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Variation of Mineral Concentrations Among Different Potato Varieties Grown at Two Distinct Locations in Ethiopia

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ABSTRACT

The extent of genetic variation in the protein and fiber contents and the iron (Fe), zinc (Zn) and phosphorus (P) concentrations of 21 different potato varieties was studied at two distinct locations in Ethiopia. The experiments were conducted in a randomized complete block design in triplicate. Analysis of variance (ANOVA) of each set of experimental data revealed significant ($P < 0.01$) genetic variation among varieties. The combined ANOVA also showed significant ($P < 0.01$) variation due to location and genotype × location interactions. Accordingly, the tuber protein and fiber contents ranged from 3.77 to 7.36% and 1.18 to 2.07%, respectively. Likewise, the Fe, Zn and P concentrations ranged from 17.13 to 164.83, 7.07 to 20.21 and 143.68 to 357.76 $mg.kg^{-1}$ dry weight, respectively. Consequently, men, women, and children can get 29, 13.3 and 65%, respectively, of their daily recommended nutrient intake (RNI) of Fe from eating 200 g fresh weight of tubers of the high Fe concentration variety Sisay and 12, 14.3 and 17%, respectively, of their daily RNI of Zn from 200 g of tuber of the high Zn variety Menagesha. Correlation analysis indicated a significant ($P < 0.01$) association among these characters but not with protein and fiber with Fe. Thus, this study found considerable variation in the mineral concentrations among potato varieties in Ethiopia which can be useful information to help curb mineral malnutrition.

Keywords: malnutrition, mineral concentration, genetic variation, potato

INTRODUCTION

Potato (*Solanum tuberosum*) is the world's third most important food crop after wheat and rice (Bradshaw and Bonierbale, 2010). It has substantial contribution to human diets in Europe, Asia, Latin America and Africa where the per capita consumption is 88, 24, 21 and 14 kg, respectively (Food and Agricultural Organization, 2008). Biologically, potato produces more dry matter per hectare than the major cereal crops in the world (Gray and Hughes, 1978) and more protein per unit area than any other crop except soybean (Smith, 1984). As a result, it has been estimated that a hectare of potato can feed 22 persons a year while the same area of rice can support 19 persons (Spedding, 1990). Nutritionally, potato is an excellent source of carbohydrate, vitamins and essential minerals; its protein notably contains a higher 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

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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 achieve the daily adult requirement of vitamin C of 100–120 $mg.d^{-1}$ (Naidu, 2003). Interestingly, the bioavailability of minerals in potato tuber is higher than 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 has a 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).

In Ethiopia, potato is one of the widely cultivated tuber crops that serves as an important food and income source to well over 2.3 million people dwelling in the highland areas (Central Agricultural Census Commission, 2003). However, like in many developing countries, most people of Ethiopia subsist on cereal-based diets that are low in essential micronutrients such as iron, zinc and vitamin A (Medhin *et al*., 2010). Malnutrition of iron and zinc has emerged as a serious problem affecting more than two billion people worldwide (Welch and Graham, 2004). Similarly, vitamin A deficiency is affecting 190 million children aged under 5 y (World Health Organization, 2009). Umeta *et al*. (2000, 2003) and Medhin *et al.* (2010) have also reported the prevalence of zinc and vitamin A deficiencies in Ethiopia and their widespread effect on the weight and height of children aged 5–12 mth and on women's eyesight. Malnutrition associated with a lack of these nutrients also impairs physical and cognitive development, increases child morbidity and mortality and reduces the productivity of both adult men and women due to the increased risk of illness and reduced work capacity (Bouis and Welch, 2010). Traditional intervention of mineral malnutrition has focused on fortification, supplementation and dietary diversification (White and Broadley, 2005). Biofortification has recently emerged as a cost effective and sustainable strategy of malnutrition management (Horton, 2006). This approach focuses on elevating the concentration of micronutrients in the edible parts of staple crops (Welch and Graham, 2002). Genetic enhancement largely depends on the genetic variability present within the available gene pool. Mineral concentration studies carried out on potato by Anderson *et al.* (1999), Burgos *et al*. (2007), Andre *et al*. (2007) and Ekin (2011) have revealed variability in the Fe concentration ranging from 11.71 to 131.05, 9 to 37, 29.87 to 157.96 and 48.85 to 122.69 $mg.kg^{-1}$, respectively. Equally, Tekaligne and Hammes (2005), Burgos *et al.* (2007), Andre *et al.* (2007) and Ekin (2011) reported Zn concentrations ranging from 13.17 to 20.83, 8 to 20, 12.60 to 28.83 and 12.50 to 18.96 $mg.kg^{-1}$, respectively. To date, no such work has been done on the released varieties and cultivars widely grown by farmers in Ethiopia. The main objective of this study was to examine the variation in tuber protein and fiber content and the iron, zinc and phosphorus concentrations among 15 released varieties, 3 cultivars widely grown by farmers and 3 candidate potato varieties at two distinct locations in Ethiopia.

MATERIALS AND METHODS

Genetic material

In total, 21 varieties composed of 15 improved varieties released by the national research system, 3 widely grown farmer's cultivars and 3 elite clones were studied. These varieties differed from each other in their maturity, yield, disease resistance, tuber quality factors and other morphological descriptions. These varieties were tested at two distinct locations, Merawi and Debretabor, which have dissimilar edaphic and climatic conditions.

Description of the experimental sites

Merawi is a mid altitude area geographically positioned at $11^0$30’0" N latitude and -$37^0$0’0″ E -longitude. Its soil type is a red Nitosol. Conversely, Debretabor is situated in the cool highlands at an elevation of 2,706 meters above sea level and $11^0$51’0″ latitude and $38^0$1’0″ E longitude. Its soil is a Luvisol. The rainy season at both sites ranges from May to October and is sufficient for growing crops with 120–150 d of maturity without any moisture supplement. The amount of rainfall received at Merawi and Debreabor during the cropping season is 1,558 and 1,488 mm, respectively (Ethiopian Bahir dar Branch Office, pers. comm.). Details of the soil pH, cation exchange capacity (CEC), organic matter (OM) content, available N, P, K and texture of these sites are indicated in Table 1(Adet Agricultural Research Center, Soil Science Research Department, pers. comm.).

Field experimentation

The 21 potato varieties were planted in a randomized complete block design with three replications on a gross plot size of 9 m^2 at the respective sites. Each plot was planted with a total of 40 tubers spaced at 0.75 × 0.3 m inter- and intra-row spacing, respectively. The plants at Merawi were fertilized with 81 $kg.ha^{-1}$ nitrogen (N) and 69 $kg.ha^{-1}$ phosphorus (P_2O_5). Conversely, at Debretabor, each plot received 108 $kg.ha^{-1}$ N and 69 $kg.ha^{-1}$ P_2O_5 following specific recommendations. All the P_2O_5 was applied at planting just below the seed tuber with a light covering of soil to avoid direct contact with the seed tuber while N was applied in equal amounts, first at planting, then two weeks after emergence and finally at flowering to reduce leaching losses and to match with the critical times of plant nutrient requirement. All other practices were undertaken as needed. At maturity, a total of 1 kg of healthy sample tubers was randomly drawn from the three replicates of each variety at each location and pooled for the nutrient concentration analysis.

Sample preparation

First, sample tubers of each variety were thoroughly washed with tap water and rinsed with distilled water to remove any soil and inert material on the tubers. Then, the tubers were lightly peeled with a peeler and shredded into pieces. Subsequently, a 500 g composite sample of randomly drawn tubers was weighed and placed onto a cleaned, dried and desiccated cap. The sliced tuber in the cap was then dried in a hot air of oven at 70 °C for 48 hr, after which the samples were removed from the oven and weighed to compute the moisture and the dry matter content of each sample. Finally, the dried sample was finely ground into a powder with a laboratory grade mill and subsequently used for mineral concentration analysis.

Table 1 Physicochemical properties of soils at Merawthei and Debretbor experimental sites.

Experimental site	Altitude (m)	Soil physical and chemical properties						
		Soil pH	Total N (%)	Available P (ppm)	Available K (Cmol(+) $.kg^{-1}$)	CEC (Meq/100g)	Organic matter (%)	Texture
Merawi	1,960	5.0	0.19	8.70	0.7680	26.00	2.75	Heavy clay
Debretabor	2,630	4.94	0.20	17.18	0.3392	31.74	3.00	Clay

Analysis by Adet Agricultural Research Center, Soil Science Research Department.
ppm = parts per million; CEC = Cation exchange capacity.

Mineral determination

The dried and ground analytical samples were analyzed for total nitrogen by the 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 whereas iron and zinc were determined using atomic absorption spectrometry.

Statistical analysis

Analysis of variance (ANOVA) was performed on the protein and fiber contents and on the iron (Fe), zinc (Zn), and phosphorus (P) concentrations of the 21 potato varieties tested at each location to examine genotypic variation. Furthermore, the pooled data of Merawi and Debretabor were subjected to a combined ANOVA to investigate genotype performance across location, location and genotype × location interaction effects. Correlation analysis was also conducted using the Pearson test to examine the strength of the link between the different minerals, tuber dry matter and marketable tuber yield. The mineral concentration trends in the varieties were also examined at both locations. Finally, the means were compared using Duncan's multiple range test with significance determined at the 1% level of probability. All the statistical computations were performed using SAS (Version 9.2) software (SAS, 2008).

RESULTS

Simple analysis of variance

The results of each separate site ANOVA on the protein and fiber content and the iron, zinc and phosphorus concentrations (on a dry weight basis as the remaining tuber constituent, being water, had no nutritional value) are indicated in Tables 2 and 3. Accordingly, significant ($P < 0.01$) genotypic variation in mineral concentrations was observed among the varieties at each location.

Protein

At Merawi, the protein concentration of these varieties ranged from 3.58% in the improved variety Belete to 7.94% in the improved variety Menagesha (Table 2). The distribution of protein concentration values revealed that 48% of the varieties also had an above average value for the Merawi site (Figure 1). Thus, sufficient genetic variability was present among the germplasm pool in the country. Likewise, at Debretabor, the protein concentration of these same varieties ranged between 3.44% (CIP-395096.2) and 6.77% (Menagesha) as shown in Table 3. In addition, 52% of the varieties tested had a protein concentration above the overall average obtained at this site (Figure 2). Hence, there was a similar trend to that seen at Merawi substantiating the availability of genotypic variability within the genetic pool on hand.

Fiber

The fiber contentof these same varieties at Merawi ranged between 1.25 and 2.51%. The lowest and highest contents, respectively, were recorded for the elite clone CIP-396004.337 and the improved variety Tolcha (Table 2). At the Debretabor site, fiber contentranged 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 the Merawi and Debretabor sites was 8 and 10, respectively (Tables 2 and 3).

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 2 and 3). At Merawi the lowest value was obtained from the improved variety Jalene while the highest was from the improved variety Challa (Table 2). This was followed by the farmer's cultivar Sisay. Equally, the lowest and the highest Fe concentrations accrued at the Debretabor site were from the improved variety Gabisa and the elite clone CIP-396004.337, respectively (Table 3). Sisay, the second lowest at Merawi, was followed by CIP-396004.337. The total number of varieties with a concentration greater than the overall average at Merawi and Debretabor was 6 (29%) and 9 (43%), respectively (Table 2 and 3). The results of these mineral concentrations at the Merawi site were generally higher than those recorded at the Debretabor site.

Zinc

Varieties also displayed considerable variations in the Zn concentration 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 (Table 2 and 3). At Merawi, the lowest value was obtained from the improved variety Belete while the highest was from Menagesha (Table 2). The lowest and the highest Zn concentrations at the Debretabor site were accrued from the elite clone

Table 2 Mean protein and fiber contents, mineral nutrient concentrations and dry matter content of potato varieties tested at Merawi site, 2011.

Variety	Protein content (%)	Fiber content (%)	Fe concentration ($mg.kg^{-1}$)	Zn, concentration ($mg.kg^{-1}$)	P concentration ($mg.kg^{-1}$)	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
CV (%)	1.73	6.13	0.64	3.30	0.07	3.95
SEM	±0.29	±0.32	±1.42	±1.17	±0.59	±2.52

CV = Coefficient of variation; SEM = Standard error of mean; DMC = Dry matter content.

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.

Hunde and Menagesha, respectively (Table 3). A total of 9 (43%) varieties at Merawi and 9 (43%) varieties at Debretabor had a concentration above the average value obtained at each respective location (Tables 2 and 3). Of the two locations, the tested varieties obtained their highest Zn concentrations at the Merawi site.

Phosphorus

Similar to the other mineral concentrations, 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 (Tables 2 and 3). At Merawi, the lowest value was obtained from

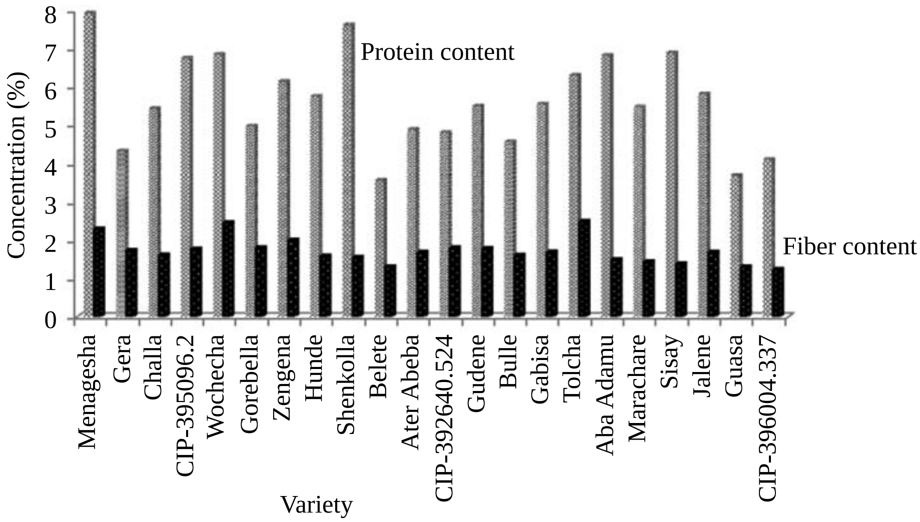

Figure 1 Protein and fiber concentration values distribution of potato varieties at Merawi site.

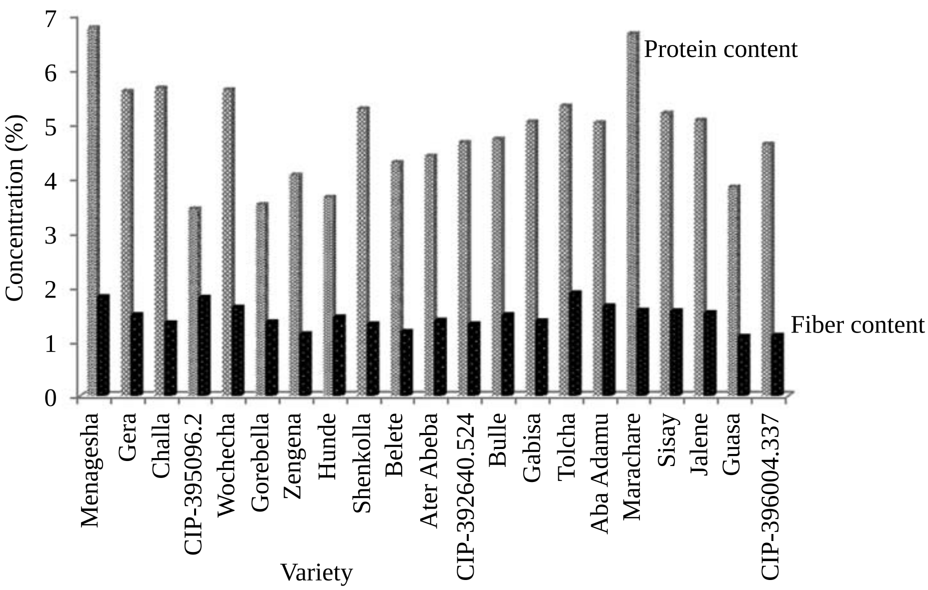

Figure 2 Protein and fiber concentrations distribution of potato varieties at Debretabor site.

the improved variety Belete while the highest was from Menagesha (Table 2). The lowest and the highest P concentrations at the Debretabor site were obtained from the improved variety Wochecha (49.45 mg.kg^{-1}) and the farmer's cultivar Sisay (362.07 mg.kg^{-1}), respectively (Table 3). In addition, 10 (48%) varieties at Merawi and 9 (43%) varieties at Debretabor exceeded the average phosphorus concentration recorded at the respective locations (Tables 2 and 3). Interestingly, varieties showed similar distribution trends in all three mineral concentrations at both locations but with quantitative differences (Figures 3 and 4).

Combined analysis of variance

The results of the across location ANOVA indicated significant (P < 0.001) variation due to genotype, location and genotype × location interactions. Accordingly, the protein and fiber contents and the Fe, Zn and P mean concentrations

Table 3 Mean protein and fiber contents, mineral nutrient concentrations and dry matter content of potato varieties tested at Debretabor site, 2011.

Variety	Protein content (%)	Fiber content (%)	Fe conc. (mg.kg^{-1})	Zn conc. (mg.kg^{-1})	P conc. (mg.kg^{-1})	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
CV (%)	6.91	6.97	1.89	6.51	0.41	3.36
SEM	±1.01	±0.31	±1.85	±1.88	±2.18	±2.59

CV = Coefficient of variation; SEM = Standard error of mean; DMC = Dry matter content.

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.

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 4).

The highest protein (7.36%) and fiber (2.07%) contents and the highest Zn (20.21 mg.kg^{-1}) concentration were obtained from the improved variety Menagesha. The highest Fe concentration of 164.83 mg.kg^{-1} and the highest P concentration of 357.76 mg.kg^{-1} were recorded for the farmer's cultivar Sisay (Table 4). The mineral concentration index of the Merawi site was higher for all mineral types. Clearly, this was a manifestation of the effects of environment on the nutritional concentration of varieties. The genotype × environment interaction also displayed varietal

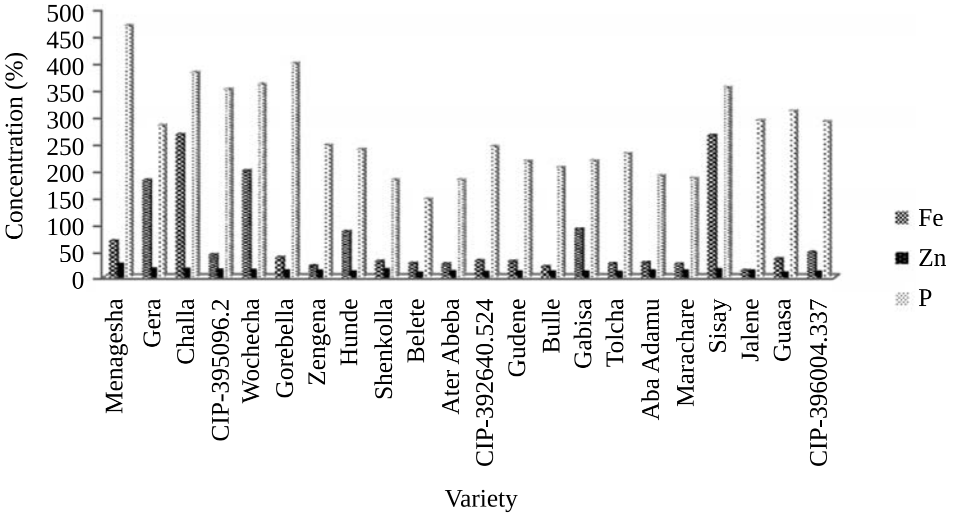

Figure 3 Fe, Zn and P concentration distribution of potato varieties at Merawi site.

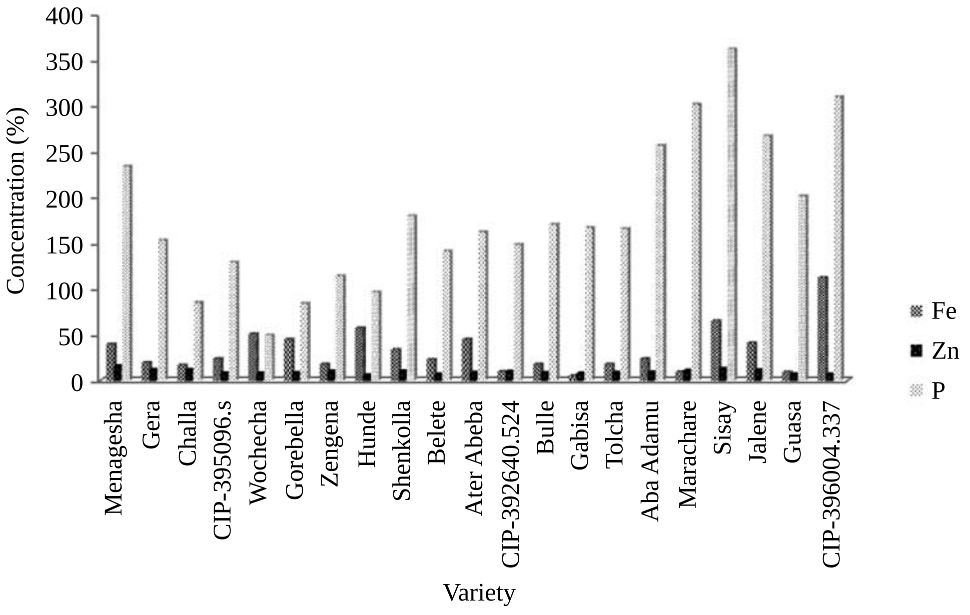

Figure 4 Fe, Zn and P concentration distribution of varieties at Debretabor site.

performance differences across environments. Overall, 48 and 33% of varieties had protein and fibercontents, 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 4). Thus, there existed a potential to complement biofortification as one of the sustainable strategies of controlling mineral malnutrition in addition to the efforts already in progress by way of dietary diversification, supplementation and fortification.

Correlation analysis among the essential nutrients and that of DMC and tuber yield (TY) is indicated in Table 5. 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

Table 4 Combined analysis of variance of mean protein and fiber contents, mineral nutrient concentrations and dry matter content of potato varieties tested at Merawi and Debretabor sites, 2011.

Variety	Protein content (%)	Fiber content (%)	Fe conc. (mg.kg^{-1})	Zn conc. (mg.kg^{-1})	P conc. (mg.kg^{-1})	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
CV (%)	4.74	7.08	1.13	4.42	0.23	2.31
SEM	±0.75	±0.34	±1.82	±1.42	±1.56	±1.63

CV = Coefficient of variation; SEM = Standard error of mean; DMC = Dry matter content.

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.

5). The association between tuber protein, fiber and Fe concentration was positive but weak and statistically insignificant. Tuber protein and fiber had a significant ($P < 0.01$) negative relationship with TY as expected. Tuber Fe and Zn had an insignificant negative association with TY. Conversely, tuber P concentration and TY had an insignificant and very weak positive association. As expected, the tuber DMC had a significant ($P < 0.05$) relationship with TY (Table 5).

DISCUSSION

Varietal differences in the 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 8.1to 12% in 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 cultivars and Ekin (2011) from 10.9 to 13.8% from a study conducted on eight varieties. Despite the variability of the genetic material and the diversified agroecologies and fertilizer management regimes in these studies, the protein content ranges obtained in the current study—namely, 3.58 to 7.94% at Merawi and 3.44 to 6.77% at Debretrabor—generally corroborate the earlier reports except for some downward deviation. Presumably, these differences can be attributed among other factors to the differential ability in the mineral mining and use efficiency of the varieties (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 a 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 disease through a 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 results of the current study of 1.8 g fiber per 100 dry weight corroborate the literature reporting an average of 2 g (Dale and Mackay, 1994).

Smith (1968) reported that the concentration of Fe, Zn and P in potato tubers could range from 30 to 185, 17 to 22 and 430 to 605 $mg.kg^{-1}$, respectively, on a dry weight basis. Ekin (2011) reported Fe and Zn concentrations of 75.03 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

Table 5 Correlation among protein and fiber contents, Fe, Zn and P mineral nutrient concentrations, dry matter content and tuber yield 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*
TY							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 ($P < 0.01$).

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 the concentrations of Fe, Zn and P were obtained. Moreover, these data indicate that breeding for increased bioavailability of Fe and Zn concentrations is, in principle, feasible as the heritability of the Fe concentration in potato is moderately high (Bradshaw and Bonierbale 2010).

The significant environment and genotype × 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 in different years. Clearly, this is a common observation for many characters as environmental factors do differ in different years and do influence crop variety performances differently pertaining to the prevailing set of environmental conditions in each set of sampled years. A Nitosol soil type, which is normally considered a good agricultural soil in the Food and Agricultural Organization soil classification system, may have contributed to the better concentrations observed at the Merawi site in contrast to the Luvisol at the Debretabor site which is classified as an infertile soil (Waithaka *et al*., 2007). This fertility difference between the two trial sites has clearly been reflected in the mineral concentrations of plants which is determined by the phyto-availability of nutrients within the soil and the variation in nutrient uptake and use efficiency (White and Brown, 2010).

The negative association between crude protein and the dry matter content observed here agrees with the earlier works of Tekaligne and Hammes (2005) and Gray 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 association in both cases is attributed to a “dilution effect” caused by the high plant growth rates that exceed the ability of the 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. 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 a low calorie intake and a lack of protein caused by the low economic capacity of the 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 the associations among minerals were also observed. The improved variety Menagesha, the farmer’s cultivar Sisay and 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 the 21% bioavailability of Zn in developing countries, the World Health Organization (2009) recommended 27.4, 58.8 and 12 $mg.d^{-1}$ of Fe for men, women and children, respectively. Additionally, the World Health Organization (2009) recommended 6, 4.9 and

4.1 mg.d^{-1} of Zn for men, women and children, respectively. Consequently, men, women and children can get 29, 13.3 and 65% , respectively, of their daily RNI of Fe from eating 200 g fresh weight (FW) of tubers of the high Fe concentration variety Sisay 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. 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 detailed analysis of soil nutrients.

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