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Sugar, Amino Acid and Fatty Acid Composition in Potato Tubers Grown in Highland Area of Gangwon Province

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Abstract - The composition of free sugar, free amino acid, and fatty acid in tubers of the cultivars ‘Superior’, ‘Sinnamjak’, and ‘Chubaek’ were evaluated at the two sites with different altitude, Gangneung (20 m altitude) as lowland and Daekwallyeong (760 m altitude) as highland. The average reducing sugar content of the three potato cultivars harvested in Daekwallyeong and Gangneung was 1.1% and 2.3%, respectively, which showed two-fold difference between the two locations. Average total sugar content was also two-folds lower in potatoes harvested in Daekwallyeong (6.3%) than those harvested in Gangneung (12.2%). Average content of free amino acids of the three potato cultivars harvested in Daekwallyeong and Gangneung was 1,325 mg/100g and 1,051 mg/100g, respectively. The cultivar ‘Chubaek’ has the highest amino acid content among the three tested cultivars. Potatoes from Daekwallyeong have higher unsaturated fatty acid levels than those from Gangneung. During the tuber development, unsaturated fatty acids levels increased in tubers grown in Daekwallyeong, but decreased in those grown in Gangneung. These results indicate that the quality of potatoes from Daekwallyeong is from Gangneung for food processing purpose for human consumption.

Key words - Highland, Potato cultivars, Tuber quality

Introduction

The potato (*Solanum tuberosum* L.) is one of the world’s major staple food crops. In 2003, 310 x 10^{12} tons of potatoes were produced over the world (FAO, 2005) and in 2006, 631 x 10^{3} ton of potatoes were produced in Korea (NAQS, 2006). The tuber is an important element in the daily diet for majority of people. It contains high nutritional proteins, fibers, potassium, and vitamins.

Sucrose, glucose, and fructose are the major sugars which accumulate in potato tubers. Potatoes can be processed in different ways: boiled, crisped, baked, roasted, fried, and so on. High levels of reducing sugars (glucose and fructose) lower the suitability of tubers for food processing. Reducing sugars react with free amino groups during frying leading to the formation of a brown pigment, which can make chips and French fries unacceptable to consumers and could lead to the formation of potentially toxic acrylamide (Spychalla and Desborough, 1990).

Protein content in tubers is an important element in the evaluation of potato quality. Although potatoes contain only small amount of protein (2.0-2.5%) compared to other crop plants, they are an important element of human and animal diet, due to their very good amino acid composition (Ciecko *et al*., 1999). Only 50% of the total nitrogen in potatoes is derived from proteins; the remaining nitrogen consists of free amino acids (15%), amide nitrogen associated with asparagines and glutamine (23%), and non-protein nitrogen associated with the glycoalkaloids solanine and chaconine, and secondary metabolites such as acetylcholine, adenide, cadaverine, guanine, hypoxanthine, nacrotine, trigoneline and xanthine (12%) (Friedman, 1996).

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Lipids represent approximately 0.1% fresh weight in a potato tuber. Greater than 94% of tuber lipids are in forms containing esterified fatty acids, of which greater than 70% are polyunsaturated fatty acids such as linoleic acid and linolenic acid (Galliard, 1968). Several chemical or physical changes can occur to a membrane's component fatty acids which can lead to increased membrane permeability which consequently could influence potato sugar content and subsequent processing quality.

The parameters mentioned above are important, not only for human nutrition but also in food processes. The concentration of these parameters could be influenced by cultivars and climatic conditions and other cultivating conditions. But few publications have been reported describing quality properties of potato tubers in contrast to research on resistance to diseases and on agronomic parameters. The contents of sugars, amino acid, and fatty acid composition in tubers of three Korean major cultivars have been evaluated.

The objective of this study was to investigate genetic resources with regard to special properties with particular applications to potato processing. Specifically it aims to find out change patterns of the sugar, amino acid and fatty acid composition in tubers during tuber development and the difference in sugar, amino acid, and fatty acid composition between potato tubers grown in lowland (Gangneung) and highland (Daekwallyeong) of Gangwon province.

Materials and Methods

Plant materials

Three potato cultivars, 'Superior', 'Sinnamjak', and 'Chubaek' were grown. Seed tubers of these cultivars were planted on 15 March and 26 April in 2006 in Gangneung and Daekwallyeong respectively. All cultivars were grown in rows, 75 cm apart with 25 cm between plants. The locations, planting dates, and period of observation are presented in Table 1. Fresh tubers were harvested at weekly intervals starting from 55 days after planting until 105 and 104 days after planting in Gangneung and Daekwallyeong, respectively when physical maturity was observed. At every harvest, three plants from each cultivar were harvested in such a manner that no tuber is left in the soil. Three replicates consisting of three tubers each were taken on each sampling date.

Freeze-drying of potatoes

Potatoes were rinsed in cool water and dried. They were then diced, weighed, and quickly cooled in a subzero freezer and stored overnight. Samples were lyophilized for five days, then weighed and grounded into fine powder. The ground samples were placed in a zip-lock plastic bag and stored at 4℃ until use.

Analysis of free sugars

Free sugars were extracted from 1.0 g of ground potato samples by adding 20 ml of 20% ethanol solution then shaking the mixture for 60 minutes at 35℃ water-bath.

It was then centrifuged at 5000 g for 5 minutes. The collected supernatant was filtered with Sep-Pak NH_2 solid phase extraction cartridge (Waters Co., Milford, MA, USA), and then 1.0 ml of filtrate was evaporated to dryness at 50℃ dry-bath by blowing with N_2 gas. The residue was dissolved in 0.2 ml of water, then 20 µl of the solution was used for free sugar analysis by HPLC. The HPLC system was composed of a pump (Waters 510, Waters, USA), a R.I. Detector (Waters 410, Waters, USA), and an Integrator (Waters 746, Waters, USA) equipped with a separation column (YMC-Pack Polyamine II, 5 um, 250 x 4.6 mm, YMC Co., LTD, Kyoto, Japan). The operating conditions were as follows: column temperature 35℃; detector temperature 39℃; mobile phase, acetonitrile: water (65:35, v/v); flow rate, 0.7 ml min^{-1}. The standard simple

Table 1. Altitude of the experimental sites and dates of cultivation practices for sample preparation.

Site	Altitude (m)	Planting (month. date)	Emergence (month. date)	Harvest (month. date)
Gangneung	20	3.15	4.07 - 4.26	6.12
Daekwallyeong	760	4.26	5.19 - 5.26	7.26

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sugars and oligosaccharides were obtained from Sigma (St. Louis, MO, USA).

Analysis of fatty acids

The fatty acid was analyzed as described by Rafael and Mancha (1993). Freeze-dried potato powder (0.5 g) was heated with a reagent containing methanol: heptane: benzene: 2,2-dimethoxypropane: H_2SO_4 (37:36:20:5:2, v/v). The simultaneous digestion and lipid transmethylation took place in a single phase at 80℃. After heating, the sample was cooled at room temperature. The upper phase containing the fatty acid methyl esters (FAMEs) was prepared for the capillary GC analysis. The GC analysis was performed on a HP 6890 system (Hewlett-Packard Co., Palo Alto, CA, USA) equipped with a FID by using a HP-Innowax capillary (cross-linked polyethylene glycol) column (0.25 µm x 30 m). The initial temperature of 150℃ was raised to the final temperature of 280℃ at a rate of 4℃ min^{-1}. The sample was transported with nitrogen gas at a flow rate of 10 ml min^{-1}. During the analysis, the temperatures of inlet and detector were maintained at 250 and 300℃, respectively. The standard FAME mix (C14-C22) was obtained from Supelco (Bellefonte, PA, USA).

Analysis of free amino acids

Free amino acid (FAA) contents were determined by L-8800 high-speed amino acid analyzer (Hitachi, Tokyo, Japan). The freeze-dried potato powder (1.0 g) was mixed with 10 ml of 3% trichloroacetic acid solution. The mixture was left at room temperature for 1 hour, then centrifuged at 10,000 g for 15 minutes. The collected supernatant was filtered with 0.45 µm syringe filters (Millipore Milford, MA, USA). The filtrate was loaded on the amino acid analyzer. The standard amino acid solutions, type ANII and type B, were obtained from Wako (Wako-shi, Japan).

Statistical analysis

There were three replicates for all measurements. The data obtained from the analysis were statistically analyzed using SAS release ver. 6.12 for Windows (Statistical Analysis Systems Institute Inc., Cary, CA, USA). The results were expressed as weighted means. For each value, the standard deviation was calculated. The ANOVA test was used to determine the statistical differences while the criterion for statistical significance was $P \leq 0.05$.

Results and Discussion

The average air temperature in Daekwallyeong was lower by about 5℃ than in Gangneung from March to August and diurnal change was higher by 2-4℃ from March to June (Fig. 1). When potatoes were grown in the field, the average air temperature in Daekwallyeong was higher approximately by 2℃ and diurnal change was higher by 2-4℃ than in Gangneung (Fig. 2).

From sixty days after planting (DAP), the average air temperature and diurnal change in Daekwallyeong were similar or even lower than those in Gangneung. This was due to a 2-week period of continuous rainfall in July 2006. In Gangneung potatoes were harvested before July, but in Daekwallyeong potatoes were grown in the field from late April and harvested early August. Rainfall was also an

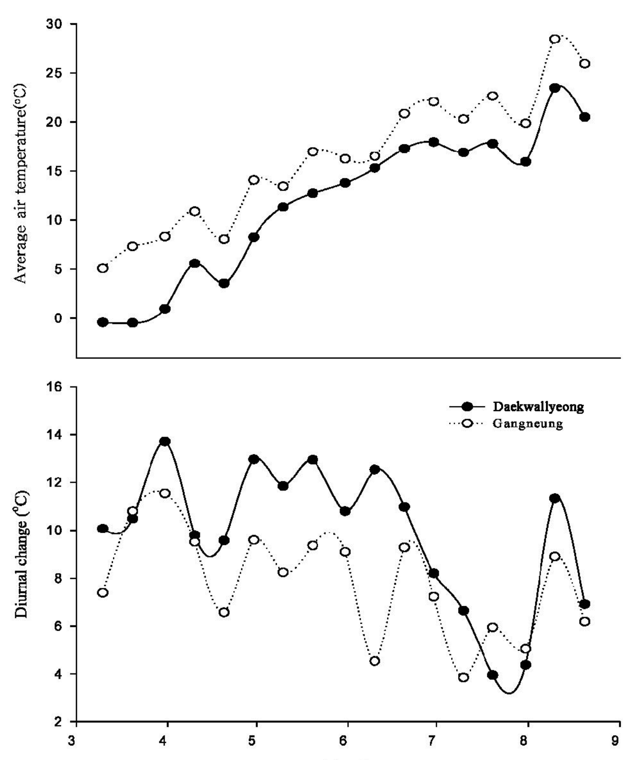

Fig. 1. Average air temperature (upper) and its diurnal changes (lower) in Gangneung and Daekwallyeong from March to August, 2006.

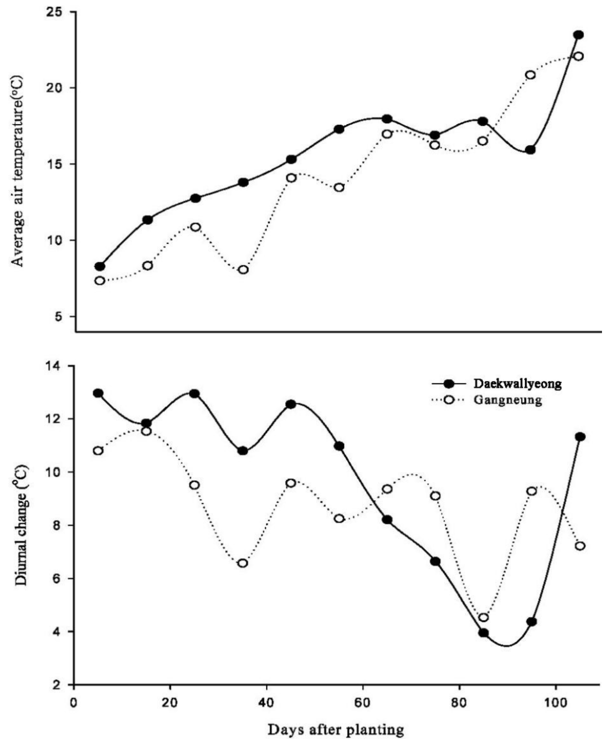

Fig. 2. Average air temperature (upper) and its diurnal changes (lower) in Gangneung and Daekwallyeong during cultivation.

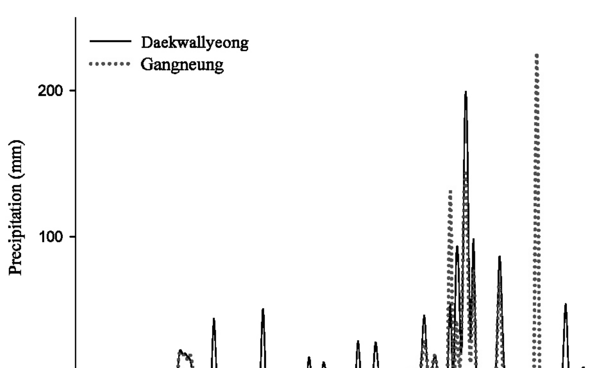

Fig. 3. Comparison of precipitation between Gangneung and Daekwallyeong from March to August, 2006.

important factor that affects solar radiation. From March to August, integrated solar radiation presented similar pattern between the two sites (Fig. 4). However, due to continuous rainfall in July, integrated solar radiation in Daekwallyeong decreased significantly.

The major sugars in potato tubers are fructose, glucose, and sucrose. Free sugar content of 'Chubaek' decreased from

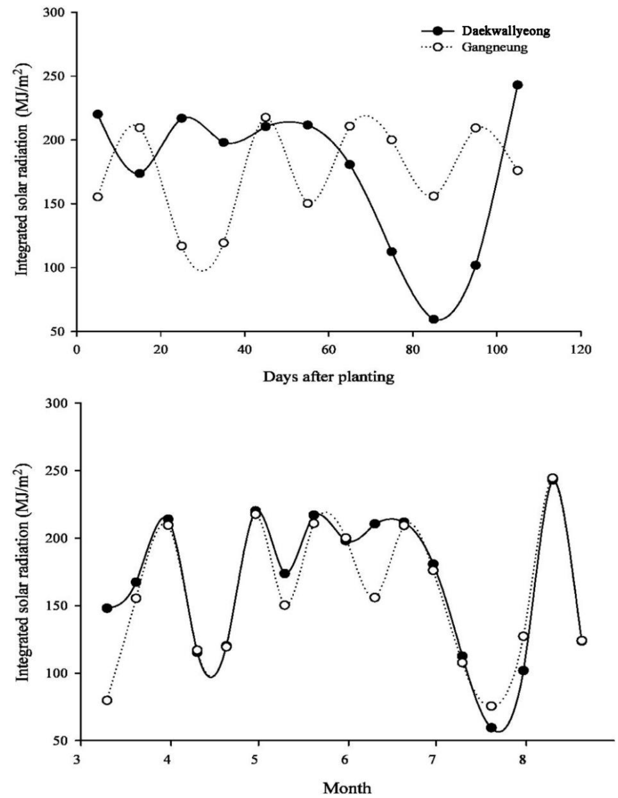

Fig. 4. Integrated solar radiation of Gangneung and Daekwallyeong at every 10 days after planting (upper) and from March to August (lower) in 2006.

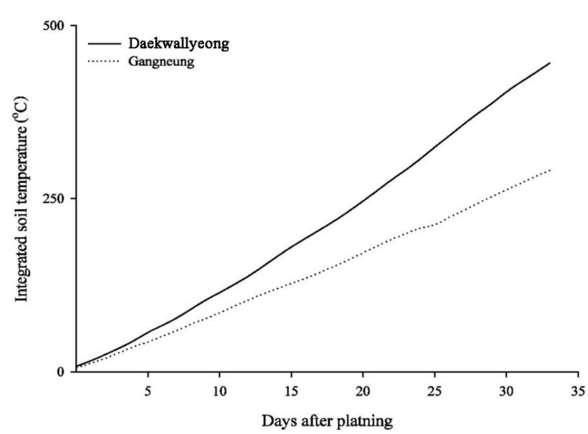

Fig. 5. Comparison of integrated soil temperature in Gangneung and Daekwallyeong in 2006.

41.39 to 15.09% in Gangneung and from 50.82 to 11.13% in Daekwallyeong (Table 2). In the case of 'Sinnamjak' it decreased from 36.48 to 9.86% in Gangneung and from 34.00 to 3.24% in Daekwallyeong. The cultivar 'Superior' showed decreased in the free sugar content from 45.20 to 11.74% in

Table 2. Reducing sugar and total sugar contents in tubers of three cultivars grown in Gangneung and Daekwallyeong.
(% , dry weight basis)

Site	Cultivar	Reducing sugar					Total free sugar				
		62DAP[†]	69DAP	77DAP	83DAP	90DAP	62DAP	69DAP	77DAP	83DAP	90DAP
Gangneung	Superior	19.30	5.81	5.30	1.28	1.84	45.20	31.74	18.42	9.37	11.74
	Sinnamjak	18.39	10.23	5.42	2.92	2.80	36.48	30.81	16.40	17.98	9.86
	Chubaek	16.58	10.23	4.35	6.15	2.31	41.39	34.10	23.91	24.33	15.09
	mean	18.09	8.76	5.02	3.45	2.31	41.02	32.21	19.58	17.23	12.23
Daekwallyeong	Superior	8.60	4.63	2.14	1.08	0.63	19.01	14.66	12.53	9.39	4.45
	Sinnamjak	9.96	4.83	1.83	1.03	0.43	19.51	17.68	11.60	5.47	3.24
	Chubaek	7.62	2.77	6.29	3.26	2.27	20.75	16.52	17.63	11.54	11.13
	mean	8.73	4.08	3.42	1.79	1.11	19.76	16.29	13.92	8.80	6.27

[†]DAP : days after planting

Table 3. Free sugar contents in tubers of three cultivars grown in Gangneung and Daekwallyeong (90 DAP[§]).
(%, dry weight basis)

Site	Cultivar	Fructose	Glucose	Sucrose	Total	Di-/mono-[†]
Gangneung	Superior	0.98	0.86	9.91	11.74	5.39
	Sinnamjak	1.36	1.44	7.07	9.86	2.53
	Chubaek	1.10	1.21	12.78	15.09	5.54
Daekwallyeong	Superior	0.06	0.56	3.82	4.45	6.10
	Sinnamjak	0.12	0.30	2.81	3.24	6.61
	Chubaek	0.25	2.02	8.86	11.13	3.90
Site		*[†]	NS	*	*	NS
Cultivar		NS	NS	*	*	NS

[†]Disaccharide/monosaccharide represents sucrose/(fructose+glucose)
[‡]Levels of significant: *$P \le 0.05$; NS (not significant), $P \ge 0.05$.
[§]DAP : days after planting

Gangneung and from 29.96 to 4.45% in Daekwallyeong. Free sugar content was highest in cultivar ‘Chubaek’ and lowest in cultivar ‘Sinnamjak’ at the two sites at 90 DAP. (Table 3). A positive correlation between the conversion ratio of monosaccharides to sucrose and the difference of temperature was observed. Michael *et al*. (2010) conducted field study designed to examine the effects of soil temperature on the development of sugar. Soil temperature was recorded in different zones (0-10 cm and 10-20 cm depths) of potato rows oriented in north-south and east-west directions. Total and marketable yields were significantly higher at the 10-20 cm depth compared to the 0-10 cm depth. These locations tend to have the lowest mean daily and maximum soil temperatures during the growing season. These data supports reports from other regions that row orientation and depth significantly influence tuber yield and grade (Sojka *et al*. 1988; O’Brien *et al*. 1998). As previously indicated, during the growing season, Daekwallyeong showed higher integrated soil temperature (Fig. 5) and diurnal change (Fig. 2) than Gangneung.

The free sugars are involved in the Maillard reaction to form acrylamide (Finotti *et al*., 2006). They are potential precursors of the acrylamide product and the cultivars with low sugar concentrations are more suitable than others for high temperature food processing. Amrein *et al*. (2003) found that acrylamide formation in 74 different potato cultivars correlated with their contents of fructose and glucose. Asparagine had less effect on the acrylamide formation, presumably because, in contrast to reducing sugars, its content among the cultivars did not vary widely. Chuda *et al*. (2003)

found that acrylamide levels were highly correlated with both glucose and fructose levels of potato tubers. In a related study on the influence of free amino acids and sugars on acrylamide formation, Becalski *et al*. (2004) found that acrylamide levels of French fries can be minimized mostly by low levels of sugars (fructose, glucose and sucrose) and to a lesser extent by low levels of aspargines. Williams (2005) also found that acrylamide levels in 5 potato varieties were significantly influenced by reducing asparagines. Therefore, potatoes grown in Daekwallyeong, which showed lower sugar content than those of Gangneung were thought to be better suited for baking and frying.

In tubers grown in Gangneung and Daekwallyeong, 17 free amino acids were detected (Fig. 6). Predominant amino acids were glutamic acid (47.4-53.6%) and GABA (gamma-aminobutyric acid, 13.2-20.9%) (Table 4). Total free amino acid content was 1,325 mg/g in potatoes from Daekwallyeong, which was 20% higher than those from Gangneung. GABA content was 277 mg/100 g in potatoes from Daekwanllyeong, which was two-fold higher than those from Gangneung.

Table 4. Comparison of free amino acids composition in tubers grown in Gangneung and Daekwallyeong.

Free amino acid	Gangneung		Daekwallyeong	
	mg/100g	%	mg/100g	%
Aspartic acid	104.00 ± 11.67[†]	9.9	121.91 ± 13.98	9.2
Threonine	30.42 ± 5.36	2.9	47.08 ± 20.04	3.6
Serine	53.49 ± 7.02	5.1	57.16 ± 16.74	4.3
Glutamic aicd	563.19 ± 180.07	53.6	628.79 ± 296.68	47.4
Glycine	13.32 ± 1.61	1.3	14.44 ± 6.19	1.1
Alanine	49.58 ± 12.33	4.7	61.55 ± 43.32	4.6
Cys	10.22 ± 3.93	1.0	6.96 ± 2.57	0.5
b-Alanine	5.34 ± 1.77	0.5	4.80 ± 0.86	0.4
gamma-aminobutyric acid	138.77 ± 15.69	13.2	277.07 ± 78.88	20.9
Hydroxylysine	5.52 ± 0.05	0.5	5.68 ± 0.29	0.4
Lysine	13.88 ± 1.47	1.3	33.80 ± 19.92	2.6
Arginine	4.50 ± 2.25	0.4	11.01 ± 5.26	0.8
Proline	21.74 ± 2.15	2.1	22.83 ± 8.66	1.7
Total	1051.28 ± 185.24	100.0	1325.47 ± 468.86	100.0

[†]Mean ± SD, n=3

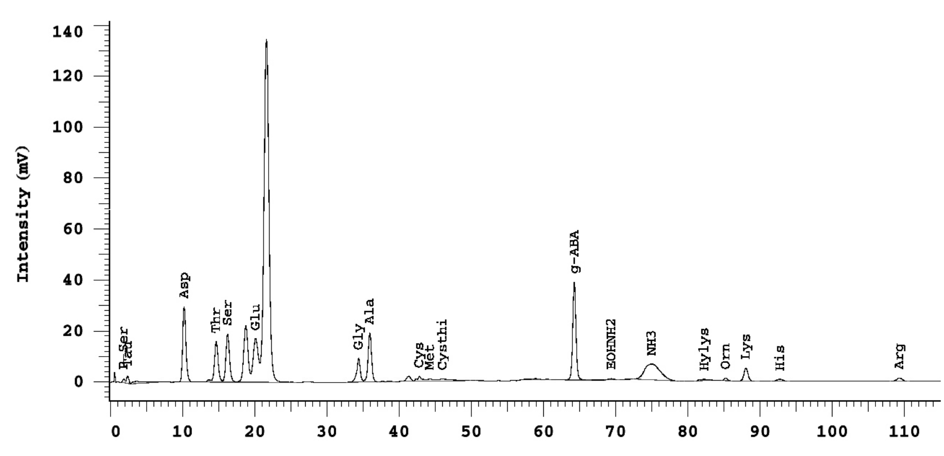

Fig. 6. Chromatogram of amino acids in tubers of ‘Superior’ cultivar grown in Gangneung (71 DAP[†]).
[†]DAP : days after planting

(Table 5). These results suggest that GABA can be ingested, for various purposes, by consumption of potatoes and potato food products.

Fatty acids were identified on the basis of GC retention time compared to those of standards and by GC- MS of the methyl esters and DMOX derivatives. The fatty acid compositions (as % of total fatty acids) in tubers were generally similar in the three cultivars during tuber development (Table 6). In both sites, a total of five fatty acids were detected in quantifiable amounts, and in all three potato cultivars the predominant

Table 5. Changes in GABA and total free amino acid contents in tubers of three cultivars grown in Gangneung and Daekwallyeong. (mg/100g dry weight basis)

Site	Cultivar	gamma-Aminobutyric acid					Total free amino acid				
		62DAP†	69DAP	77DAP	83DAP	90DAP	62DAP	69DAP	77DAP	83DAP	90DAP
Gangneung	Superior	23.80	137.39	90.03	139.71	126.67	351.58	913.73	774.42	761.72	953.36
	Sinnamjak	18.88	133.45	-	93.88	133.14	228.46	807.71	-	438.14	935.57
	Chubaek	27.73	100.77	136.05	110.94	156.51	481.90	836.92	1041.13	699.82	1264.93
	mean	23.47	123.87	113.04	114.85	138.77	353.98	852.79	907.78	633.23	1051.28
Daekwallyeong	Superior	190.75	237.21	270.67	231.54	358.23	1109.24	1317.21	1803.55	1691.82	1491.59
	Sinnamjak	228.25	30.93	249.04	141.79	200.68	818.35	266.82	910.89	877.49	796.17
	Chubaek	185.98	268.54	345.65	326.64	272.28	1336.76	1105.14	2485.60	3989.00	1688.65
	mean	201.66	178.89	288.45	233.33	277.07	1088.12	896.39	1733.34	2186.10	1325.47

†DAP : days after planting

Table 6. Fatty acid composition in tubers of three cultivars grown in Gangneung (90 DAP†) and Daekwallyeong (92DAP). (%)

Fatty acid	Gangneung			Daekwallyeong		
	Superior	Sinnamjak	Chubaek	Superior	Sinnamjak	Chubaek
Palmitic acid	38.6	39.4	24.9	24.3	26.2	25.8
Stearic acid	10.5	6.4	4.8	3.0	3.2	1.7
Oleic acid	4.7	2.3	0.0	0.0	2.2	0.0
Linoleic acid	37.0	41.6	56.8	58.5	54.3	58.3
α-Linolenic acid	9.2	10.3	13.5	14.2	14.1	14.2
SFA‡	49.1	45.8	29.7	27.3	29.4	27.5
USFA§	50.9	54.2	70.3	72.7	70.6	72.5

†DAP : days after planting
‡SFA : saturated fatty acid
§USFA : unsaturated fatty acid

Table 7. Changes in fatty acid composition in tubers of three cultivars (averaged value) grown in Gangneung and Daekwallyeong. (%)

Fatty acid	Gangneung					Daekwallyeong				
	62 DAP†	69 DAP	77 DAP	83 DAP	90 DAP	62 DAP	70 DAP	77 DAP	86 DAP	92 DAP
Palmitic acid	25.2	30.1	25.6	39.4	34.3	26.1	39.7	25.8	23.8	25.4
Stearic acid	3.9	5.4	4.7	7.6	7.2	4.9	4.1	5.1	3.0	2.6
Oleic acid	1.8	2.6	1.8	4.6	2.3	1.7	0.5	1.2	0.8	0.7
Linoleic acid	51.1	50.1	53.1	41.7	45.1	51.3	46.1	52.7	55.0	57.0
α-Linolenic acid	18.0	11.8	14.8	6.7	11.0	16.0	9.5	15.2	17.4	14.2
SFA‡	29.1	35.5	30.3	47.0	41.5	31.0	43.8	30.9	26.8	28.0
USFA§	70.9	64.5	69.7	53.0	58.4	69.0	56.1	69.1	73.2	71.9

†DAP : days after planting
‡SFA : saturated fatty acid
§USFA : unsaturated fatty acid

fatty acid was linoleic acid (37.0-58.5%) followed by palmitic acid (24.3-39.4%) and -linolenic acid (9.2-14.2%) in order of decreasing abundance (Table 6). Cultivars with higher levels of unsaturated fatty acid had lower rates of membrane electrolyte leakage and lower sugar contents (Spychalla and Descorough, 1990). They reported that high initial levels or high induced levels of membrane lipid unsaturation mitigated increases in tuber membrane permeability during storage, thus positively influencing the processing quality of stored potato tubers. Table 7 shows fatty acid composition in tubers of three cultivars grown in Gangneung and Daekwallyeong at different sampling time. Potatoes from Daekwallyeong had higher unsaturated fatty acid levels than those from Gangneung. With maturation of tubers, unsaturated fatty acid levels increased in tubers grown in Daekwallyeong, on the contrary, they decrease in tubers from Gangneung. Potatoes grown in Daekwallyeong are more profitable to potato processing with its higher unsaturated fatty acid level than those grown in Gangneung.

In summary, growth and quality characteristics of tubers of the thee test cultivars suggest that potatoes produced in Daekwallyeong are better suitable for processed foods for human consumption.

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