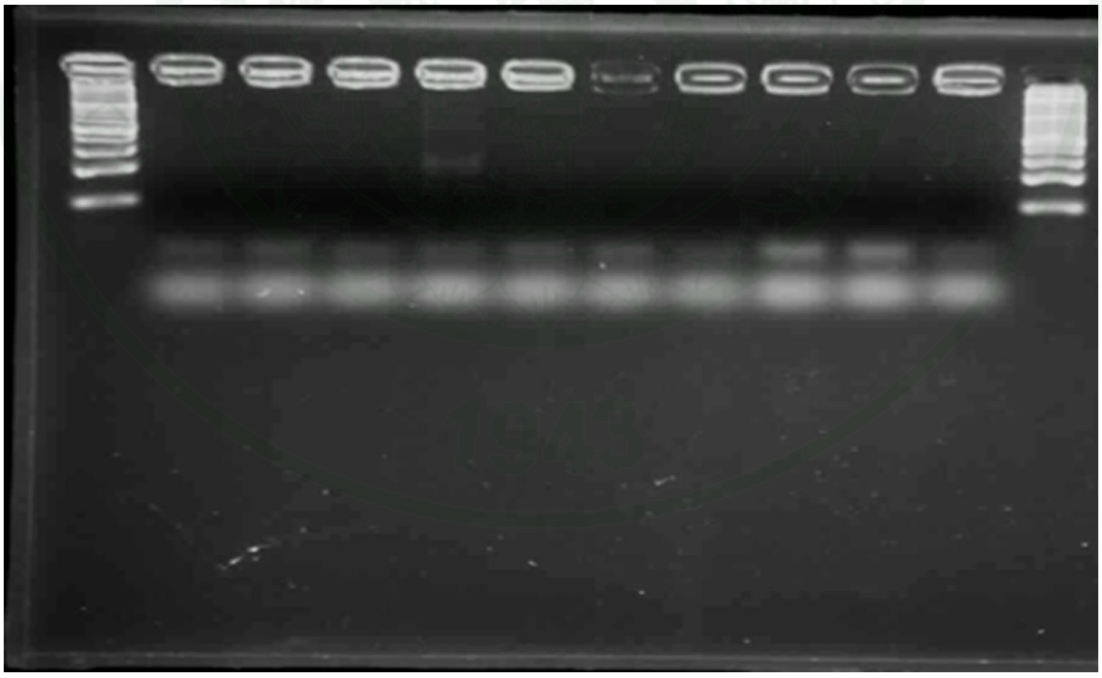


PCR amplified DNA products of varieties 16 to 25 by primer pair **STS1_3.**

Appendix Figure D1 (Continued)

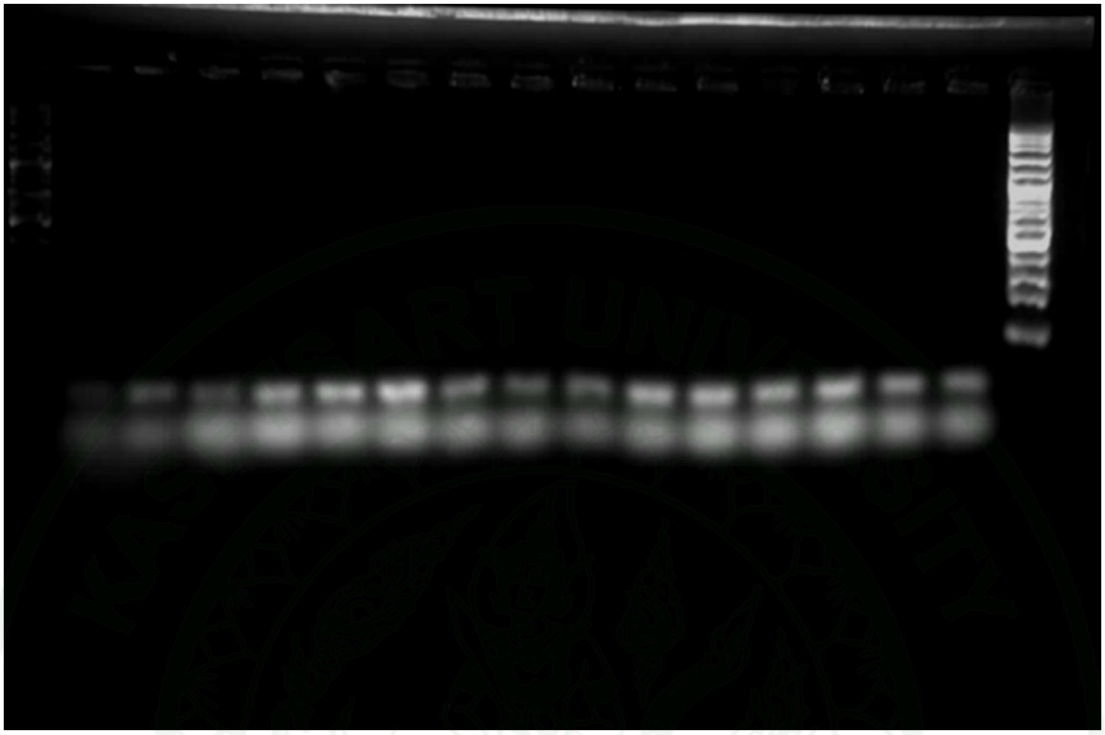


PCR amplified DNA products of varieties 1 to 15 by primer pair **STIIKA**.

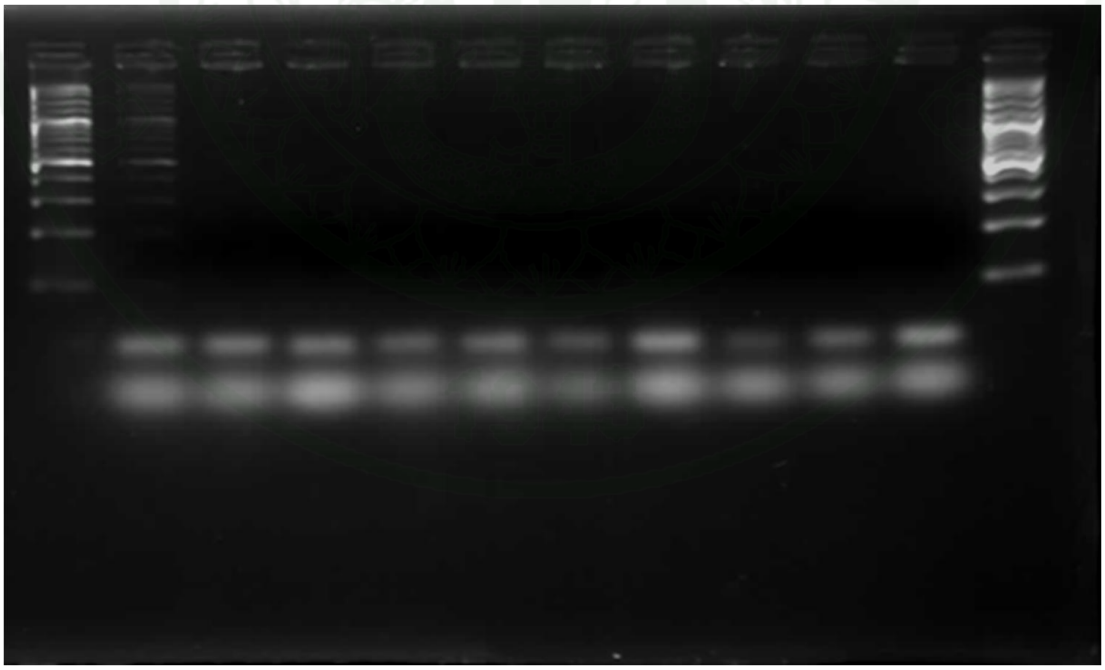


PCR amplified DNA products of varieties 16 to 25 by primer pair **STIIKA.**

Appendix Figure D1 (Continued)

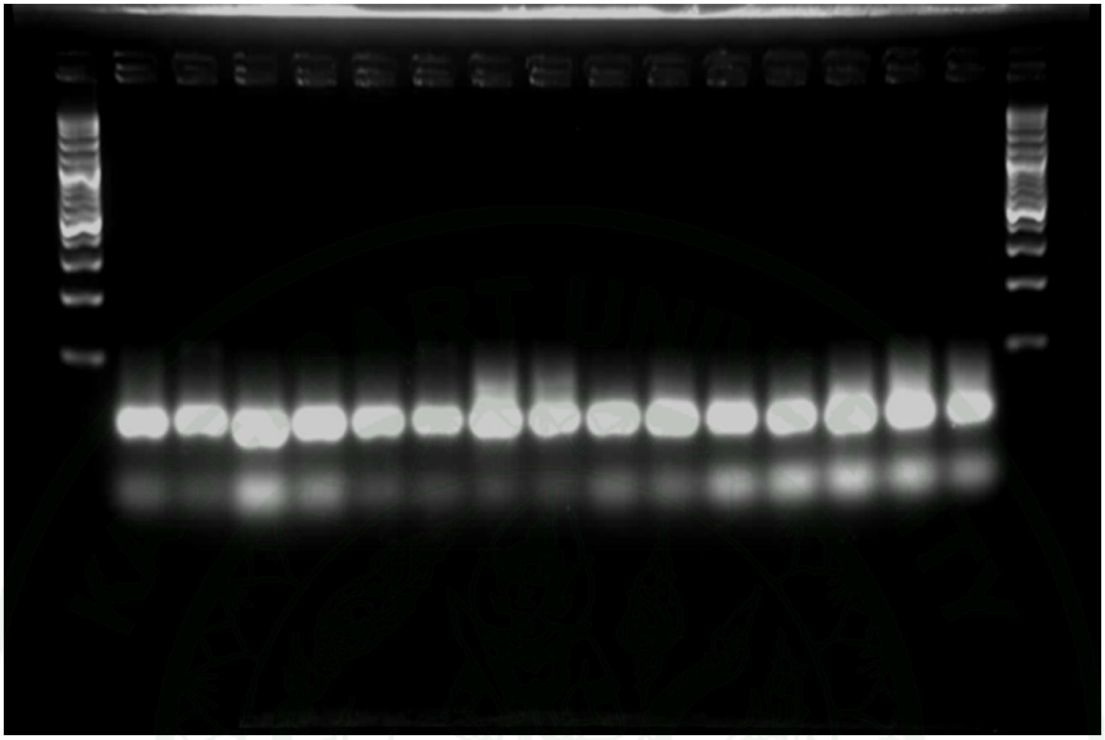


PCR amplified DNA products of varieties 1 to 15 by primer pair **STWIN12G**.

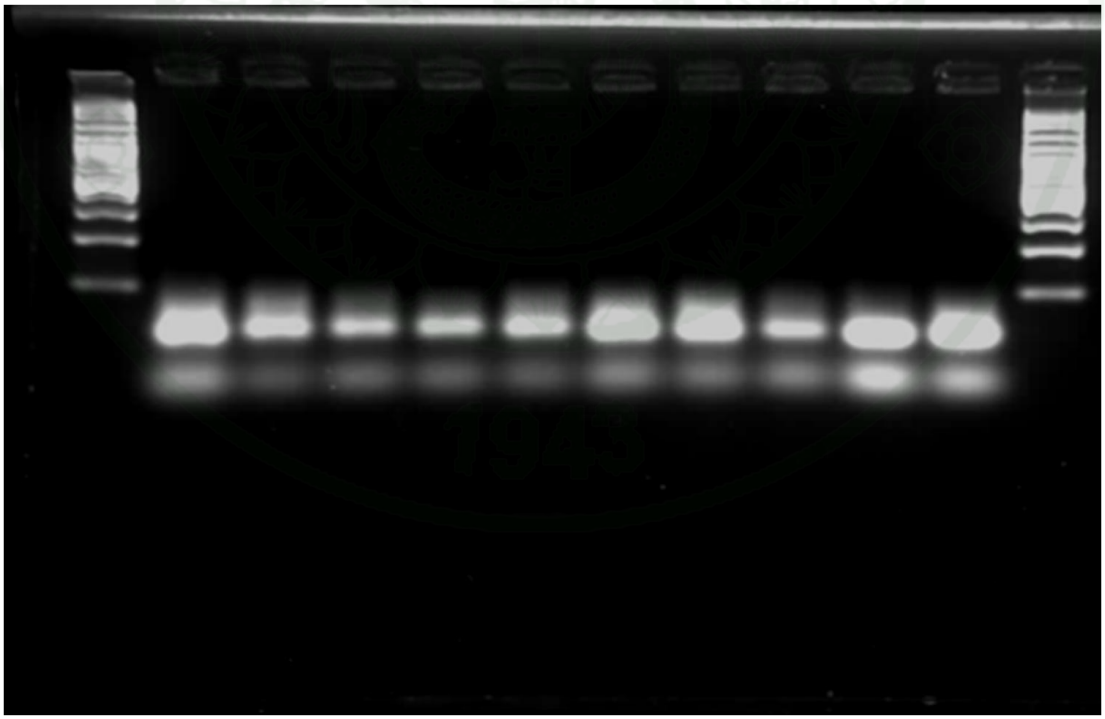


PCR amplified DNA products of varieties 1 to 15 by primer pair **STWIN12G**.

Appendix Figure D1 (Continued)

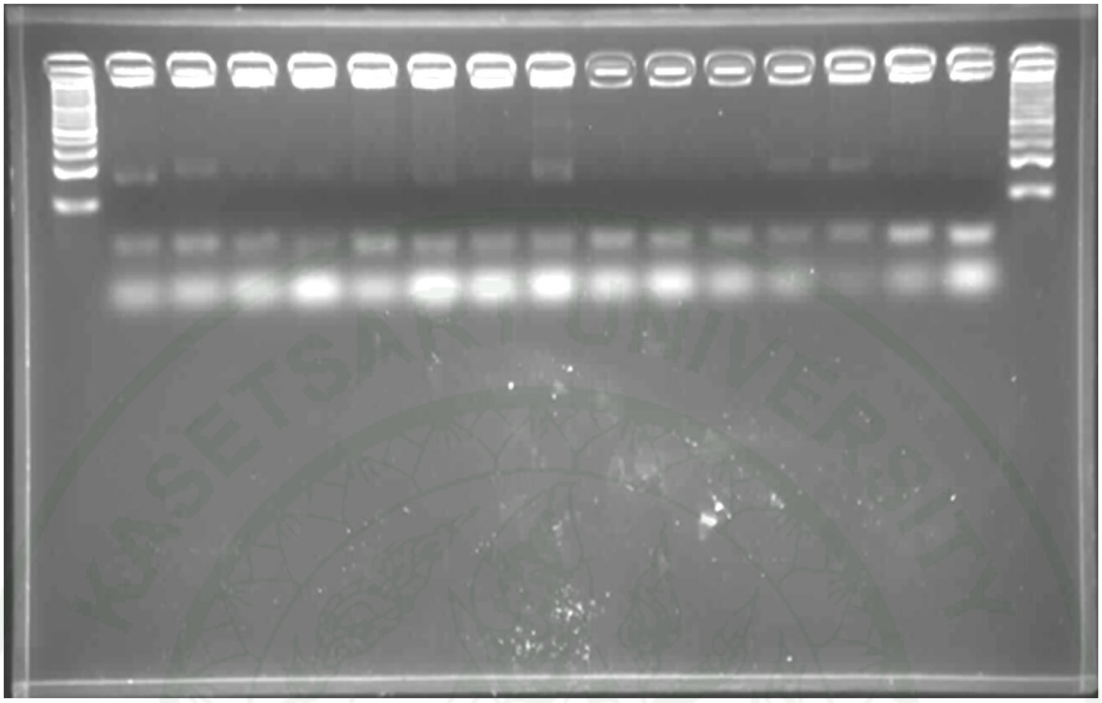


PCR amplified DNA products of varieties 1 to 15 by primer pair **STGBSS**.

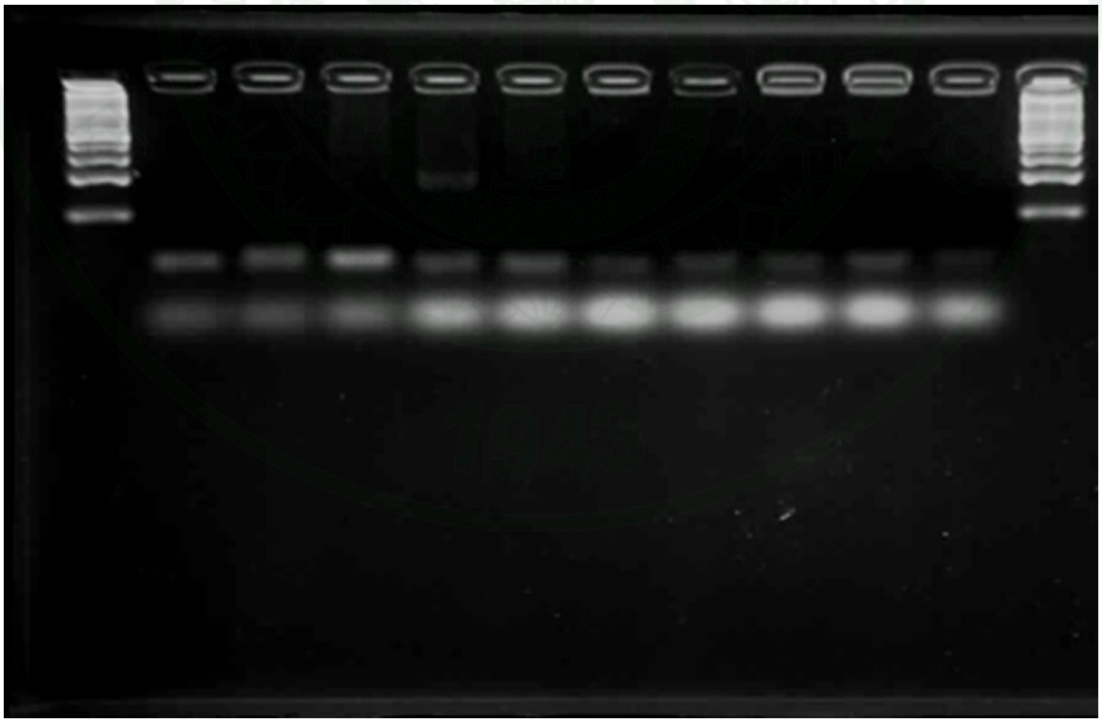


PCR amplified DNA products of varieties 16 to 25 by primer pair **STGBSS**.

Appendix Figure D1 (Continued)

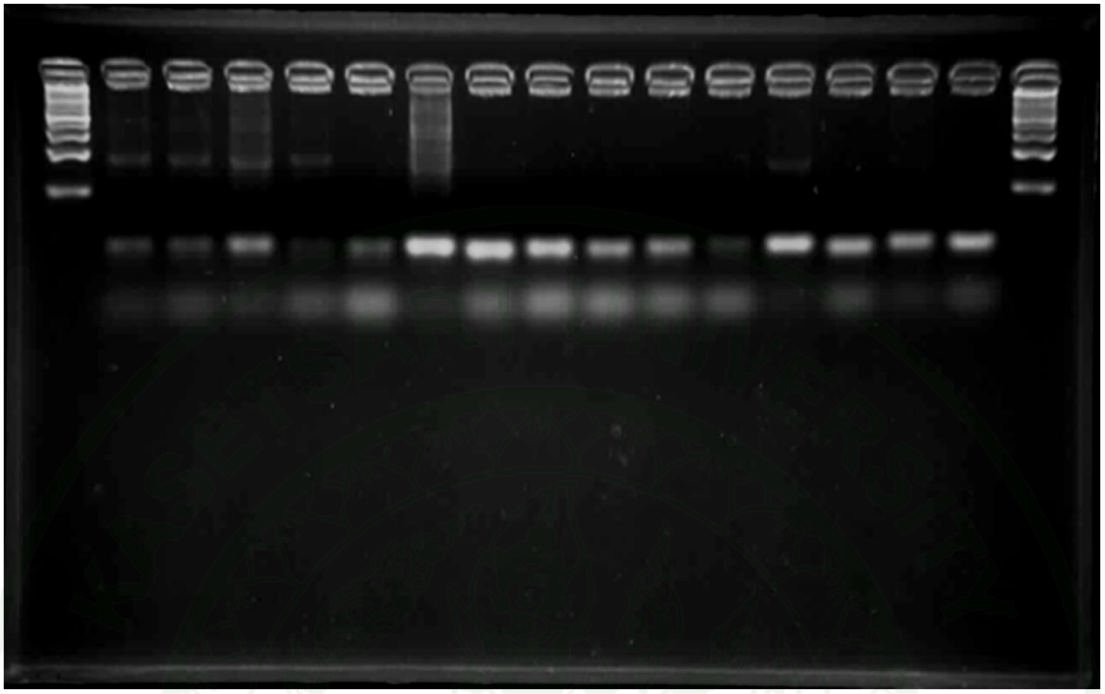


PCR amplified DNA products of varieties 1 to 15 by primer pair **STINHWI**.

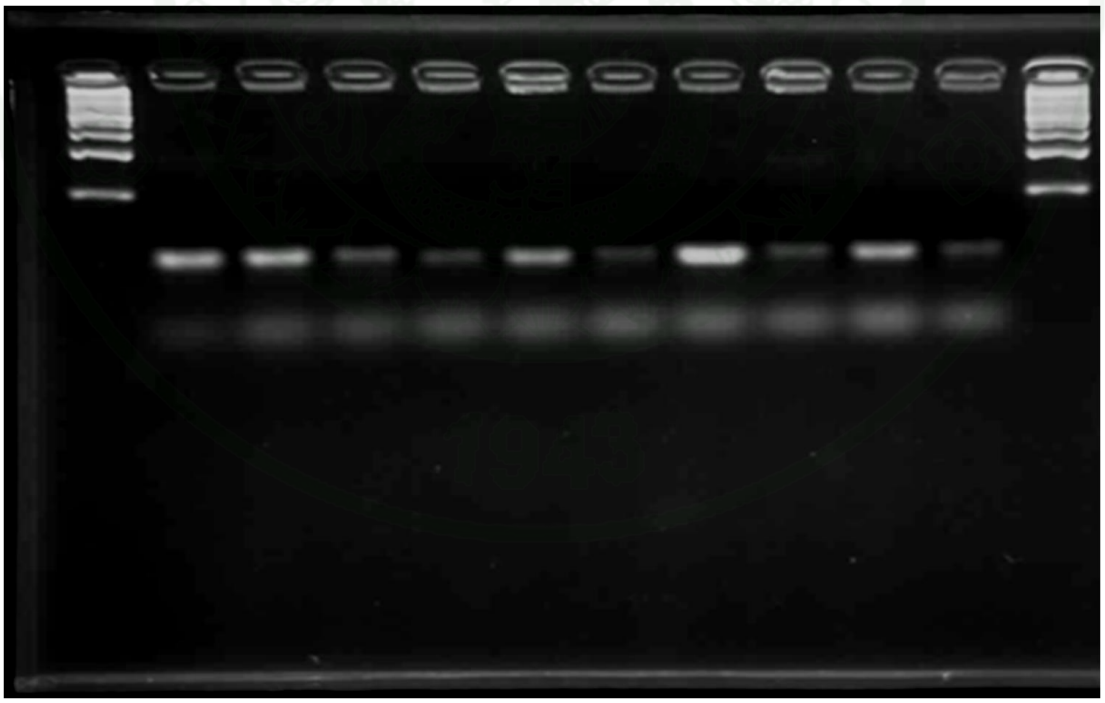


PCR amplified DNA products of varieties 16 to 25 by primer pair **STINHWI**.

Appendix Figure D1 (Continued)

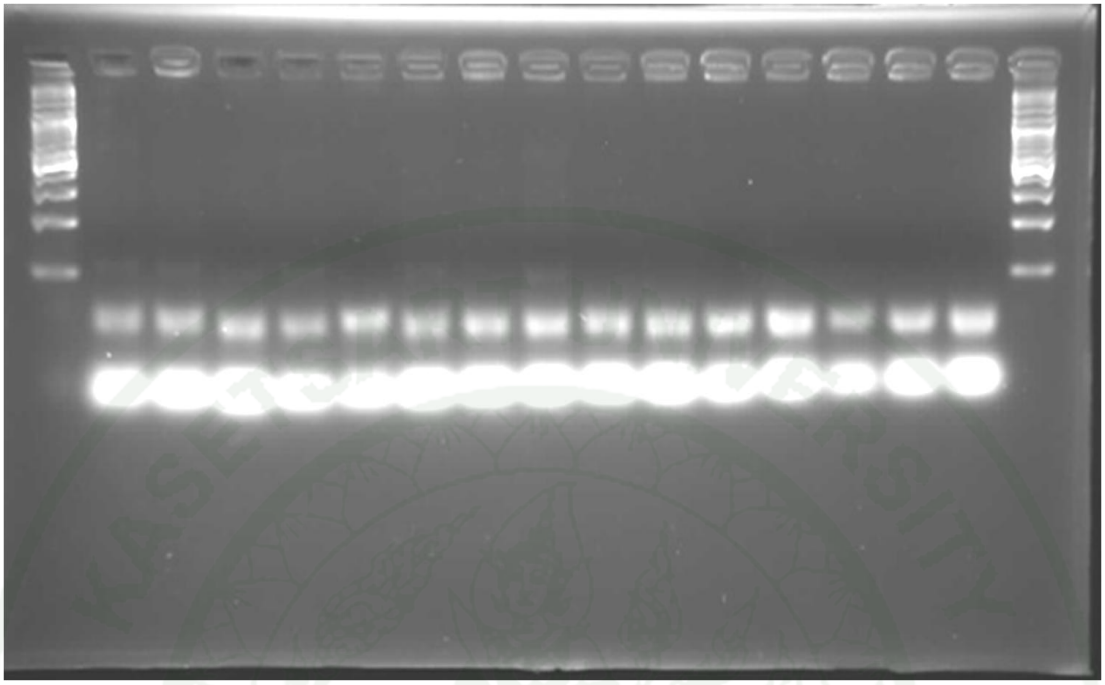


PCR amplified DNA products of varieties 1 to 15 by primer pair **STSNRA10**.

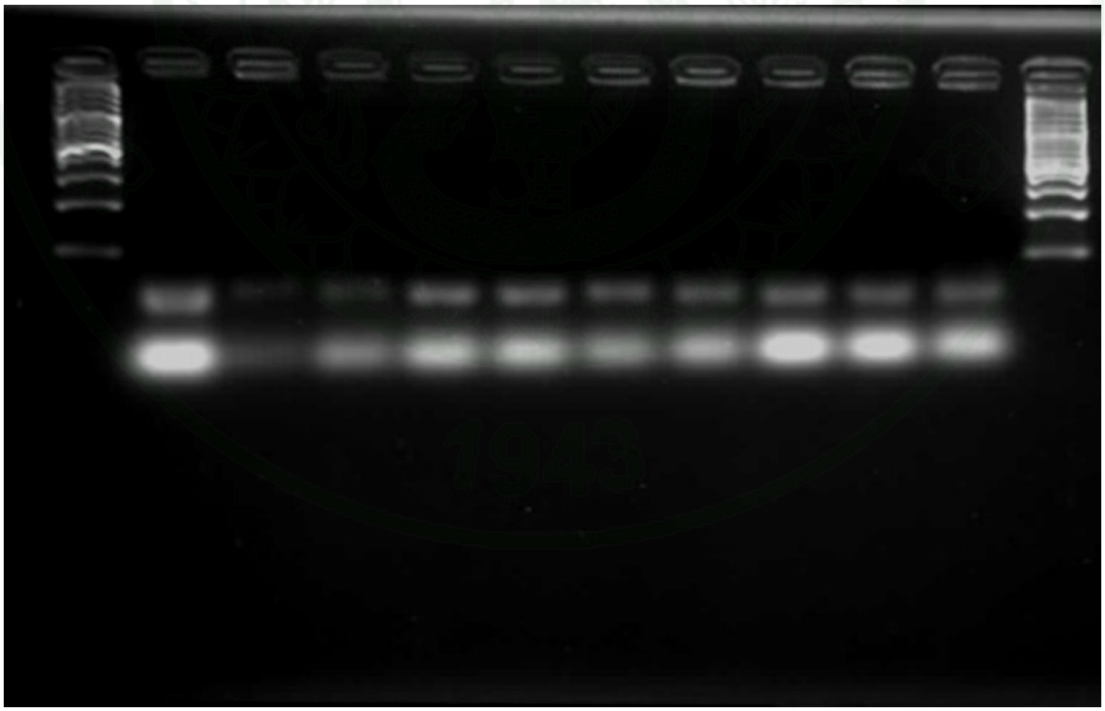


PCR amplified DNA products of varieties 16 to 25 by primer pair **STSNRA10**.

Appendix Figure D1 (Continued)

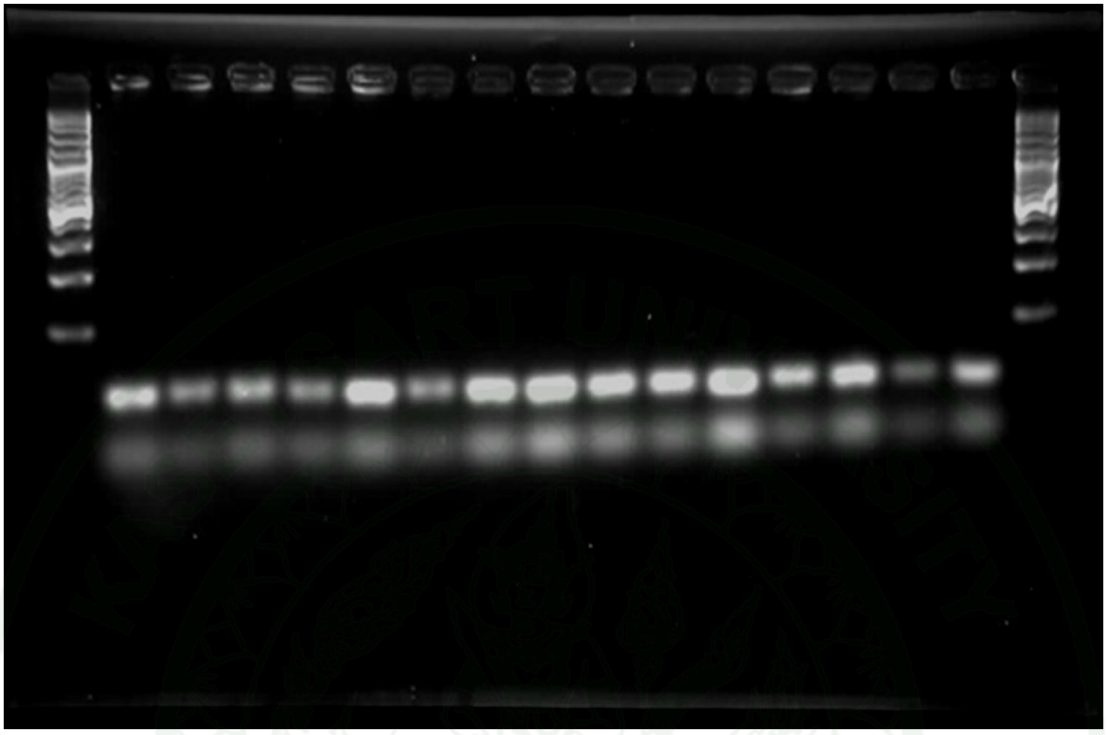


PCR amplified DNA products of varieties 1 to 15 by primer pair **PII**.

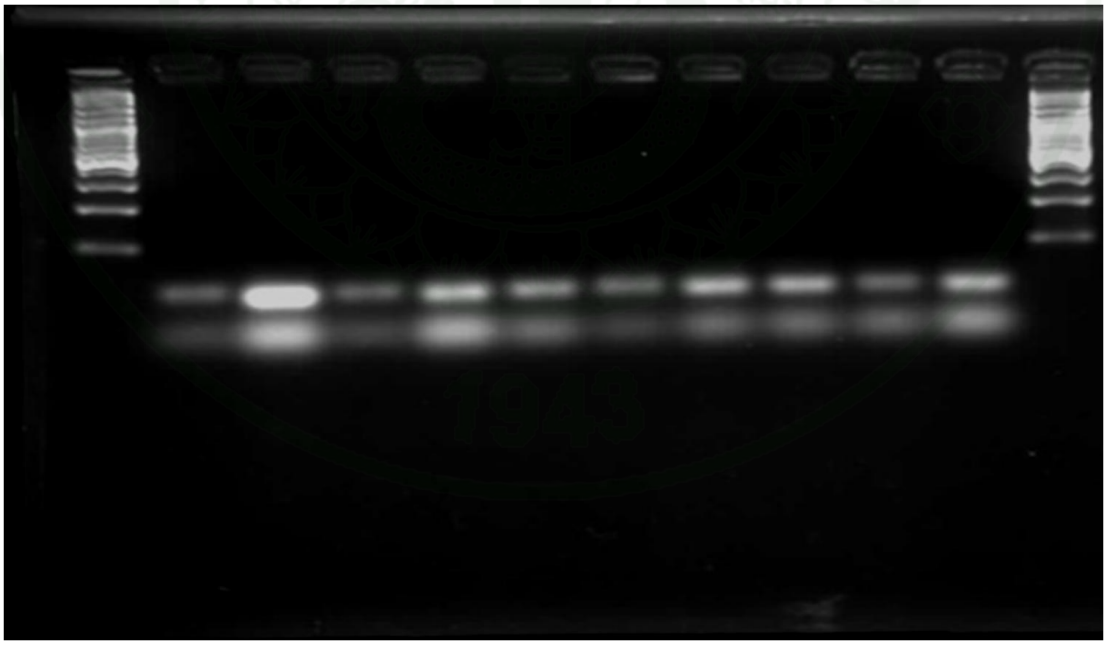


PCR amplified DNA products of varieties 16 to 25 by primer pair **PII.**

Appendix Figure D1 (Continued)

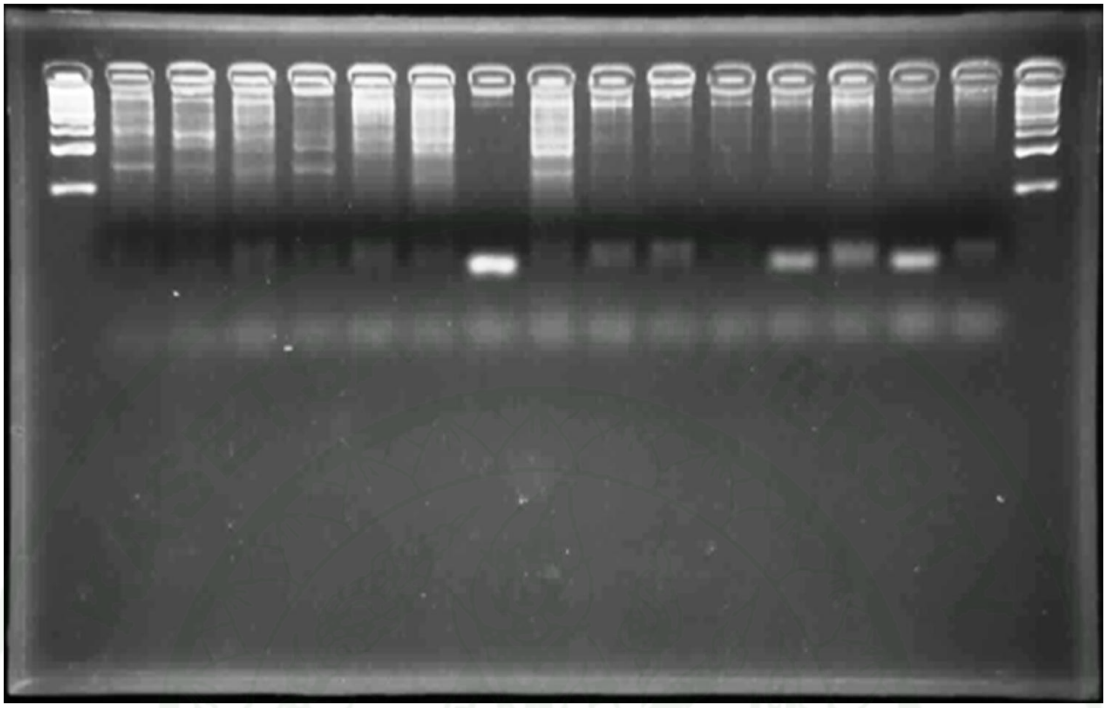


PCR amplified DNA products of varieties 1 to 15 by primer pair **STRBCS3**.

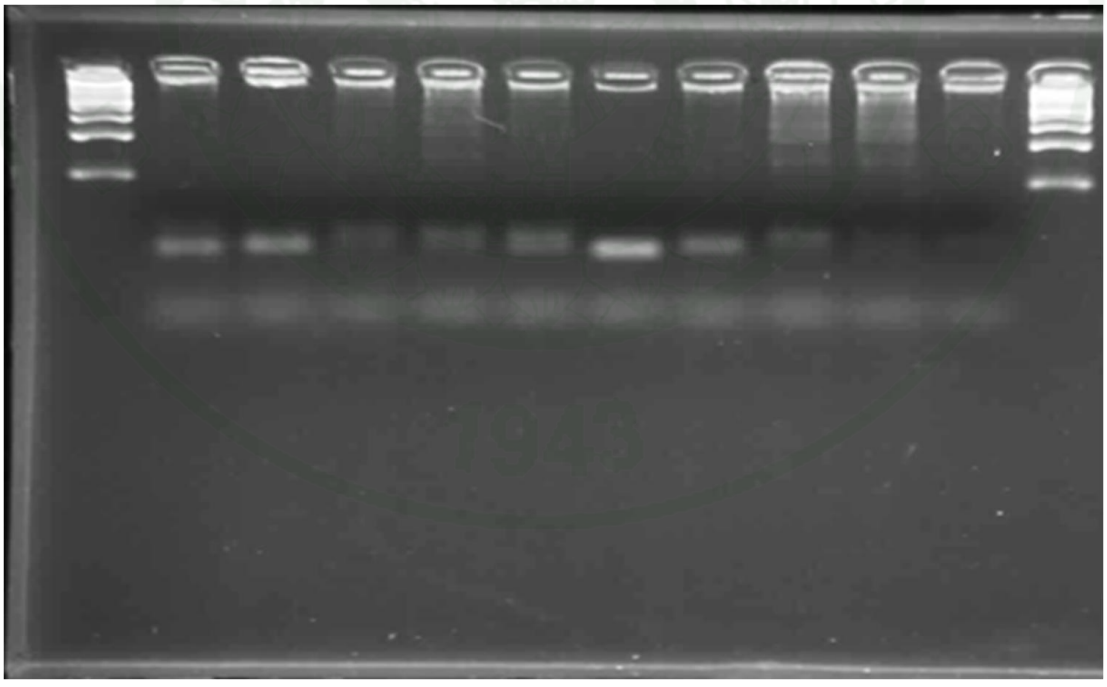


PCR amplified DNA products of varieties 16 to 25 by primer pair **STRBCS3**.

Appendix Figure D1 (Continued)

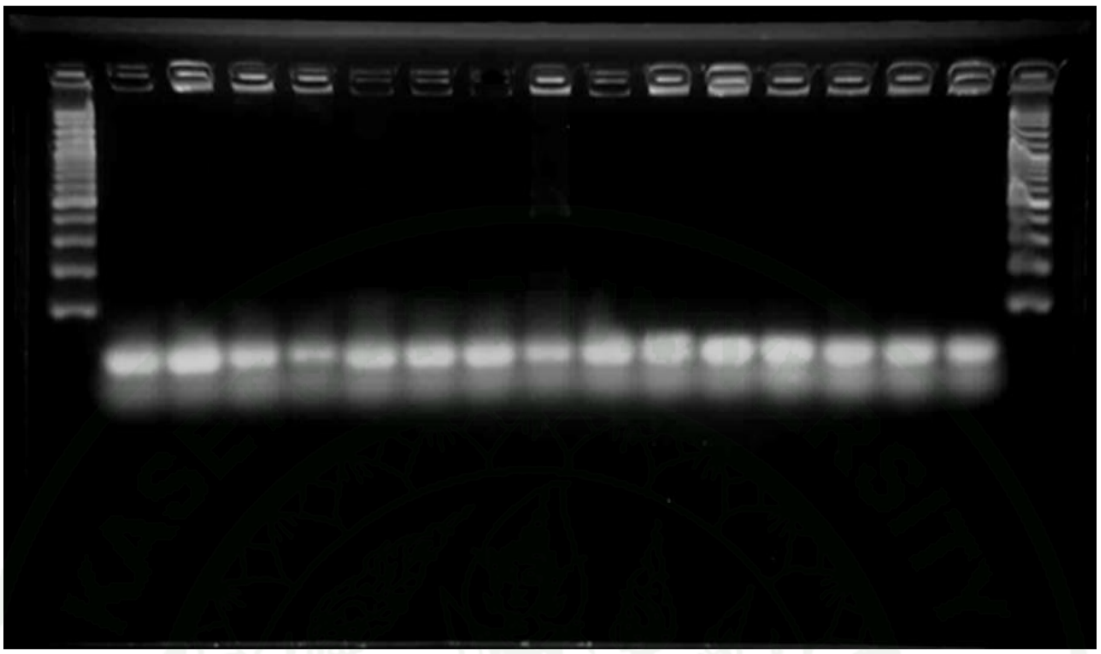


PCR amplified DNA products of varieties 1 to 15 by primer pair **STCPKIN3**.

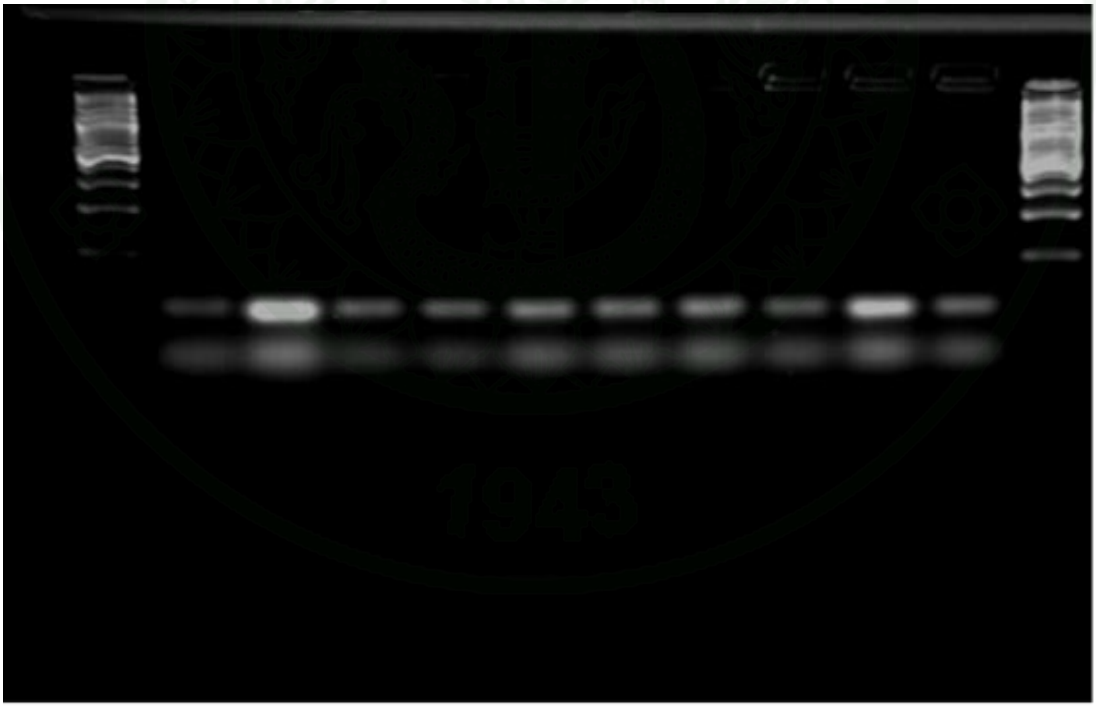


PCR amplified DNA products of varieties 16 to 25 by primer pair **STCPKIN3**.

Appendix Figure D1 (Continued)



PCR amplified DNA products of varieties 1 to 15 by primer pair STPATP1/**TF11**.



PCR amplified DNA products of varieties 16 to 25 by primer pair STPATP1/**TF11**.

Appendix Figure D1 (Continued)

CURRICULUM VITAE

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BIRTH DATE May 9, 1967

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1990	Haromaya University /Ethiopia	B. Sc. (Plant Science)
2001	Free State University /South Africa	M. Sc. (Plant Breeding)

POSITION/TITLE Associate Researcher

WORK PLACE Adet Agricultural Research Center/ Ethiopia

SCHOLARSHIP/AWARDS Rural Capacity Building Project of Ministry of Agriculture of Ethiopia Scholarship 2010-2013

PUBLICATION

Published 18 proceeding articles, two bulletins related to potato production, handling and utilization, and on-farm healthy seed tuber production in local language (Amharic) to be used by researchers, extension workers and farmers. Compiled and edited a proceeding containing two decades research and extension endeavors and future strategy on potato in Amhara Region of Ethiopia.

Published and on review process journal articles from the thesis are:

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

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

Tesfaye, A., S. Wongchaochant, T. Taychasinpitak and O. Leelapon. 2013. Evaluation of specific gravity of potato varieties in Ethiopia as a criterion determining processing quality. To be published in **Kasetsart J.**.**(Natural Sci.)** 47(1):

Tesfaye, A., S. Wongchaochant, T. Taychasinpitak and O. Leelapon. 2013. Variation in chemical composition and pasting properties of starches of different potato varieties grown at three different locations in Amhara Region. To be published in **Kasetsart J**. **(Natural Sci.)** 47(2):

Tesfaye, A., S. Wongchaochant and T. Taychasinpitak. 2013. Phenotypic diversity analysis within cultivated potato (*Solanum tuberosum* L.) in Ethiopia at three distinct locations based on morphological characteristics. On review process.