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Full Length Research Paper

Some analytical quality characteristics for evaluating the utilization and consumption of potato (S*olanum tuberosum* L.) tubers

Zehra Ekin

Yüzüncü Yil University, Faculty of Agriculture, Department of Field Crops, Van, Turkey.
E-mail: zehraekin@yyu.edu.tr. Fax: +90 432 2251104.

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Potato tubers were widely evaluated as a source of carbohydrates, protein, minerals and vitamins for the human diet. In view of the importance of consumer's preferred potato types in use and consumption, the purpose of this research was to determine the physical and chemical quality of potato tubers and identify the best forms of use and consumption. The experiment was designed in randomized block design with three replications under field conditions in Ahlat district of Eastern Anatolia region of Turkey, in 2007 and 2008. The physical quality aspects represented by tuber width, tuber length, tuber shape, tuber calibration, specific gravity and water content and the some chemical quality characteristics represented by crude protein, starch content and mineral elements were influenced by cultivar. In this study, the highest starch content and specific gravity obtained from Melody and Lady Olympia, whilst the lowest protein content obtained from Pasinler 92 and Caspar. Tubers of cultivars Melody, Pasinler 92 and Lady Olympia were outstanding with best characteristics for industrial processing. Lady Olympia and Melody were suitable for frying, cooking and roasting. Tubers of Pasinler 92, Caspar, Lady Christl, Granola, Van Gogh and Marfona were appropriate suitable for boiling and more specifically for salads. However, this study demonstrated the wide variability of health-promoting micronutrient levels within the potato cultivars as well as the significant contribution that distinct potato tubers may impart to the intake in dietary iron and zinc.

Key words: Potato, cultivar, starch content, minerals, iron, zinc.

INTRODUCTION

Traditionally, consumers select potatoes by visual characteristics such as tuber size, shape, color and skin brightness in the fresh market. However, there has been an increasingly higher interest on the part of consumers for use of the nutrient-rich potato, because population-based epidemiological studies have stressed the important role of diet (especially mineral malnutrition) and lifestyle in the emergence of many degenerative chronic diseases such as cancers and cardiovascular diseases, in both developed and developing countries (Andre et al., 2007). Potato is a frequent item in the human diet; it is used in a variety of ways. Freshly harvested, it contains about 80% water and 20% dry matter. About 60 to 80% of the dry matter is starch. On a dry weight basis, the protein content of potato is similar to that of cereals and is very high in comparison with other roots and tubers. Potato protein is of a fairly high quality because of the physiologically valuable amino acid composition that well matches human requirements. In addition, the potato is low in fat and rich in several micronutrients (Lutaladio and Castaldi, 2009). It supplies the necessary daily requirements of various substances including macro and micro elements. Humans require at least 25 mineral elements for their well-being (White and Brown, 2010) and these mineral elements enter the food chain through plants. Potatoes are also an excellent source of these elements. A single, medium-sized potato weighing 200 g fresh

Abbreviations: DW, Dry weight; **FW,** fresh weight; **IV,** index value; **FAO,** food and agriculture organization; **WHO,** World Health Organization; **RNI,** reference nutrient intake; **DRI,** dietary reference intake; **LTA,** long term average.

weight can provide about 26% of the US dietary reference intake (DRI) of Cu, 17 to 18% of the DRI of K, P and Fe and between 5 and 13% of the DRI of Zn, Mg and Mn (White et al., 2009). Potatoes are generally not rich in Ca, but can be a valuable source of trace elements, such as Se and I, if fertilized appropriately (Karenlampi and White, 2009). Moreover, since potato tubers have relatively high concentrations of organic compounds that stimulate the absorption of mineral micronutrients by humans, such as ascorbate (vitamin C), protein cysteine and various organic and amino acids and low concentrations of compounds that limit their absorption, such as phytate (0.11 to 0.27% dry matter) and oxalate (0.03% dry matter), the bioavailability of mineral elements in potatoes is potentially high (Karenlampi and White, 2009).

The potato has high biological and nutritional value. Unlike most other vegetable crops, it also has a high-energy value. Potato is a vegetatively-propagated crop, producing harvestable tubers below ground. A potato tuber is a greatly shortened and swollen part of an underground stem. Potato tubers have high water content and are sensitive to environmental impacts during their production and storage. Cultivar, growth conditions, crop management, cultivation practices and storage conditions influence tuber quality (Karenlampi and White, 2009). Each potato cultivar has unique tuber appearance and nutritional composition. The maintenance of tuber quality is also important for potatoes destined for direct consumption, processing and propagation. There are two important classes of tuber quality: Physical and chemical or external and after-cooking quality (Storey and Davies, 1992). Physical quality aspects were determined with regard to tuber size, physical characteristics such as shape and wounds, appearance, defects and health, specific gravity and dry matter content (Högy and Fangmeier 2009). Chemical quality analyses comprised concentration of proteins, mineral elements, starch, reducing carbohydrates, organic acids, amino acids, glycoalkaloids and anions (Storey and Davies, 1992). Dry matter accounts for as much as 60 to 80% of the tuber DW and is the major storage component of tubers (Kolbe and Stefan-Beckmann, 1997). Starch concentration is very often considered to represent the dry matter content of potatoes (Högy and Fangmeier, 2009). It is of major importance for the taste and the properties such as viscosity and consistency of the tubers. The potato is used for a large number of industrial and food processing applications because of its high starch content. Especially to produce crisps and potato chips, quality aspects are of particular importance (Liu et al., 2003). In growing potato tubers, starch concentration increases towards maturity and thus, mature tubers have high starch and protein concentrations, but are low in sugar. Therefore, the length of growing period of tubers has an important effect on the starch concentration of harvested tubers. Its concentration depends on cultivar, growth conditions and cultivation practices and desired functional properties of starch could be achieved by the selection of potato cultivar and controlling growth time (Storey and Davies, 1992). However, the potato processing industry sets high quality standards and when tubers are marketed for industrial processing of tubers, the portions of certain size-grades and the dry matter content of tubers play an important role. The industry processing potatoes into French fries demands tubers graded >50 mm for French fries and 40 to 65 mm for crisps (Haase et al., 2007). In addition to size and shape, tuber specific gravity is the most important quality parameter of tubers (Storey and Davies, 1992). Specific gravity is highly correlated with dry matter content and the lower tuber specific gravity may result in poorer processing quality (Högy and Fangmeier, 2009). The proteins and macro-minerals are important potato quality criteria because of their physiological and nutritional value in human food. Typical average concentrations are 8.8% DW for protein, 3.3 mg P g^{-1} DW, 18 mg K g^{-1} DW, 0.4 mg Ca g^{-1} DW, 1 mg Mg g^{-1} DW and 9 g Mn g^{-1} DW (Kolbe and Stefan-Beckmann, 1997). Mineral elements are not synthesized by the plant. They must be acquired from the soil solution by the plant roots. Although, tubers have associated roots, with the possible exception of Ca, these roots appear to supply only small amounts of minerals to tubers (Karenlampi and White, 2009). Most of the minerals present in potato tubers appear to have been taken up originally by the main roots that deliver them first to the shoot via the xylem. The mineral composition of potato tubers is determined to a great extent by the availability of mineral elements in the soil. It is generally observed that the application of mineral fertilizers increases tuber concentrations of the minerals supplied. This is true for fertilizers containing both macronutrients, such as N, P, K, Ca and Mg (White et al., 2009) and micronutrients, such as B, Zn, Fe, Mn, Cu, Mo, Se and I (Karenlampi and White, 2009). Besides, there is considerable variation in tuber mineral concentrations among genotypes of cultivated potatoes (White et al., 2009). When grown under identical conditions, S*olanum tuberosum* genotypes have been shown to differ in tuber N, P, S, K, Ca, Mg, Fe, Zn, Mn and Cu concentrations (Tekalign and Hammes, 2005; Karenlampi and White, 2009; White et al., 2009) and systematic differences in tuber K, Mg, Fe, Zn, Mn and Cu concentrations have been observed between potato varieties obtained commercially (Rivero et al., 2003; Di Giacomo et al., 2007).

Also, the concentrations of mineral elements in tissues of potato plants change with plant age. Tuber concentrations of many mineral elements change dramatically in the weeks following tuber initiation, but their concentrations remain relatively constant during the final stages of crop development (Kolbe and Stephan-Beckmann, 1997; Karenlampi and White, 2009). The distribution of mineral elements also varies within the potato tuber. Variations in concentrations of mineral elements can exist between the stem end and the distal end of the potato tuber and some elements such as the cations K, Ca, Mg, Fe, Zn, Mn and Cu are more concentrated in the potato skin relative to the flesh (Karenlampi and White, 2009). Because there is now heightened awareness of potential nutritional differences among cultivars, the objective of this study therefore, was to determine the physical and chemical quality of potato cultivar tubers in order to identify their best forms of use and consumption.

MATERIALS AND METHODS

The physiologically mature tubers of potato cultivars, from field experiments were conducted on a farm located in Ahlat district (38°46'N and 42°30'E with an altitude of 1722 m), Eastern Anatolia region of Turkey in 2007 and 2008, were used in the analysis of physical and chemical quality. In this study, Caspar (late maturity), Van Gogh (medium late), Pasinler-92 (medium early), Lady Olympia (medium late), Lady Christl (early maturity), Marfona (medium early), Melody (medium late) and Granola (medium late) were used as plant materials.

The experimental soil was a silt-clay-loam with organic matter content of 2.6%, pH 7.7 and 4.5% lime content. Available P_2O_5 (Spectrophotometrically), K_2O (Ammonium acetate method) and total nitrogen (Kjeldahl method) contents were 8.18 ppm, 2076.7 ppm and 0.13%, respectively. In 2007 to 2008 and 2008 to 2009, total rainfall during growing season (from May to September) was 133.8 and 201.8 mm, respectively and the average temperature for the same period was 17.5 and 16.3°C, respectively (Table 1).

The experimental design was completely randomized block design with three replications. Half of the N (200 kg N ha^{-1} as ammonium sulfate, 21%), full P (100 kg P_2O_5 ha^{-1} as triple super phosphate, 45%) and K (150 kg K_2O ha^{-1} as potassium phosphate, 50%) were applied at planting. The remaining half of the N was applied at the time of hilling when the plants were about 15 to 25 cm high. The experimental crop was planted in furrows 10 cm depth at 70 cm inter row spacing and 30 cm intra row spacing on late May in each year (Ekin et al., 2009). Plots were harvested to maturating period of cultivars on 20 September-10 October 2007 and 25 September-20 October 2008. Throughout the growing season, the production system was managed according to the management practices recommended in the region, which included irrigation as needed.

Physical quality analysis

Physical quality aspects were determined with regard to tuber shape, tuber calibration, specific gravity and water content (Högy and Fangmeier, 2009). In line with commercial practice to allow the tuber skins to set before being harvested, the tubers were sampled seven days after aboveground harvest. Potato tubers were rinsed in water and immediately subdivided by using a sieve into three size classes (<35 mm: not for consumption or non-commercial; 35 to 50 mm: for direct consumption or commercial; >50 mm: for industrial use) (Ekin, et al., 2009). Tubers in each size class were counted and fresh weight (FW) was determined. Tuber shape was calculated by the relation I.V.= L/Wx100, where, I.V. is the index value of the tuber; L is the length of the tuber and W is the width of the tuber. Tuber shape was determined by index value as round (<109), oval (130 to 149), long (170 to 199), short-oval (110 to 129), long-oval (150 to 169) and so on (Esendal, 1990; Pieterse and Hils, 2009). Tuber specific gravity was determined using the weight in air/ weight in water method on a 5 kg sample of the marketable potatoes (Edgar, 1951; Esendal, 1990). Tuber water content was the ratio between dry and fresh mass expressed as a percentage and determined by drying a representative 1 kg sliced sample at 70°C for 48 h (Esendal, 1990).

Chemical quality analysis

Chemical quality analyses comprised content of starch, protein and mineral elements (P, K, Mg, Ca, Fe, Mn, Zn and Cu). Analyses for physical and chemical quality parameters were performed for the tubers larger than 35 mm in order to identify the important quality traits for consumption and industrial processing. Tubers were processed with their skin due to the difficulty of uniformly peeling certain potato tubers with irregular shape. The starch content was determined according to Esendal (1990) using the specific gravity measurements. Total nitrogen (N) was analyzed by the Kjeldahl method and used for the calculation of the crude protein concentration by multiplying with a conversion factor of 6.25. Total phosphorus (P) was measured with spectrophotometer at 580 nm. Minerals were determined after extraction using atomic absorption spectrometers in a thermo solar AA series instrument at the Yüzüncü Yil University. Concentrations were expressed on a dry weight (DW) basis (Högy and Fangmeier, 2009).

Statistical analysis

Data were evaluated by analysis of variance using SAS software (SAS Institute, Cary, NC, USA) and significant differences of means were determined by Duncan's multiple range test by MSTAT-C software at $p < 0.05$ level. The significantly different means were denoted by different letter.

RESULTS AND DISCUSSION

Analysis of variance showed statistically significant differences between years for the all characteristics evaluated (Tables 2, 3, 4 and 5). The potatoes are known to be sensitive to environmental impacts, which are primarily due to the effects on tuber formation and cultivar, growth conditions, crop management and cultivation practices influence tuber quality (Storey and Davies, 1992). More favorable climatic conditions throughout vegetative period of tubers resulted in a relatively higher tuber quality characteristics in 2007. The preferable rainfall distribution, growing season mean temperatures and global irradiance, the main driving forces for crop growth and tuber production, coincided with the tuber initiation and the establishment of the crop canopy in 2007 (Table 1). The summer 2008 was also cool and irregularly wet when compared with the warmer and sunnier growing season 2007. Thus, favorable conditions during haulm growth in 2007 resulted in a large haulm surface and maintained tuber growth at a higher rate for a longer time period leading to higher starch content and specific gravity (Salisburry and Ross, 1992). However, the potato cultivars may vary significantly in tuber appearance, processing, sensory and nutritional qualities. Each potato cultivar has a

Table 1. Monthly rainfall (mm), temperature (°C), and relative humidity (%) in 2007 and 2008 with long term averages (1975 to 2007).

Month	Mean air temperature (°C)			Monthly rainfall (mm)			Relative humidity (%)		
	2007	2008	LTA*	2007	2008	LTA	2007	2008	LTA
May	13.8	10.7	12.1	30.6	39.0	73.3	59.3	51.8	65
June	17.6	16.7	17.6	35.3	4.6	26.8	50.2	39.2	56
July	20.4	21.6	22.1	20.7	2.0	6.7	47.8	32.1	50
August	21.1	22.7	21.9	8.3	7.7	3.6	46.2	34.9	49
September	18.8	16.1	17.2	14.1	80.9	7.8	37.2	47.4	51
October	13.5	9.8	10.7	24.8	67.6	59.1	56.3	59.4	64
Period (M/T)	17.5	16.3	16.9	133.8	201.8	177.3	49.5	44.1	56
Yearly (M/T)	8.8	8.4	9.0	438.0	401.4	545.9	59.7	52.8	64

*LTA, Long-term average; M, mean; T, total.

Table 2. Tuber width and length, tuber shape and tuber calibration of potato cultivar[1].

Cultivar	Tuber Width (mm)			Tuber Length (mm)			Tuber Shape[2]		
	2007	2008	Mean	2007	2008	Mean	2007	2008	Mean
Caspar	63.6	59.1^{d}	61.3^{bc}	80.8^{ab}	73.9^{b}	77.3^{b}	127.3^{a}	125.0^{bc}	126.2
Van Gogh	64.0	63.4^{de}	63.7^{ab}	82.1^{ab}	76.3^{ab}	79.2^{ab}	128.2^{a}	120.5^{bc}	124.4
Pasinler92	64.7	56.5^{b}	60.6^{bc}	81.3^{ab}	79.6^{ab}	80.5^{ab}	125.8^{a}	141.8^{a}	133.8
L. Olympia	61.3	62.9^{c}	62.1^{b}	81.9^{ab}	80.4^{ab}	81.2^{ab}	134.2^{a}	127.9^{bc}	131.0
L. Christyl	66.4	65.5^{de}	65.9^{a}	79.6^{ab}	76.0^{ab}	77.8^{b}	120.0^{ab}	116.0^{c}	118.0
Marfona	60.3	55.1^{f}	57.7^{c}	65.3^{c}	65.3^{c}	65.3^{d}	108.8^{b}	118.6^{bc}	113.7
Melody	68.0	64.1^{a}	66.1^{a}	85.6^{a}	83.3^{a}	84.5^{a}	126.1^{a}	130.0^{b}	128.1
Granola	61.3	54.9^{e}	58.1^{c}	76.7^{b}	65.3^{c}	71.0^{c}	125.2^{a}	116.8^{c}	121.0
Mean	63.7^{a}	60.2^{b}		79.2^{a}	75.0^{b}		124.5^{b}	124.6^{a}	
F- test									
Cultivars	2.24	5.32**	6.41**	10.04*	7.21**	11.37**	2.77*	5.35**	0.002
CV%	4.93	5.35	4.97	5.59	5.72	5.78	6.23	5.21	5.85

Culitvar	Tuber calibration (%)								
	Unmarketable (<35 mm)			Marketable (35-50 mm)			Industrial (>50 mm)		
	2007	2008	Mean	2007	2008	Mean	2007	2008	Mean
Caspar	4.0^{e}	4.9^{e}	4.5^{d}	15.5^{de}	26.9^{c}	21.2^{c}	80.5^{bc}	68.2^{cd}	74.3^{c}
Van Gogh	8.0^{b}	6.9^{c}	7.5^{b}	17.2^{cd}	26.2^{cd}	21.7^{c}	74.8^{cd}	67.5^{d}	71.2^{c}
Pasinler92	4.5^{de}	4.7^{e}	4.6^{d}	15.5^{de}	19.4^{e}	17.4^{d}	80.0^{bc}	75.8^{b}	77.9^{b}
L. Olympia	5.7^{ce}	6.1^{d}	5.9^{c}	21.2^{bc}	22.6^{de}	21.9^{c}	73.1^{d}	71.3^{c}	72.2^{c}
L. Christyl	7.2^{bc}	9.1^{a}	8.1^{b}	11.4^{e}	25.1^{cd}	18.3^{d}	81.4^{b}	65.8^{d}	73.6^{c}
Marfona	10.6^{a}	8.4^{b}	9.5^{a}	31.4^{a}	40.1^{a}	35.8^{a}	57.9^{e}	51.2^{f}	54.5^{e}
Melody	1.8^{f}	1.6^{f}	1.7^{e}	10.7^{e}	13.6^{f}	11.5^{e}	87.4^{a}	83.8^{a}	86.5^{a}
Granola	6.5b^{d}	5.7^{d}	6.1^{c}	22.5^{b}	33.2^{b}	27.8^{b}	70.9^{d}	61.1^{e}	66.0^{d}
Mean	6.1	5.9		18.0^{b}	25.9^{a}		76.0^{a}	68.1^{b}	
F test									
Cultivars	17.51**	110.34**	52.98**	19.68**	39.24**	53.27**	24.79**	80.34**	76.04**
CV%	18.42	6.55	13.77	14.56	8.66	11.12	4.11	2.75	3.59

[1:] Means followed by different letter within each column are significantly different. CV, Coefficient of variation; **significant at 1%; *, **significant at 5%. [2]Index values for tuber shape; 110-129 is short-oval, 130-149 is oval.

Table 3. Specific gravity and water content of potato cultivar tubers.

Cultivar	Specific gravity (g/cm^3)			Water content (%)		
	2007	2008	Mean	2007	2008	Mean
Caspar	1.077^{a}	1.066^{bc}	1.071^{b}	80.2	80.4^{cd}	80.3^{bd}
Van Gogh	1.073^{b}	1.061^{d}	1.067^{cd}	80.6	83.2^{a}	81.9^{a}
Pasinler92	1.075^{ab}	1.069^{b}	1.072^{b}	79.1	82.6^{ab}	80.9^{ac}
L. Olympia	1.077^{a}	1.076^{a}	1.077^{a}	80.5	79.5^{cd}	80.0^{bd}
L. Christyl	1.070^{c}	1.066^{bc}	1.068^{c}	77.9	79.9^{cd}	78.9^{d}
Marfona	1.066^{d}	1.063^{cd}	1.065^{d}	80.7	80.2^{cd}	80.5^{ac}
Melody	1.077^{a}	1.077a	1.077^{a}	80.0	79.3^{d}	79.6^{cd}
Granola	1.068^{cd}	1.067^{bc}	1.067^{cd}	81.2	81.2^{bc}	81.2^{ab}
Overall mean	1.073^{a}	1.068^{b}		80.0^{b}	80.8^{a}	
F test						
Cultivars	15.59**	4.05**	44.22**	2.18	6.57**	4.23**
CV%	0.18	0.13	0.16	1.57	1.21	1.40

*Data are expressed as mg/kg of dry weight, and the water content of the tubers is given in percent.
Means followed by different letter within each column are significantly different. CV, Coefficient of variation; **significant at 1%; *, **significant at 5%.

relatively characteristic tuber shape and size, carbohydrates, protein and mineral concentrations at maturity and there is considerable variation in tuber characteristics among genotypes of cultivated potatoes (White et al., 2009). As mentioned earlier, significant differences in cultivar according to years were supposed to be related to the genotype × environment interaction effect, since variations in physical and chemical quality aspects of tubers from the same cultivar produced in different environments are common (Salisburry and Ross, 1992; Pieterse and Hils, 2009).

Physical quality aspects of potato tubers

Tables 2 and 3 presented the physical quality aspects, which are relevant for consumption and industrial processing of potato tubers. Significant differences in the tuber width and tuber length were noted among cultivars in both years (Table 2). According to the mean of two years, medium late cultivar Melody produced the higher tuber width (66.1 mm) and length (84.5 mm), followed by L. Olympia, Pasinler 92 and Van Gogh, while Marfona and Granola had generally a lower values than the other cultivars.

With respect to tuber shape, a classification identical to that of tuber width and length was observed. Pasinler 92 and the L. Olympia cultivar with best results for industrial processing presented oval tuber shape (133.8 and 131.0, respectively), while the other cultivars with best results for use and consumption belong to the interval from 110 to 129, that is, Melody, Caspar, Van Gogh, Granola, L. Christyl and Marfona, which had a short-oval tuber shape. In this study, Marfona produced the highest proportion of small (9.5%) and marketable (35 to 50 mm tubers) (35.8%) tubers cultivar, while cultivar Melody had a much smaller proportion of unmarketable (<35 mm, small tubers) and marketable among cultivars. A significant difference was observed among cultivars with respect to large (>50 mm) tuber proportion as required for industrial use (Table 2). According to both years, Melody produced the highest large tuber proportion by 86.5%, followed by Pasinler 92 producing 77.9%, while Marfona (54.5%) and Granola (66.0%) had a lower large tuber proportion than the other cultivars. When tubers are marketed for industrial processing, the portions of certain size-grades and the tuber shape play an important role (Haase et al., 2007). Therefore, the industry processing potatoes into French fries demands tubers grade >50 mm for French fries and 40 to 65 mm for crisps. In this connection, the choice of cultivar for industry processing may also be an efficient agronomic measure to increase financial returns when high portions of larger tubers are required.

Specific gravity showed values ranging between 1.065 and 1.077 g cm^{-3} (Table 3). These values are consistent with the values reported by Tekaling and Hammes (2005). The highest specific gravity was obtained from Lady Olympia and Melody in both years. High specific gravity potatoes are better suited for baking, frying, mashing and chipping; low specific gravity for boiling and canning. The potato chip manufacturers prefer potatoes of high specific gravity. Also, specific gravity is highly correlated with dry matter content, and the lower tuber specific gravity may result in poorer processing quality (Högy and Fangmeier, 2009). Therefore, taking only specific gravity and consequently, yield and oil absorption into consideration during the frying processes (Lulai and

Orr, 1979), the cultivars with best results for frying belong to the interval from 1.070 to 1.085, that is, Melody, Lady Olympia, Pasinler 92 and Caspar, while cultivar Marfona showed the poorest performance for this cooking procedure.

In this study, tuber water content showed values ranging between 78.9 and 81.9% among cultivars according to the mean of two years (Table 3). These values are in general agreement with the levels reported by Andre et al. (2007) in 74 cultivated potato genotypes (70.0 to 81.5%) and Casanas et al. (2002) in five cultivars (77.1 to 81.9%). It is known strongly that negative relationships between tuber dry matter content and water content decreased the quality of potato. Concerning the tuber dry matter content, a level above a threshold of 22% is favorable for commercial manufacturing of potato products such as crisps and chips, because it results in higher product yield and profitability due to the lower water content (Högy and Fangmeier, 2009). Besides, low water content related to dry matter improves crispness of the fried products and prevents excessive fat absorption in frying (Storey and Davies, 1992). In view of the circumstances, these values for water content of evaluated potato cultivar tubers are the optimum intervals required for commercial manufacturing of potato products, as described by Högy and Fangmeier, (2009).

According to the mean values of two years, starch content showed values ranging between 10.9 and 13.2% of FW in confirming results obtained by Casanas et al. (2002) and Liu et al. (2003) (Table 4). Cultivar Melody and Lady Olympia, however, showed the highest starch content, while Marfona showed the lowest content. The starch content plays very important roles in the quality of potato products and varies with potato cultivars. Potatoes with higher starch content are well suited for food use, processing or starch manufacture (Liu et al., 2003). In this connection, Esendal (1990) suggested that starch content values should be assembled into three groups: the highest starch content (contents higher than 19.0%, mashing), high starch content (contents between 16.0 and 19.0%, roasting) intermediate starch content (contents between 13.0 and 15.9%, cooking or roasting), and low starch content (contents to 12.0%, boiling). According to this classification, cultivars Lady Olympia and Melody belong to the intermediate starch content group. Conversely, Pasinler 92, Caspar, Lady Christl, Granola, Van Gogh and Marfona were categorized in the group showing a low starch content. Also, the significant differences in cultivar according to years were supposed to be related to the genotype × environmental condition interaction effect, since variations in starch contents of tubers from the same cultivar produced in different climatic conditions are common (Liu et al., 2003; Högy and Fangmeier, 2009).

Cultivar is the major factor that influenced the protein content and protein content varies with potato cultivars and growth time. The tested cultivars differed in crude protein content and the concentration of macronutrients as indicated in Table 4. According to the mean values of two years, cultivar Lady Olympia produced tubers with the highest crude protein content (13.8%), while Pasinler 92 showed the lowest content (10.9%). These values are in general agreement with those reported in the literature (Tekaling and Hammes, 2005; Kolbe and Stephan-Beckmann, 1997). The macro and micro minerals are important potato quality criteria because of their physiological and nutritional value in human food (Högy and Frangmeier, 2009). Cultivars differed in tuber macro and micro nutrient concentrations. Cultivar Van Gogh produced tubers containing higher concentration of macro elements such as P, Ca and Mg and Zn micro element than the other cultivars, while cultivar Marfona produced tubers containing the highest potassium (K) content according to the mean values of two years. Cultivar Melody and Lady Olympia were also characterized by having higher concentrations of micro element such as Fe, Mn and Cu in the tuber. In this study, the average content of P varied from 0.223 to 0.280%, the average content of K from 1.95 to 2.34%, the average content of Mg from 0.135 to 0.167% and the average content of Ca from 0.094 to 0.128% of DW. In general, the contents in phosphorus, calcium, potassium and magnesium are similar to those reported by other authors for unpeeled potatoes (Kolbe and Stephan-Beckmann, 1997; Rivero et al., 2003; Tekaling and Hammes, 2005; Andre et al., 2007; Di Giacamo et al., 2007). Also, the differences in macro and micro element concentrations of tuber could be explained by several factors. First of all, the potato cultivar characteristics can be of major importance. Indeed, the tuber mineral concentrations may vary among genotypes of cultivated potatoes. There is evidence that potato genotypes, grown under identical conditions, have been shown to differ in tuber macro and micro element concentrations, (Tekalign and Hammes, 2005; White et al., 2009) and systematic differences in tuber K, Mg, Fe, Zn, Mn and Cu concentrations have been observed between commercial potato cultivars (Rivero et al., 2003; Di Giacomo et al., 2007). Secondly, the potato sampling can be important. The distribution of mineral elements may vary within the potato tuber. Variations in concentration of mineral elements can exist between the stem end and the distal end of the potato tuber and some elements such as the cations K, Ca, Mg, Fe, Zn, Mn and Cu are more concentrated in the potato skin relative to the flesh (Karenlampi and White, 2009). To overcome these aspects and process each cultivar in the same way, whole unpeeled tubers were sliced, dried and mixed before analysis. Because the tubers were processed with their skin due to the difficulty of uniformly peeling certain potato tubers with irregular shape, the ratio of skin to flesh may vary between the samples, according to the tuber size and shape, but may be attributed to a genotypic characteristic. Lastly, it is recognized that the

Table 4. Starch content, crude protein and macroelement contents of potato tubers[1].

Cultivar	Starch (%)			Protein (%)			P (%)		
	2007	**2008**	**Mean**	**2007**	**2008**	**Mean**	**2007**	**2008**	**Mean**
Caspar	13.3^{a}	11.1^{bd}	12.2^{b}	10.2^{d}	12.3^{cd}	11.3^{cd}	0.229	0.217	0.223
Van Gogh	12.4^{bc}	10.2^{e}	11.3^{c}	11.2^{bc}	13.0^{bc}	12.1^{b}	0.273	0.286	0.280
Pasinler92	12.8^{ab}	11.7^{b}	12.3^{b}	10.1^{d}	11.6^{d}	10.9^{d}	0.264	0.258	0.261
L. Olympia	13.2^{a}	13.1^{a}	13.2^{a}	12.2^{a}	15.4^{a}	13.8^{a}	0.287	0.232	0.260
L. Christyl	11.8^{cd}	11.0^{cd}	11.4^{c}	11.0^{c}	13.6^{b}	12.3^{b}	0.255	0.281	0.268
Marfona	11.1^{d}	10.6^{de}	10.9^{d}	11.7^{b}	12.9^{bc}	12.3^{b}	0.251	0.258	0.249
Melody	13.2^{a}	13.2^{a}	13.2^{a}	11.1^{c}	12.6^{bd}	11.9^{bc}	0.249	0.212	0.231
Granola	11.5^{d}	11.3^{bc}	11.4^{c}	11.4^{bc}	13.5^{bc}	12.5^{b}	0.246	0.241	0.243
Mean	12.4^{a}	11.5^{b}		11.1^{b}	13.1^{a}		0.255	0.248	
F- test									
Cultivars	15.21**	30.13**	36.64**	20.05**	9.28**	17.88**	1.11	1.27	1.70
CV%	3.10	2.98	2.99	2.43	4.96	4.24	11.10	17.04	14.21

	K (%)			Ca (%)			Mg (%)		
	2007	**2008**	**Mean**	**2007**	**2008**	**Mean**	**2007**	**2008**	**Mean**
Caspar	2.10^{b}	2.08^{b}	2.09^{cd}	0.101^{bc}	0.146^{a}	0.123^{b}	0.135^{c}	0.162^{b}	0.148
Van Gogh	2.03^{bc}	2.24^{b}	2.14^{bc}	0.112^{a}	0.144^{a}	0.128^{a}	0.148^{ab}	0.185^{a}	0.167
Pasinler92	2.11^{b}	2.09^{b}	2.10^{cd}	0.099^{c}	0.118^{c}	0.108^{e}	0.131^{c}	0.154^{bc}	0.143
L.Olympia	2.37^{a}	2.11^{b}	2.24^{ab}	0.086^{e}	0.116^{c}	0.101^{f}	0.159^{a}	0.175^{ab}	0.167
L. Christyl	1.95^{c}	2.04^{b}	2.00^{de}	0.105^{b}	0.118^{c}	0.111^{d}	0.141^{bc}	0.130^{c}	0.135
Marfona	1.95^{c}	2.74^{a}	2.34^{a}	0.098^{c}	0.132^{b}	0.115^{c}	0.141^{bc}	0.158^{bc}	0.150
Melody	2.05^{b}	2.04^{b}	2.05^{ce}	0.082^{e}	0.107^{d}	0.094^{g}	0.143^{bc}	0.161^{b}	0.152
Granola	1.84^{d}	2.05^{b}	1.95^{e}	0.092^{d}	0.133^{b}	0.112^{d}	0.143^{bc}	0.165^{b}	0.154
Mean	2.05^{b}	2.17^{a}		0.097^{b}	0.127^{a}		0.143^{b}	0.161^{a}	
F- test									
Cultivars	28.25**	9.71**	10.27**	37.48**	30.22**	54.96**	3.92*	4.61**	2.00
CV%	2.50	6.09	4.68	2.87	3.53	3.25	4.59	8.07	12.41

[1]For each genotype, the mean value represents analyses of four samples from four different plants (n= 4).
Means followed by different letter within each column are significantly different. CV: Coefficient of variation; **significant at 1%;*, **significant at 5%.

mineral concentrations are related to the nutritional status as well as crop developmental stages and the potato tubers are sensitive to environmental impacts, which are primarily due to the effects on tuber formation. In potato, mobile minerals are mainly transported from the wilting aboveground plant parts to the tubers during the end of the growing season and the concentration of tuber minerals is very different throughout the vegetation period because of differences in nutrient supply and weather conditions (availability of assimilates) (Kolbe and Stefan-Beckmann, 1997). In this study, different climatic conditions between experimental years and difficulties to define exactly the identical development stage at maturity may also have influenced the results. Salisbury and Ross (1992) also reported that an increased rate of transpiration enhances the rate of mineral uptake. Hence, the decrease in some mineral contents of the tested tubers may be as a result of the reduced transpiration rate lowering mineral absorption from the soil and subsequently transport within the plant.

Concerning the macro elements (Ca, Mg, K and P) that are vital for human health, calcium plays a crucial role in providing rigidity to the skeleton and is involved in neuromuscular function, blood clotting and many metabolic processes (Frossard et al., 2000). Deficiency may result in muscle spasms and cramps in the short term and osteoporosis (Andre et al., 2007). The FAO/WHO's reference nutrient intake (RNI) for calcium in adults is estimated as 1000 mg day^{-1} (Anonymous, 2002). The highest calcium-ranking cultivar, Van Gogh, contained 46.3 mg 200 g^{-1} of fresh weight (FW). Thus, a single potato tuber from this cultivar could contribute only

Table 5. Microelement content of potato cultivar tubers (as a dry weight) [1].

Cultivar	Fe (mg/kg)			Zn (mg/kg)		
	2007	2008	Mean	2007	2008	Mean
Caspar	85.51^{d}	48.85^{e}	67.18^{e}	13.30^{b}	15.21^{c}	14.26^{c}
Van Gogh	75.03^{e}	64.74^{cd}	69.89^{e}	16.78^{a}	18.96^{a}	17.87^{a}
Pasinler92	115.94^{b}	67.23^{c}	91.58^{b}	13.34^{b}	16.90^{bc}	15.12^{b}
L.Olympia	82.98^{d}	75.6^{a}	79.47^{d}	15.67^{a}	16.21^{c}	15.94^{b}
L. Christyl	102.84^{c}	76.31^{a}	89.58^{b}	12.56^{b}	15.53^{c}	14.05^{c}
Marfona	106.10^{c}	62.55^{d}	84.33^{c}	12.50^{b}	18.02^{ab}	15.26^{bc}
Melody	122.69^{a}	71.70^{b}	97.19^{a}	13.92^{b}	15.50^{c}	14.71^{c}
Granola	82.64^{d}	77.74^{a}	80.19^{d}	13.24^{b}	16.03^{c}	14.63^{c}
Overall mean	96.72^{a}	68.14^{b}		13.91^{b}	16.55^{a}	
F- test						
Cultivars	86.77**	68.99**	90.280**	8.55**	5.72**	10.59**
CV%	3.37	2.95	3.26	6.50	5.82	6.04

	Mn (mg/kg)			Cu (mg/kg)		
	2007	2008	Mean	2007	2008	Mean
Caspar	10.58^{bd}	4.96^{c}	7.77^{d}	7.13^{f}	6.06^{c}	6.59^{c}
Van Gogh	9.66^{d}	6.71^{a}	8.18^{cd}	10.08^{cd}	5.02^{d}	7.55^{b}
Pasinler92	10.79^{bd}	4.85^{c}	7.82^{d}	8.58^{e}	7.80^{ab}	8.19^{b}
L.Olympia	13.35^{a}	6.53^{ab}	9.94^{a}	11.34^{ab}	8.29^{a}	9.81^{a}
L.Christl	10.19^{cd}	5.45^{bc}	7.82^{d}	12.19^{a}	7.18^{b}	9.68^{a}
Marfona	11.58^{b}	6.43^{ab}	9.01^{b}	10.99^{bc}	7.82^{ab}	9.40^{a}
Melody	11.63^{b}	5.82^{ac}	8.73^{bc}	8.93^{e}	7.59^{ab}	8.26^{b}
Granola	10.99^{bc}	6.49^{ab}	8.75^{bc}	9.61^{de}	8.50^{a}	9.06^{a}
Overall mean	11.10^{a}	5.91^{b}		9.86^{a}	7.28^{b}	
F- test						
Cultivars	8.64**	4.85**	9.21**	22.01**	14.21*	21.46**
CV%	5.98	9.91	7.18	6.16	5.69	6.96

[1]For each genotype, the mean value represents analyses of four samples from four different plants (n= 4).
Means followed by different letter within each column are significantly different. CV: Coefficient of variation; **significant at 1%;*, **significant at 5%.

4.6% to the dietary calcium intake. Regarding the potato production, increased calcium content in tubers may also be beneficial because it increases the tuber quality and storability (Andre et al., 2007).

Magnesium is needed for bone, protein, making new cells, activating B vitamins, relaxing nerves and muscles, clotting blood and in energy production. Insulin secretion and function also requires magnesium. Magnesium also assists in the absorption of calcium, vitamin C and potassium (WHO, 2004). The FAO/WHO's RNI ranges from 220 (for men) to 260 mg day^{-1} (for women) magnesium in adults (Anonymous, 2002). The highest magnesium-ranking cultivars, Lady Olympia and Van Gogh, contained 70.5 and 60.5 mg 200 g^{-1} of FW, respectively and a high-magnesium tuber of medium-sized potato weighing 200 g fresh weight from these cultivars could contribute from 23.3 to 32.0% to the dietary magnesium intake.

Besides, UK guidance daily reference nutrient intakes for potassium and phosphorus in adults are noted as 3500 and 550 mg day^{-1}, respectively (White and Broadley, 2005). The highest potassium-ranking cultivar, Marfona, contained 912.6 mg 200 g^{-1} of FW and phosphorus-ranking cultivar, Van Gogh, contained 101.4 mg 200 g^{-1} of FW, respectively. Thus, a single potato tuber from these cultivars could contribute 26.1 and 18.4% to the dietary potassium and phosphorus intake, respectively.

In this study, the iron content in the potato cultivars varied from average 67.18 to 97.19 mg/kg of DW and the zinc content ranged from average 14.05 to 17.87 mg/kg of DW (Table 5). The highest ranking cultivars for iron, zinc and manganese element were Melody, Van Gogh and Lady Olympia, respectively. According to the study of

Frossard et al. (2000), Fe and Zn are essential nutrients that are often lacking in human diets, either due to insufficient intake or to poor absorption from food. In developing countries, deficiencies of Fe and Zn lead to much suffering and death. It is estimated that of the world's 6 billion people, 60 to 80% are Fe deficient and >30% are Zn deficient (White and Broadley, 2005). The FAO/WHO's RNI for iron depends therefore, on the bioavailability of the mineral. In developing countries (assumed bioavailability of 5%), the RNI ranges from 27.4 (for men) to 58.8 mg day^{-1} (for women) and in developed countries (assumed bioavailability of 12%) the RNI ranges from 11.4 to 24.5 mg day^{-1} (Anonymous, 2002). In this study, the highest iron-ranking Melody cultivar contained 4.1 mg 200 g^{-1} of FW. Thus, a high-iron tuber of medium-sized potato weighing 200 g fresh weight from the Melody cultivar could contribute from 7.0 to 37.3% to the dietary iron intake. In this study, the contents in iron are also in agreement with the results of Anderson et al. (1999) by 11.71 to 131.05 mg kg^{-1} of DW for unpeeled potatoes and Andre et al. (2007) by 29.87 to 157.96 mg kg^{-1} of DW.

In Turkey, Zn deficiency is also the most widespread micronutrient deficiency in soils and plants and suggested to be one of the major causes of the widespread occurrence of Zn deficiency in humans in Turkey (Cakmak et al., 1999). Zinc is an essential micronutrient and its deficiency has serious consequences for health (Andre et al., 2007). This metal is important in a number of key activities, ranging from protein and carbohydrate metabolism to the immune system, wound healing, growth and vision (WHO, 2004). In addition, zinc plays an important role in protecting cellular components from oxidation and dietary deficiencies may enhance the risk of cancer (Ho, 2004). The FAO/WHO's RNI assuming a high zinc bioavailability (50%) ranges from 3.6 (for women) to 4.3 mg day^{-1} (for men), while the RNI assuming a low zinc bioavailability (15%) ranges from 11.9 to 14.4 mg day^{-1} (Anonymous, 2002). Considering that the highest zinc-ranking cultivar, Van Gogh, contained 0.65 mg 200 g^{-1} of FW, the consumption of one tuber from this cultivar could contribute from 4.5 to 18.1% to the dietary zinc intake. The study results are consistent with those obtained by Högy and Frangmeier (2009), who reported values ranged from 8.7 to 17.1 mg zinc kg^{-1} of DW, Tekaling and Hammes (2005) by 13.17 to 20.83 mg zinc kg^{-1} of DW and Andre et al. (2007) by 12.6 to 28.83 mg zinc kg^{-1} of DW for potato genotypes. In tise study, the manganese content ranged from average 7.77 to 9.94 mg/kg of DW, and the highest manganese-ranking cultivar was Lady Olympia (Table 5). These values of manganese are consistent with the values reported by Di Giacamo et al. (2007) in potato tubers (3.026 to 7.297 mg kg^{-1} of DW). The manganese is a trace mineral that participates in many enzyme systems in the body. The manganese deficiency, very rare in humans, is associated with nausea, vomiting, poor glucose tolerance (high blood sugar levels), skin rash, loss of hair color, excessive bone loss, low cholesterol levels, dizziness, hearing loss and compromised function of the reproductive system (WHO, 2004). However, the highest ranking cultivar, Lady Olympia, contained 0.42 mg of manganese 200 g^{-1} of FW, the consumption of one tuber from this cultivar could provide about 18.3% of the UK guidance daily reference intake (2.3 mg day^{-1} for adults) of manganese (Anonymous, 2010).

As with other minerals, there was variation in tuber copper concentration within potato cultivars in this study. The copper content in the potato cultivars varied from average 6.59 to 9.81 mg/kg of DW, in consistent with results obtained by Di Giacamo et al. (2007) (Table 5). The highest copper-ranking cultivars, Lady Olympia contained 0.41 mg 200 g^{-1} of FW, Lady Christyl contained 0.39 mg 200 g^{-1} of FW, Marfona contained 0.37 mg 200 g^{-1} of FW and Granola contained 0.34 mg 200 g^{-1} of FW. Although, Cu is essential for the normal healthy growth of humans as well as all higher plants, excess Cu could be a potential health risk. It helps iron-rich foods make red hemoglobin in the blood. Copper is also involved in the formation of collagen (the fibrous protein in bone, cartilage, tendons and other connective tissue) and protective coverings for nerves (WHO, 2004). White and Broadley (2005) noted that the severe Cu deficiency occurs throughout the developed and developing world. United States food and nutrition board have issued a recommended daily allowance of 0.9 mg and daily reference nutrient intake of 1.2 mg in copper per day for both men and women (White and Broadley, 2005; Anonymous, 2010). Thus, the consumption of one tuber from these cultivars could provide from 28.3 to 45.6% to the dietary copper intake.

Conclusion

Tuber physical and chemical quality characteristics represented by specific gravity, starch content, protein content, size distribution, tuber shape and nutrient composition were influenced by cultivar. Cultivars Lady Olympia and Melody are suitable for frying, cooking and roasting. Tubers of cultivars Pasinler 92, Caspar, Lady Christl, Granola, Van Gogh and Marfona are suitable for boiling and specifically appropriate to be consumed in the form of salads. When tubers are marketed for industrial processing of tubers, the portions of certain size-grades and the specific gravity of tubers play an important role. In this connection, the choice of cultivars Melody, Pasinler 92 and L. Olympia with best results for industrial processing may be an efficient agronomic measure to increase financial returns. In view of tuber shape, the tubers of cultivars Caspar, Van Gogh, Granola, L. Christyl and Marfona also had best results for use and consumption presented short-oval tuber shape. These varieties could be exploited through direct use or through crop improvement. Packaged together, these results could positively impact both production and the well being of consumers.

Also, results of the current experiment demonstrated that the certain potato cultivars should be regarded as a significant source of iron and zinc in the human diet. By contrast, potato cannot be considered as a relevant source of dietary calcium. The nutrient-rich potato can contribute to improved diets, thus, reducing mortality rates caused by malnutrition. It can improve food security and health, especially among women and children.

Consequently, this study could provide useful information concerning the potential of the potato cultivars to contribute to the dietary mineral intake and appropriate utilization policies for its production and consumption. Furthermore, the identification of potato cultivars with high iron and zinc content adds value to potato consumption and might open new market niches for these cultivars. In addition, scientists can use the data to increase mineral and other chemical components in foods or in breeding programs to improve their nutritional status without changing native potato consumption habits.

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