

Analysis of Phenolic Compounds in Sorghum, Foxtail Millet and Common Millet

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ABSTRACT The cereal grain crops have strong flexibility against adverse environment and they have various functional compounds. The objective of the present study was to screen phenolic compounds in sorghum [*Sorghum bicolor* (L.) Moench], foxtail millet (*Setaria italica*), common millet (*Panicum miliaceum* L.) by high performance liquid chromatography (HPLC) with photodiode array (PDA) detector. Sorghum contained the highest amount of phenolic compounds among three different crops (sorghum, foxtail millet, common millet). Especially Moktaksusu showed the highest amount of phenolic compounds concentrations and biggest regional differences. The comparison of average phenolic compounds in sorghums by regions showed order to Milyang ($963.3 \mu\text{g}\cdot\text{g}^{-1}$), Yeongyang ($923.1 \mu\text{g}\cdot\text{g}^{-1}$), Gijang ($831.3 \mu\text{g}\cdot\text{g}^{-1}$) and Bonghwa ($735.6 \mu\text{g}\cdot\text{g}^{-1}$). Among the sorghum cultivars, Moktaksusu ($1407.9 \mu\text{g}\cdot\text{g}^{-1}$) had the highest concentration of phenolic compounds. The average phenolic compounds of foxtail millets showed similar amount among Milyang ($319.0 \mu\text{g}\cdot\text{g}^{-1}$), Gijang ($288.1 \mu\text{g}\cdot\text{g}^{-1}$) and Bonghwa ($281.9 \mu\text{g}\cdot\text{g}^{-1}$) areas. The phenolic compounds of Yeongyang ($246.6 \mu\text{g}\cdot\text{g}^{-1}$) slightly low and that showed similar concentrations among three different regions. The concentration of phenolic compounds in foxtail millets, Chungchajo ($335.6 \mu\text{g}\cdot\text{g}^{-1}$) showed the highest concentrations. The average phenolic compounds of common millets showed the highest concentrations in Milyang ($305.5 \mu\text{g}\cdot\text{g}^{-1}$), Bonghwa ($262.0 \mu\text{g}\cdot\text{g}^{-1}$), Gijang ($195.1 \mu\text{g}\cdot\text{g}^{-1}$), Yeongyang ($237.2 \mu\text{g}\cdot\text{g}^{-1}$) in decreasing order. The concentration of phenolic compounds of common millets was the highest in the Norangchalgijang ($337.0 \mu\text{g}\cdot\text{g}^{-1}$), Hwanggumgijang ($250.0 \mu\text{g}\cdot\text{g}^{-1}$) was also relatively higher than others. The results of this study will provide basic information for breeding sorghums, foxtail millets and common millets with higher phenolic compound concentrations.

Keywords : HPLC, phenolic compounds, sorghum, foxtail millet, common millet

Cereals such as sorghum [*Sorghum bicolor* (L.) Moench], foxtail millet (*Setaria italica*), common millet (*Panicum miliaceum* L.), and others were attention to people. The 21 century people's life is very stabilized and also increased about health care. In this regard cereal's value is really high. Many people always dream about maintenance of youth extension of life. To meet the needs of these human eager that research has been conducted in different direction. One such study is the access from the diet. Some of the specific substances can help about human health and maintained the youth that have revealed through various researches (Harbone and Williams, 2000). And other study helps lower risk of cardiovascular disease, ischemic stroke, type II diabetes, metabolic syndrome, and gastrointestinal cancers. Those substances are anthocyanidin, flavonoids, isoflavones and some kind of plant secondary metabolite. Of these materials, the phenolic compounds are representative of a plant secondary metabolites (Naczka and Shaahidi, 2004).

Cereals like foxtail millet and sorghum were consumed as whole grain. Such consumption pattern has helpful to prevent about some kind of disease (cardiovascular disease, ischemic stroke, type II diabetes, metabolic syndrome, and cancers) (Jones, 2006; Maggiolini *et al.*, 2005). Epidemiological evidence shows that increased levels of fruit and vegetables in the diet reduce the risk of cancer and heart disease (Block *et al.*, 1992; Nothling *et al.*, 2007). Numerous studies show that the high correlations were observed between total phenols and antioxidant activity (Dykes and Rooney, 2007).

Recent studies showed that fruits and various vegetables were revealed antioxidant activities and very effective about oxidative damage diseases such as coronary heart disease, stroke and cancers (Jacob and Burri, 1996; Paganga *et al.*, 1999; Huang and Ferraro, 1992; Powles and Ness, 1996;

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Block *et al.*, 1992). One area of work has been in trying to elucidate the role of antioxidants and free radical scavengers in reducing the severity of degenerative diseases. Free radicals have been implicated in playing a role in over 100 diseases, including cancer there is currently only proof that free radicals are involved in the pathogenesis of a few diseases (Kehrer, 1993; Stohs *et al.*, 1995; Thomas, 1995). Specially, sorghums had strong radical scavenging activity and inhibitory activity against bacteria (Kil *et al.*, 2009). The possible health benefits of specific phenolic compounds such as remain unproved as exists for all types of phenolic compounds (Rebecca, 2003). All cereal grains containing the phenolic compounds, which are located in the pericarp, testa, aleurone layer, and endosperm (Hahn *et al.*, 1983). Research indicates that phenolic compounds may reduce the risk of cardiovascular disease and cancer.

Since phenolics are virtually ubiquitous in plant material and may occur at very high levels, it seems likely that, given a sufficient bioavailability, these compounds will play a major role in determining the antioxidant potential of food stuffs.

As more work has been carried out, many more specific, targeted roles for phenolics have also been identified. Many flavonoids in particular are also able to modulate the activity of key human enzymes such as tyrosine kinases (Sharma *et al.*, 1994). Phenolic compounds are a group of chemical substances found in plants, characterized by the presence of more than one unit or building block. They are generally divided into phenolic acids, flavonoids, condensed tannins, and lignans. Phenolic acids are divided into benzoic acid, cinnamic acids, and others. They were included in all cereal grains. Flavonoids are more than 5,000 and have been identified in nature. Phenolic compounds are divided into hydroxybenzoic acids and hydroxycinnamic acids. Hydroxybenzoic acids include gallic, protocatechuic, gentisic, *p*-hydroxybenzoic, vanillic, syringic, veratric, benzoic, and β -resorcylic acids (Hahn *et al.*, 1983). Hydroxycinnamic acids include chlorogenic, caffeic, *p*-coumaric, ferulic, *m*-coumaric, *o*-coumaric and *t*-cinnamic acids. Flavonoids can divide into anthocyanins, flavanols, flavones, flavanones, and flavonols. Flavanols include myricetin and quercetin. Flavones include rutin, hesperidin, naringenin, hesperetin and naringin. Anthocyanins include cyanidin, cyanidin-3-glucoside, delphinidin, malvidin, malvidin-

3-glucoside, pelargonidin, pelargonidin-3-glucoside, peonidin, peonidin-3-glucoside, and petunidin (Yao *et al.*, 2004). Anthocyanins are type of flavonoids that are water-soluble materials of colors like blues, purples, and reds in plant. These compounds exist in the pericarp (Naczka and Shaahidi, 2004).

Some phenolic compounds have been associated with color, sensory qualities, and nutritional and antioxidant properties of foods (Maga, 1978). One impetus for analytical investigations has been the role these phenolics have in the organoleptic properties of foods (Peleg *et al.*, 1991; Naim *et al.*, 1992; Tan, 2000). Variation of phenolic compounds according to seed colors was shown in previous study (Lee *et al.*, 2010).

Phenolic compounds together with the physical plant structures. The potential differential effects of elevated atmospheric carbon dioxide and temperature can affect to plant growth and chemistry (Veteli *et al.*, 2002).

This study was carried out to investigate the different concentrations of phenolic compounds in Korean 5 sorghums, 5 foxtail millets and 5 common millets which were cultivated at the four different regions of Korea.

MATERIALS AND METHODS

Samples Preparation for Analysis

The samples used in this experiment were 5 sorghums [*Sorghum bicolor* (L.) Moench], 5 foxtail millets (*Setaria italica*) and 5 common millets (*Panicum miliaceum* L.). The sixty cereal grains were cultivated and harvested at four site: Bonghwa (Gyeongsangbuk-do, 15 cultivars), Yeongyang (Gyeongsangbuk-do, 15 cultivars), Milyang (Gyeongsangnam-do, 15 cultivars), and Gijang (Busan, 15 cultivars) in Korea. 4 cultivation regions have suitable climate conditions for growing of sorghum, foxtail millet and common millet (Fig. 1). Each of the cereal grains were separated by varieties and regions (Table 1) and stored at dry keeper (SANPLATEC Corp.) for the analysis of phenolic compounds.

Color Measurements of Samples

The color value of cereal grains was determined by using a Minolta Chromaticity Meter CR-310 (Konica Minolta, Osaka, Japan). The color testing method used was the CIE-Lab method where L stands for lightness, and a, b stand for

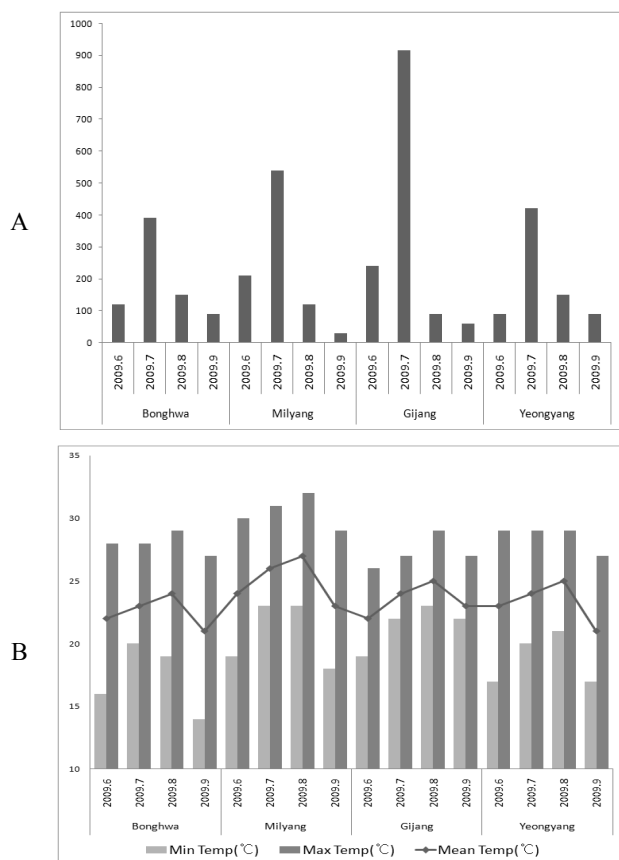


Fig. 1. Regional climate conditions during crop growth. A; Precipitation, B; Temperature

chromaticity. The sign of a and b indicate color direction: +a is the direction to red, -a is direction to green, +b is direction to yellow and -b is direction to blue (Table 1).

Sample Preparation for Phenolic Compounds Analysis

Each cereal grains were freeze-dried below -40°C under vacuum to prepare the sample that have been used for these experiments and then ground. The ground samples (2 g) were mixed with 2 mL of 0.1 N HCl and 10 mL of acetonitrile (ACN), stirred for 2 h at room temperature, and filtered through a No. 42 filter paper (Whatman, USA). The filtrate was concentrated to dryness under vacuum at temperature (25°C). The concentrated samples were redissolved in 10 mL of 80% aqueous methanol (HPLC grade J. T. Baker, USA). A aliquot samples were filtered through a $0.45\ \mu\text{m}$ filter (TITAN syringe filter nylon membrane). The filtrate was used for the HPLC analysis.

HPLC Conditions for Phenolic Compounds Analysis

The high performance liquid chromatography (HPLC) system was used in a SHIMADZU HPLC system equipped with the SPD-M10A Photo Diode Array detector (Japan), Midas autoinjector (Hamilton, Netherlands), and a $20\ \mu\text{l}$ sample

Table 1. List of the samples and their chromaticity.

Crops	Varieties	Growing region (in Korea)											
		Bonghwa			Yeongyang			Milyang			Gijang		
		L	a	b	L	a	b	L	a	b	L*	a**	b***
Sorghum	Moktaksusu	45.92	+13.24	+24.20	47.46	+12.2	+25.30	45.54	+12.42	+23.30	47.75	+13.40	+17.87
	Tojongsusu	59.32	+5.8	+17.31	56.54	+6.53	+19.93	60.27	+4.42	+15.56	58.39	+5.99	+20.66
	Hwanggumsusu	43.61	+13.1	+0.70	44.73	+12.67	+21.94	40.60	+14.24	+19.67	40.87	+13.60	+20.66
	Hwanggumchalsusu	43.62	+13.48	+21.25	46.67	+12.50	+23.31	39.22	+13.77	+18.25	41.86	+13.37	+21.76
	Whenchalsusu	61.48	+5.39	+24.54	59.50	+5.76	+24.29	59.40	+4.92	+22.09	57.47	+5.24	+20.89
Foxtail millet	Hwanggumjo	59.76	+6.26	+29.31	59.33	+5.79	+27.90	59.04	+6.31	+27.47	59.56	+5.94	+28.55
	Jaeraejo	65.82	+5.20	+29.52	61.77	+5.45	+27.86	61.66	+6.08	+28.72	59.78	+4.53	+25.44
	Chungchajo	57.26	+2.58	+23.04	58.32	+2.74	+24.61	56.49	+3.05	+23.72	56.64	+2.61	+21.70
	Whachunchajo	62.57	+5.93	+29.46	58.75	+5.64	+28.79	62.94	+7.25	+31.95	62.14	+6.69	+31.28
	Bulgeunjo	59.46	+2.65	+23.66	59.21	+3.25	+25.40	58.45	+3.71	+24.76	55.08	+3.83	+23.39
Common millet	Hwanggumgijang	26.89	+9.84	+9.66	45.02	+9.08	+33.25	29.35	+9.41	+10.52	29.75	+8.51	+10.77
	Bulgeungijang	45.19	+19.27	+33.26	55.49	+12.71	+29.97	45.42	+19.27	+33.37	42.84	+19.07	+31.32
	Norangchalgijang	64.58	+7.10	+23.94	65.90	+6.68	+24.14	68.74	+6.81	+25.14	67.11	+6.62	+23.94
	Jaeraegijang (Pocheon)	54.72	+12.14	+30.64	44.16	+18.45	+32.46	58.05	+12.52	+32.50	58.01	+12.20	+30.83
	Jaeraegijang	44.92	+19.41	+33.95	29.82	+9.44	+11.77	39.91	+10.41	+17.73	39.21	+10.59	+17.93

*L; lightness, **a; (+) red to (-) green, ***b; (+) yellow to (-) blue

loop. Analysis was primarily achieved on a YMC-Pack ODS AM-303 (5 μm , 250 mm \times 4.6 mm I.D.) column. The absorbance of each sample solution was measured at 280 nm. The solvent gradient HPLC analysis was applied using the modified method of Kim *et al.* (2006). The mobile phase consisted of solvents A and B. The solvent A was 0.1% glacial acetic acid in distilled water and solvent B was 0.1% glacial acetic acid in acetonitrile and the flow rate was 1 mL \cdot min $^{-1}$. The injection volume was 20 μl , the linear gradient of HPLC solvent was followed; B was increased from 8% to 10% for 2 min, then from 10% to 30% for 25 min, from 30% to 90% for 23 min, from 90% to 100% for 2 min, and kept at 100% of B for 5 min, before a return to the initiation state. The next sample was injected after 15 min.

Standard Materials and Generation of Calibration Curves

29 phenolic compounds were purchased from Sigma-Aldrich (USA) and Extrasynthese (France) and those were dissolved with dimethylsulfoxide (DMSO). The calibration curves for standards were made from the serial dilution of samples dissolved in dimethylsulfoxide (DMSO). The linear range and the equation of regression were obtained high linearity from 0.991 to 1.000 sequentially for each calibration at 10, 50, 100 $\mu\text{g}\cdot\text{mL}^{-1}$. All of the solvents were used as HPLC grade (J.T. Baker, USA). The 29 phenolic compounds were gallic acid, protocatechuic acid, vanillic acid, syringic acid, veratric acid, benzoic acid, β -resorcylic acid, chlorogenic acid, caffeic acid, *p*-coumaric acid, ferulic acid, *m*-coumaric acid, *o*-coumaric acid, *t*-cinnamic acid, myricetin, quercetin, (+)catechin, rutin, hesperidin, naringenin, hesperetin, naringin, formononetin, biochanin A, salicylic acid, homogentisic acid, kaempferol, resveratrol and vanillin.

Statistical Analysis

A statistical analysis was undertaken using the general linear model procedure (GLM) of the statistical analysis system (SAS, 9.1) program. Comparisons among regional and varieties were made at the 0.05 probability level using least significant difference (LSD). All experiments were repeated twice.

RESULTS AND DISCUSSION

Regional Comparison of Phenolic Compounds

Sorghum contained the highest amount of phenolic compounds among three different species (sorghum, foxtail millet, common millet).

Figure 2 exhibited variation of phenolic compounds concentrations in sorghum varieties. Among different regions, the phenolic compounds concentration showed higher amount in Yeongyang and Milyang regions of sorghums. The comparison of average phenolic compounds in sorghums grown in different regions showed order to Milyang (963.3 $\mu\text{g}\cdot\text{g}^{-1}$), Yeongyang (923.1 $\mu\text{g}\cdot\text{g}^{-1}$), Gijang (831.3 $\mu\text{g}\cdot\text{g}^{-1}$) and Bonghwa (735.6 $\mu\text{g}\cdot\text{g}^{-1}$). Moksaksusu had the highest amount of phenolic compounds concentrations and showed the biggest regional differences. And, Yeongyang and Gijang regions were showed big differences of phenolic compounds concentrations. Specially, Gijang region had the highest minimum temperature and the lowest maximum temperature. Bonghwa (1215.6 $\mu\text{g}\cdot\text{g}^{-1}$) and Milyang (1507.8 $\mu\text{g}\cdot\text{g}^{-1}$) regions showed similar phenolic compounds concentrations. However, Yeongyang (2067.6 $\mu\text{g}\cdot\text{g}^{-1}$) and Gijang (840.7 $\mu\text{g}\cdot\text{g}^{-1}$) regions showed big differences. In case of Hwanggumsusu, Gijang (1448.5 $\mu\text{g}\cdot\text{g}^{-1}$) region had the highest concentration and Bonghwa (670.5 $\mu\text{g}\cdot\text{g}^{-1}$) region revealed the lowest concentration of phenolic compounds.

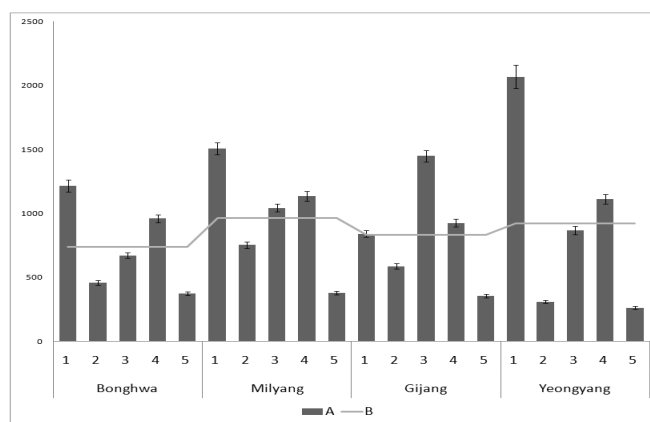


Fig. 2. Comparison of phenolic compound concentrations in sorghums in four cultivation regions. Each vertical bar indicates the standard error values.

A; Total phenolic compounds in each varieties, B; Average phenolic compounds of 5 sorghums total phenolic compounds, 1; Moksaksusu, 2; Tojongsusu, 3; Hwanggumsusu, 4; Hwanggumchalsusu, 5; Whenchalsusu

In Tojingsusu, Milyang region had the highest concentration and Yeongyang region had the lowest concentrations of phenolic compounds. Hwanggumchalsusu and Whenchalsusu did not show a significant difference of phenolic compounds concentrations according to different regions. In this study, the concentrations of phenolic compounds revealed difference between Yeongyang and Gijang regions. These differences were caused by the concentration of (+)catechin. (+)Catechin had the highest concentrations in Yeongyang region and the lowest concentrations in Gijang area. However, as the production of phenolic compounds composed of complex reactions between the crops and growth conditions like average temperature, rainfall and other various factors and it is hard to select for high contained phenolic compounds varieties in cereal germplasm.

Figure 3 showed variation of phenolic compounds concentration in foxtail millet varieties. The foxtail millets average phenolic compounds showed similar amount in the Milyang ($319.0 \mu\text{g}\cdot\text{g}^{-1}$), Gijang ($288.1 \mu\text{g}\cdot\text{g}^{-1}$) and Bonghwa ($281.9 \mu\text{g}\cdot\text{g}^{-1}$) areas. The phenolic compounds of Yeongyang ($246.6 \mu\text{g}\cdot\text{g}^{-1}$) slightly low and that showed similar concentrations in another three regions. There was not a relationship of average phenolic compounds according to the regional difference with climate. However, it can be found the relationship with climate in Jaeraejo and Chungchajo. That two varieties showed

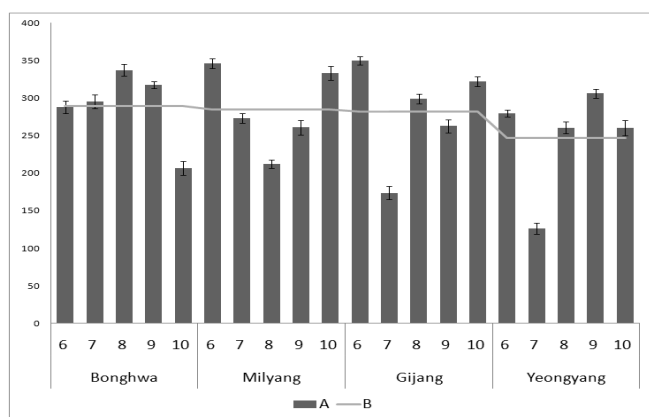


Fig. 3. Comparison of phenolic compound concentrations in foxtail millets in four cultivation regions. Each vertical bar indicates the standard error values.

A; Total phenolic compounds in each varieties, B; Average phenolic compounds of 5 foxtail millets total phenolic compounds, 6; Hwanggumjo, 7; Jaeraejo, 8; Chungchajo, 9; Whachunchajo, 10; Yeongjujo

the highest contents of phenolic compounds in Bonghwa region. In the comparison of climates, Bonghwa region showed 18.6 degrees of minimum temperature during seed ripening. That was 3 or more degrees lower than Milyang (21.7°C) and Gijang (21.9°C) region and also 1 or more degrees lower than Yeongyang (19.9°C) region (Fig. 1). It could be thought of phenolic compounds were associated with temperature during seed ripening.

The variation of phenolic compounds concentrations among common millet varieties was recognized (Fig. 4). The concentration of phenolic compounds of common millet showed the range from $305.5 \mu\text{g}\cdot\text{g}^{-1}$ (Milyang) to $237.2 \mu\text{g}\cdot\text{g}^{-1}$ (Yeongyang). It was hard to find associate with regional phenolic compounds concentrations with temperature in common millet. However, it can be associated with precipitation in Norangchalgijang. Norangchalgijang in Gijang region had small amount of phenolic compounds concentrations, and that could be caused by rainfall. Gijang area showed the highest precipitation. Especially, more than 900 mm of rain fell in July (Fig. 1).

This results was supported by another previous study (Veteli *et al.*, 2002). On the other hand, some materials were not showed to significantly differences of some phenolic acids including quercetin and tannins. Another research reported that plant grown at low temperature, total concentrations of

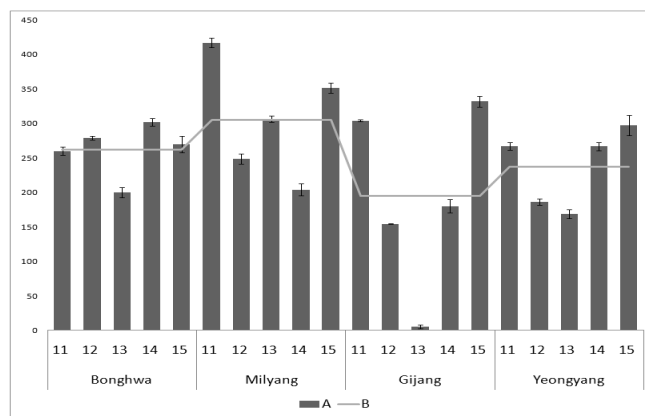


Fig. 4. Comparison of phenolic compound concentrations in common millets in four cultivation regions. Each vertical bar indicates the standard error values.

A; Total phenolic compounds in each varieties, B; Average phenolic compounds of 5 common millets total phenolic compounds, 11; Hwanggumgijang, 12; Bulgeungijang, 13; Norangchalgijang, 14; Jaraegijang (Pochun), 15; Jaeraegijang

phenolic compounds during the early growth phase were lower than that of plants grown at high temperature, but the concentrations increased and was by 40% higher than in plants grown at high temperature (Rudikovskaya *et al.*, 2008). In this experiment, sorghum had significant differences of phenolic compounds concentrations by regional differences. Especially, Moktaksusu showed bigger differences than other sorghum. That was due to the concentration of (+)catechin. Yeongyang and Bonghwa region had much more (+)catechin than another two regions. Those Yeongyang and Bonghwa regions were had lower minimum temperature in July and August than Gijang and Milyang region. That concentration of (+)catechin in Moktaksusu was similar with Veteli.

However, chlorogenic acid was the lowest concentrations in Bonghwa region. Yeongyang region showed the highest contents and second order were Milyang and Gijang regions (Table 2-5). The Milyang, Gijang, Yeongyang region of high

concentrations chlorogenic acid were higher mean temperature than Bonghwa region. The result of this experiment was similar to that of Rudikovskaya *et al.*, (2008), who reported relationship between phenolic compounds concentration and temperature.

When compared to phenolic compounds concentrations with climate conditions it could not found any associated with foxtail millet or common millet. On the other hand, Norangchalgijang in Gijang region has little phenolic compounds concentrations, and that could be caused by rainfall. Gijang region has the highest precipitation. Especially, more than 900 mm of rain fell in July. It can be associated with precipitation in Norangchalgijang. This results was supported by another previous study (Vallejo *et al.*, 2003) that was the significantly reduce of phenolic compounds by increased rainfall.

Further investigation will require needed to analyze the

Table 2. The total phenolic compounds in Bonghwa-gun, Gyeongsangbuk-do.

	GA*	PA	VA	SA	VE	BA	bR	CA	CF	pC	FA	mC	oC	tC
1**	nd	50.37	22.32	17.67	10.09	110.94	2.67	51.41	41.90	tr	22.24	13.77	tr	8.92
2	14.45	20.07	nd	0.92	tr	153.53	0.82	45.56	32.34	tr	15.82	tr	tr	7.24
3	17.19	43.27	12.64	15.50	5.48	88.14	84.41	51.05	41.15	tr	19.63	3.18	tr	7.44
4	16.88	44.57	19.43	22.78	19.56	251.90	75.24	51.72	42.42	tr	22.37	2.50	tr	7.58
5	14.53	nd	18.20	tr	tr	17.52	1.17	48.06	35.49	tr	16.41	nd	tr	8.90
6	13.66	40.70	3.76	tr	tr	14.53	tr	45.87	33.11	tr	15.81	nd	tr	7.93
7	14.02	36.53	1.74	tr	tr	20.08	tr	44.37	27.57	tr	14.60	nd	nd	6.96
8	13.20	33.94	3.12	tr	tr	14.82	tr	47.95	37.59	tr	14.84	tr	tr	7.08
9	14.06	39.26	3.33	tr	nd	7.18	tr	45.18	31.84	tr	14.92	nd	tr	6.91
10	13.64	32.61	1.81	tr	nd	nd	tr	22.17	35.35	tr	7.19	nd	nd	6.96
11	nd	nd	3.81	tr	tr	21.28	tr	49.86	0.00	tr	7.14	nd	tr	8.26
12	15.51	31.73	6.07	tr	tr	6.96	3.35	46.14	27.47	tr	14.71	nd	nd	7.41
13	13.29	35.36	3.06	tr	tr	5.74	10.94	44.93	27.83	tr	14.44	nd	nd	nd
14	14.89	35.38	3.39	tr	tr	7.77	2.17	44.95	27.53	tr	14.71	tr	tr	7.28
15	12.81	32.26	5.43	tr	tr	6.05	3.42	45.41	13.74	tr	14.15	nd	tr	7.22
Mean	12.54	31.74	7.21	3.79	2.34	48.43	12.28	45.64	30.35	0.00	15.26	1.30	0.00	7.07
CV (%)	6.02	23.67	9.81	55.32	7.27	119.61	12.41	17.86	16.66	—	24.40	29.94	—	2.83
LSD (0.05)	1.61	16.15	1.51	4.47	0.36	123.47	3.42	17.38	10.78	0.00	7.94	0.83	0.00	0.43

GA*; Gallic acid, PA; Protocatechuic acid, VA; Vanillic acid, SA; Syringic acid, VE; Veratric acid, BA; Benzoic acid, bR; β -Resorcylic acid, CA; Chlorogenic acid, CF; Caffeic acid, pC; *p*-Coumaric acid, FA; Ferulic acid, mC; *m*-Coumaric acid, oC; *o*-Coumaric acid, tC; *t*-Cinnamic acid, nd; not detected, tr; trace, **1; Moktaksusu, 2; Tojongsusu, 3; Hwanggumsusu, 4; Hwanggumchalsusu, 5; Whenchalsusu, 6; Hwanggumjo, 7; Jaeraejo, 8; Chungchajo, 9; Whachunchajo, 10; Yeongjujo, 11; Hwanggumgijang, 12; Bulgeungijang, 13; Norangchalgijang, 14; Jaeraegijang (Pocheon), 15; Jaeraegijang

Table 2. (Continued)

	MY*	QC	Ct	FO	BI	RT	HD	NE	HT	NI	SC	HA	KA	RV	Vn
1**	89.31	53.42	536.81	tr	nd	10.11	12.48	tr	11.28	69.39	35.71	44.80	tr	tr	tr
2	51.51	53.05	nd	nd	nd	8.56	8.62	tr	nd	12.67	0.40	31.48	tr	tr	tr
3	62.61	53.45	30.70	tr	nd	5.14	6.14	tr	11.28	50.05	19.57	42.50	tr	tr	tr
4	67.97	54.80	41.43	tr	1.01	79.54	13.95	tr	11.65	53.25	25.61	31.48	tr	tr	2.56
5	52.70	68.42	tr	tr	nd	4.44	10.50	22.53	12.50	6.88	4.09	32.06	tr	tr	tr
6	54.04	tr	0.35	tr	4.22	0.87	8.06	tr	11.77	2.35	nd	31.12	tr	nd	tr
7	51.94	54.68	tr	nd	3.79	tr	7.82	tr	11.22	nd	nd	nd	tr	tr	tr
8	49.63	52.87	tr	tr	4.07	tr	8.22	tr	11.97	4.76	3.22	30.01	tr	tr	tr
9	50.91	53.03	tr	tr	4.69	0.29	4.35	tr	10.97	0.47	nd	30.23	tr	tr	tr
10	nd	50.79	tr	tr	2.31	nd	3.74	tr	nd	nd	nd	29.91	tr	nd	tr
11	24.70	55.52	62.40	nd	nd	nd	4.34	tr	13.47	6.86	2.07	nd	tr	tr	tr
12	nd	53.19	nd	nd	nd	tr	12.66	tr	5.30	3.11	0.85	44.43	tr	tr	tr
13	nd	nd	tr	nd	nd	nd	nd	nd	nd	4.76	nd	39.41	tr	nd	tr
14	47.82	50.64	tr	nd	nd	nd	3.96	tr	nd	3.38	3.40	34.62	nd	tr	tr
15	22.16	52.75	nd	nd	nd	nd	12.12	nd	nd	nd	nd	41.97	nd	tr	0.23
Mean	41.69	47.11	44.78	0.00	1.34	7.26	7.80	1.50	7.43	14.53	6.33	30.93	0.00	0.00	0.19
CV (%)	29.39	2.77	14.91	—	28.34	335.73	48.28	11.18	26.84	13.90	20.21	4.84	—	—	24.12
LSD (0.05)	26.11	2.78	14.23	0.00	0.81	51.98	8.02	0.36	4.25	4.31	2.73	3.19	0.00	0.00	0.10

MY*; Myricetin, QC; Quercetin, Ct; (+)Catechin, FO; Formononetin, BI; Biochanin A, RT; Rutin, HD; Hesperidin, NE; Naringenin, HT; Hesperetin, NI; Naringin, SC; Salicylic acid, HA*; Homogentisic acid, KA; Kaempferol, RV; Resveratrol, Vn; Vanillin nd; not detected, tr; trace, **1; Moktaksusu, 2; Tojongsusu, 3; Hwanggumsusu, 4; Hwanggumchalsusu, 5; Whenchalsusu, 6; Hwanggumjo, 7; Jaeraejo, 8; Chungchajo, 9; Whachunchajo, 10; Yeongjujo, 11; Hwanggumgijang, 12; Bulgeungijang, 13; Norangchalgiang, 14; Jaeraegijang (Pocheon), 15; Jaeraegijang

Table 3. The total phenolic compounds in Milyang-si, Gyeongsangnam-do.

	GA*	PA	VA	SA	VE	BA	bR	CA	CF	pC	FA	mC	oC	tC
1**	14.16	42.40	59.60	9.07	41.09	137.89	21.15	218.94	60.07	7.85	28.06	65.33	tr	8.27
2	14.56	38.12	18.50	10.82	21.08	105.20	0.94	56.37	41.56	tr	25.41	tr	tr	7.24
3	14.23	40.45	86.20	19.39	28.54	56.28	139.85	64.16	45.35	nd	20.96	32.12	tr	7.93
4	15.75	38.67	316.00	7.55	8.94	38.85	48.40	58.18	38.32	tr	20.02	17.66	tr	7.46
5	16.47	31.11	12.10	tr	0.55	25.53	tr	54.97	37.66	nd	17.24	nd	tr	7.22
6	7.33	41.55	12.60	tr	tr	11.38	tr	47.52	29.78	tr	15.15	nd	tr	6.94
7	13.47	30.94	4.40	tr	tr	17.75	tr	45.17	27.97	tr	14.46	nd	nd	7.14
8	nd	33.94	15.00	tr	tr	nd	nd	nd	29.89	tr	15.07	tr	tr	7.26
9	12.97	41.08	8.30	tr	nd	nd	tr	46.79	27.54	tr	14.56	nd	tr	7.02
10	nd	34.64	15.20	tr	nd	19.21	tr	44.57	27.43	tr	14.91	nd	nd	7.31
11	6.61	33.07	4.70	tr	0.04	28.20	tr	54.01	13.84	tr	15.09	nd	tr	8.42
12	13.62	33.65	8.60	tr	0.04	6.47	14.34	nd	13.93	tr	15.41	nd	nd	8.33
13	12.86	36.87	4.10	tr	0.07	7.22	15.66	46.67	30.39	tr	14.95	nd	nd	7.03
14	12.76	36.73	1.50	tr	nd	9.40	0.40	22.68	14.54	tr	7.00	tr	tr	3.43
15	13.69	42.58	4.60	tr	0.71	25.78	tr	52.64	27.53	tr	14.75	nd	tr	6.96
Mean	11.23	37.05	38.09	3.12	6.74	32.61	16.05	54.18	31.05	0.52	16.87	7.67	0.00	7.20
CV (%)	33.73	4.60	250.34	13.29	15.89	32.56	112.21	15.91	29.70	57.79	16.35	7.39	—	18.30
LSD (0.05)	8.33	3.75	217.59	0.95	2.44	23.69	41.27	19.11	20.51	0.69	6.13	1.30	0.00	2.92

GA*; Gallic acid, PA; Protocatechuic acid, VA; Vanillic acid, SA; Syringic acid, VE; Veratric acid, BA; Benzoic acid, bR; β -Resorcylic acid, CA; Chlorogenic acid, CF; Caffeic acid, pC; *p*-Coumaric acid, FA; Ferulic acid, mC; *m*-Coumaric acid, oC; *o*-Coumaric acid, tC; *t*-Cinnamic acid, nd; not detected, tr; trace, **1; Moktaksusu, 2; Tojongsusu, 3; Hwanggumsusu, 4; Hwanggumchalsusu, 5; Whenchalsusu, 6; Hwanggumjo, 7; Jaeraejo, 8; Chungchajo, 9; Whachunchajo, 10; Yeongjujo, 11; Hwanggumgijang, 12; Bulgeungijang, 13; Norangchalgiang, 14; Jaeraegijang (Pocheon), 15; Jaeraegijang

Table 3. (Continued)

	MY*	QC	Ct	FO	BI	RT	HD	NE	HT	NI	SC	HA	KA	RV	Vn
1**	188.28	61.67	35.84	nd	nd	57.76	25.07	tr	13.40	174.63	161.59	48.21	tr	1.19	26.26
2	64.54	61.74	129.23	tr	nd	12.15	5.26	nd	11.23	37.75	56.62	30.92	tr	tr	3.08
3	142.86	72.44	nd	tr	nd	74.38	13.80	nd	13.26	42.50	91.41	32.28	tr	0.13	4.71
4	56.12	78.80	211.38	tr	nd	32.31	10.60	tr	12.34	29.28	51.21	37.81	tr	tr	0.57
5	47.53	53.03	6.46	nd	nd	8.54	9.37	tr	11.92	6.54	1.34	29.30	tr	tr	tr
6	47.43	56.96	1.12	tr	7.30	nd	8.49	tr	14.21	2.57	4.10	31.70	tr	tr	tr
7	nd	53.64	tr	tr	4.08	tr	7.63	tr	14.01	3.32	nd	29.37	tr	tr	tr
8	nd	51.93	tr	tr	3.99	tr	8.03	tr	13.56	1.38	2.82	29.19	tr	tr	tr
9	nd	52.38	tr	tr	7.73	0.10	nd	tr	12.92	nd	nd	29.39	tr	nd	tr
10	48.62	56.83	tr	tr	5.95	tr	8.43	tr	14.35	3.37	2.74	29.65	tr	tr	tr
11	49.17	57.69	75.35	tr	nd	3.59	9.42	tr	15.44	3.80	6.74	31.85	tr	tr	tr
12	nd	63.77	nd	tr	nd	0.83	15.07	tr	13.39	2.30	3.00	32.85	tr	tr	2.79
13	24.31	51.81	nd	tr	nd	0.34	7.99	tr	9.78	0.67	2.16	33.68	tr	tr	tr
14	24.77	25.10	nd	nd	nd	nd	4.41	tr	nd	5.50	2.36	33.36	nd	nd	tr
15	49.08	52.05	nd	nd	nd	0.78	7.60	tr	10.77	8.76	1.30	31.96	tr	tr	tr
Mean	49.51	56.66	30.63	0.00	1.94	12.72	9.41	0.00	12.04	21.49	25.83	32.77	0.00	0.09	2.49
CV (%)	68.30	17.16	255.97	—	12.41	18.58	29.87	—	9.33	19.31	19.07	6.31	—	111.36	24.44
LSD (0.05)	74.94	21.86	1.88	0.00	0.55	5.40	6.27	0.00	2.50	9.38	11.26	4.59	0.00	0.22	1.40

MY*; Myricetin, QC; Quercetin, Ct; (+)Catechin, FO; Formononetin, BI; Biochanin A, RT; Rutin, HD; Hesperidin, NE; Naringenin, HT; Hesperetin, NI; Naringin, SC; Salicylic acid, HA*; Homogentisic acid, KA; Kaempferol, RV; Resveratrol, Vn; Vanillin nd; not detected, tr; trace, **1; Moktaksusu, 2; Tojongsusu, 3; Hwanggumsusu, 4; Hwanggumchalsusu, 5; Whenchalsusu, 6; Hwanggumjo, 7; Jaeraejo, 8; Chungchajo, 9; Whachunchajo, 10; Yeongjujo, 11; Hwanggumgijang, 12; Bulgeungijang, 13; Norangchalgiang, 14; Jaeraegijang (Pocheon), 15; Jaeraegijang

Table 4. The total phenolic compounds in Gijang-gun, Busan.

	GA*	PA	VA	SA	VE	BA	bR	CA	CF	pC	FA	mC	oC	tC
1**	nd	36.84	45.29	7.19	22.91	56.42	tr	113.64	35.50	tr	17.91	3.10	tr	8.65
2	nd	31.85	10.62	9.59	9.59	77.97	tr	49.35	28.28	tr	18.41	tr	tr	7.18
3	14.52	37.39	125.06	30.61	54.57	131.46	191.37	nd	39.00	tr	27.49	54.91	tr	7.47
4	12.72	39.25	95.26	19.96	18.71	86.60	163.73	nd	45.50	tr	21.49	36.88	tr	7.84
5	12.80	30.72	18.58	tr	1.79	11.17	tr	49.28	36.98	tr	15.61	tr	tr	6.89
6	16.98	31.18	4.24	tr	1.66	18.07	tr	46.69	30.63	tr	15.63	nd	tr	7.37
7	13.04	nd	nd	tr	tr	23.62	tr	nd	28.10	tr	nd	nd	tr	7.40
8	13.76	40.65	2.26	tr	tr	22.89	tr	nd	27.74	tr	16.25	tr	tr	7.54
9	6.47	30.17	6.19	tr	tr	15.91	tr	45.36	27.74	tr	15.17	tr	tr	6.92
10	6.58	32.25	16.13	tr	nd	14.99	nd	45.25	29.63	tr	14.34	nd	tr	6.86
11	6.36	33.03	3.32	nd	nd	14.88	tr	67.70	29.74	tr	13.87	nd	nd	7.97
12	13.29	33.50	2.62	nd	nd	nd	tr	51.65	nd	tr	nd	nd	nd	7.12
13	5.57	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
14	nd	36.37	1.97	tr	nd	nd	2.52	46.53	28.63	tr	14.10	nd	nd	3.45
15	12.70	nd	3.52	tr	nd	23.95	tr	54.86	28.44	tr	14.23	nd	tr	8.43
Mean	8.99	27.55	22.34	4.49	7.28	33.20	23.84	38.02	27.73	0.00	13.63	6.33	0.00	6.74
CV (%)	51.70	5.15	4.62	85.59	58.46	46.47	39.71	6.35	2.10	—	7.85	8.37	—	18.78
LSD (0.05)	9.90	3.02	2.20	8.19	9.07	32.88	20.18	5.14	1.24	0.00	2.28	1.13	0.00	2.70

GA*; Gallic acid, PA; Protocatechuic acid, VA; Vanillic acid, SA; Syringic acid, VE; Veratric acid, BA; Benzoic acid, bR; β -Resorcylic acid, CA; Chlorogenic acid, CF; Caffeic acid, pC; *p*-Coumaric acid, FA; Ferulic acid, mC; *m*-Coumaric acid, oC; *o*-Coumaric acid, tC; *t*-Cinnamic acid, nd; not detected, tr; trace, **1; Moktaksusu, 2; Tojongsusu, 3; Hwanggumsusu, 4; Hwanggumchalsusu, 5; Whenchalsusu, 6; Hwanggumjo, 7; Jaeraejo, 8; Chungchajo, 9; Whachunchajo, 10; Yeongjujo, 11; Hwanggumgijang, 12; Bulgeungijang, 13; Norangchalgiang, 14; Jaeraegijang (Pocheon), 15; Jaeraegijang

Table 4. (Continued)

	MY*	QC	Ct	FO	BI	RT	HD	NE	HT	NI	SC	HA	KA	RV	Vn
1**	63.28	59.56	29.07	tr	1.04	31.69	13.58	tr	14.82	116.87	111.80	42.51	tr	0.67	8.33
2	64.52	67.67	94.51	tr	nd	5.55	10.81	tr	12.30	47.40	11.17	29.75	tr	tr	tr
3	69.75	83.43	47.35	tr	0.33	99.18	19.18	tr	44.72	169.14	150.86	32.94	tr	3.60	14.17
4	60.65	70.24	nd	tr	nd	13.57	12.70	tr	13.64	104.30	68.21	32.82	tr	0.13	0.95
5	49.04	52.95	17.92	nd	nd	2.39	nd	tr	11.72	6.45	0.48	31.10	tr	tr	tr
6	47.95	51.48	2.13	tr	5.89	1.27	7.66	tr	12.90	3.39	1.59	43.12	tr	tr	tr
7	nd	54.02	nd	tr	4.35	1.49	nd	tr	10.62	nd	nd	30.95	tr	tr	tr
8	50.80	57.59	2.24	tr	3.43	1.13	nd	tr	11.95	7.48	2.63	30.29	tr	0.61	tr
9	nd	50.11	tr	tr	4.62	0.50	8.20	tr	11.96	1.49	2.03	29.74	tr	tr	tr
10	47.32	51.26	nd	tr	2.83	0.07	7.41	tr	11.77	nd	1.91	33.86	tr	tr	tr
11	23.45	52.18	nd	nd	nd	nd	7.60	tr	12.34	nd	nd	31.59	tr	tr	tr
12	nd	nd	nd	nd	nd	tr	12.47	tr	nd	nd	1.79	31.88	nd	tr	tr
13	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
14	nd	nd	tr	nd	nd	nd	nd	nd	nd	5.41	nd	40.92	nd	tr	nd
15	48.30	57.35	23.41	nd	nd	nd	4.12	tr	11.65	6.65	1.98	32.18	tr	tr	tr
Mean	35.00	47.19	14.44	0.00	1.50	10.46	6.92	0.00	12.03	31.24	23.63	31.58	0.00	0.33	1.56
CV (%)	25.87	5.95	124.31	—	13.98	34.66	23.39	—	101.80	10.64	30.49	9.25	—	393.94	197.98
LSD (0.05)	19.30	5.99	38.27	0.00	0.45	7.72	3.45	0.00	26.09	7.08	15.36	6.23	0.00	2.80	6.59

MY*; Myricetin, QC; Quercetin, Ct; (+)Catechin, FO; Formononetin, BI; Biochanin A, RT; Rutin, HD; Hesperidin, NE; Naringenin, HT; Hesperetin, NI; Naringin, SC; Salicylic acid, HA*; Homogentisic acid, KA; Kaempferol, RV; Resveratrol, Vn; Vanillin nd; not detected, tr; trace, **1; Moksaksusu, 2; Tojongsusu, 3; Hwanggumsusu, 4; Hwanggumchalsusu, 5; Whenchalsusu, 6; Hwanggumjo, 7; Jaeraejo, 8; Chungchajo, 9; Whachunchajo, 10; Yeongjujo, 11; Hwanggumgijang, 12; Bulgeungijang, 13; Norangchalgiang, 14; Jaeraegijang (Pocheon), 15; Jaeraegijang

Table 5. The total phenolic compounds in Yeongyang-gun, Gyeongsangbuk-do.

	GA*	PA	VA	SA	VE	BA	bR	CA	CF	pC	FA	mC	oC	tC
1**	12.61	36.83	51.42	9.94	23.01	53.19	16.73	337.52	34.05	tr	21.90	13.79	tr	7.07
2	nd	31.50	1.07	tr	tr	18.23	tr	45.52	33.94	tr	14.55	tr	tr	6.86
3	nd	37.39	46.55	1.02	13.64	48.21	172.71	nd	57.63	tr	23.31	16.10	tr	7.30
4	nd	38.45	65.18	36.89	24.87	78.13	225.69	nd	40.89	tr	32.45	20.67	tr	7.66
5	14.02	nd	21.70	tr	nd	nd	nd	52.14	28.01	tr	16.18	tr	tr	8.08
6	13.02	40.53	nd	tr	nd	13.52	tr	45.84	29.82	tr	14.96	nd	tr	7.49
7	13.76	nd	1.96	tr	nd	nd	nd	nd	26.52	tr	6.94	tr	nd	7.28
8	12.81	nd	12.66	tr	nd	15.92	nd	45.45	28.91	tr	14.15	nd	tr	8.11
9	12.87	41.82	7.44	tr	tr	8.36	tr	45.28	29.72	tr	15.24	nd	tr	7.77
10	5.57	36.09	13.65	tr	nd	nd	nd	44.75	28.58	tr	14.37	nd	nd	7.28
11	nd	nd	6.22	nd	nd	nd	nd	54.56	26.52	tr	14.78	nd	nd	9.82
12	12.59	nd	1.13	tr	nd	nd	tr	45.15	26.52	tr	14.33	nd	nd	nd
13	nd	32.00	1.88	tr	nd	nd	2.87	nd	26.52	tr	14.07	nd	nd	6.96
14	nd	32.51	5.72	tr	nd	6.57	nd	53.82	27.92	nd	nd	nd	tr	7.40
15	25.07	32.33	3.10	nd	nd	11.19	nd	64.34	26.52	tr	14.20	nd	tr	8.87
Mean	8.15	23.96	15.98	3.19	4.10	16.89	27.87	55.62	31.47	0.00	15.43	3.37	0.00	7.20
CV (%)	24.99	2.26	15.71	8.06	13.23	39.66	7.01	0.87	1.24	—	16.64	15.83	—	3.86
LSD (0.05)	4.44	1.18	5.33	0.56	1.18	14.44	4.26	1.05	0.85	0.00	5.60	1.16	0.00	0.61

GA*; Gallic acid, PA; Protocatechuic acid, VA; Vanillic acid, SA; Syringic acid, VE; Veratric acid, BA; Benzoic acid, bR; β -Resorcylic acid, CA; Chlorogenic acid, CF; Caffeic acid, pC; *p*-Coumaric acid, FA; Ferulic acid, mC; *m*-Coumaric acid, oC; *o*-Coumaric acid, tC; *t*-Cinnamic acid, nd; not detected, tr; trace, **1; Moksaksusu, 2; Tojongsusu, 3; Hwanggumsusu, 4; Hwanggumchalsusu, 5; Whenchalsusu, 6; Hwanggumjo, 7; Jaeraejo, 8; Chungchajo, 9; Whachunchajo, 10; Yeongjujo, 11; Hwanggumgijang, 12; Bulgeungijang, 13; Norangchalgiang, 14; Jaeraegijang (Pocheon), 15; Jaeraegijang

Table 5. (Continued)

	MY*	QC	Ct	FO	BI	RT	HD	NE	HT	NI	SC	HA	KA	RV	Vn
1**	50.92	62.50	1116.6	tr	nd	22.23	9.35	tr	11.22	91.87	9.84	34.97	tr	tr	40.01
2	48.29	51.89	24.10	nd	nd	3.13	5.07	tr	nd	12.48	11.97	nd	nd	nd	nd
3	60.19	93.95	nd	tr	nd	25.47	11.47	tr	12.09	135.08	74.22	29.77	tr	0.51	tr
4	68.16	95.27	nd	tr	nd	nd	14.39	tr	30.74	182.17	106.80	31.26	tr	0.39	10.87
5	nd	52.20	35.69	nd	nd	tr	15.04	tr	14.66	2.32	1.51	nd	tr	nd	tr
6	nd	51.57	tr	tr	5.64	0.54	8.29	tr	13.45	1.48	3.30	30.22	tr	tr	tr
7	nd	50.77	nd	tr	3.51	tr	3.82	tr	11.50	nd	nd	nd	tr	tr	tr
8	nd	57.14	nd	tr	6.61	tr	8.23	tr	13.43	3.75	1.90	31.53	tr	tr	tr
9	15.79	52.42	tr	tr	7.97	0.68	9.51	tr	14.51	1.68	4.20	30.88	tr	nd	tr
10	nd	55.45	nd	tr	7.27	tr	8.36	tr	nd	3.85	5.00	30.18	tr	tr	tr
11	nd	96.07	nd	tr	nd	nd	10.82	tr	12.47	nd	4.05	29.74	tr	nd	1.67
12	nd	56.77	24.68	nd	nd	tr	nd	tr	nd	nd	5.34	nd	nd	nd	tr
13	nd	50.59	nd	nd	nd	tr	nd	tr	nd	nd	4.92	29.08	tr	nd	tr
14	23.67	59.57	nd	tr	nd	nd	3.67	tr	nd	16.65	nd	29.14	tr	tr	tr
15	nd	57.68	nd	tr	nd	nd	4.81	tr	11.80	2.54	5.49	29.38	tr	nd	tr
Mean	17.80	62.92	80.07	0.00	2.07	3.47	7.52	0.00	9.72	30.26	15.90	22.41	0.00	0.06	3.50
CV (%)	72.18	10.57	6.61	—	26.81	34.70	47.13	—	8.64	10.24	16.54	0.83	—	173.07	13.29
LSD (0.05)	28.82	14.50	11.53	0.00	1.25	2.63	7.77	0.00	1.84	6.75	5.74	0.41	0.00	0.23	1.01

MY*; Myricetin, QC; Quercetin, Ct; (+)Catechin, FO; Formononetin, BI; Biochanin A, RT; Rutin, HD; Hesperidin, NE; Naringenin, HT; Hesperetin, NI; Naringin, SC; Salicylic acid, HA*; Homogentisic acid, KA; Kaempferol, RV; Resveratrol, Vn; Vanillin nd; not detected, tr; trace, **1; Moktaksusu, 2; Tojongsusu, 3; Hwanggumsusu, 4; Hwanggumchalsusu, 5; Whenchalsusu, 6; Hwanggumjo, 7; Jaeraejo, 8; Chungchajo, 9; Whachunchajo, 10; Yeongjujo, 11; Hwanggumgijang, 12; Bulgeungijang, 13; Norangchalgijang, 14; Jaeraegijang (Pocheon), 15; Jaeraegijang

phenolic compounds, to examine the influence of environmental and varietal variation, and to determine their significance under field conditions.

Comparison of Phenolic Compounds by Different Varieties

Among the sorghum cultivars, Moktaksusu had the highest concentration of phenolic compounds. And followed by Hwanggumchalsusu ($1033.1 \mu\text{g}\cdot\text{g}^{-1}$), Hwanggumsusu ($1007.0 \mu\text{g}\cdot\text{g}^{-1}$), Tojongsusu ($526.1 \mu\text{g}\cdot\text{g}^{-1}$), Whenchalsusu ($342.2 \mu\text{g}\cdot\text{g}^{-1}$).

The phenolic compounds of sorghums were related to the color of seed. Moktaksusu, Hwanggumsusu and Whanggeumchalsusu had dark red color, and they had much more phenolic compounds concentrations than Tojong and Whenchalsusu. Tojongsusu and Whenchalsusu had light yellow color (Fig. 5).

The concentration of phenolic compounds in foxtail millet

varieties, Chungchajo ($335.6 \mu\text{g}\cdot\text{g}^{-1}$) concentrations was the highest, and followed by Hwanggumjo ($275.5 \mu\text{g}\cdot\text{g}^{-1}$), Yeongjujo ($179.5 \mu\text{g}\cdot\text{g}^{-1}$), Whachunchajo ($96.0 \mu\text{g}\cdot\text{g}^{-1}$) and Jaeraejo ($60.1 \mu\text{g}\cdot\text{g}^{-1}$). According to the color in foxtail millet varieties, the concentration of phenolic compounds was not showed significant difference. However, when compared with the lightness, the darker varieties had higher concentration of phenolic compounds. Dark colored Chungchajo, Yeongjujo and Whanggeumjo were showed higher contents of phenolic compounds than that of light colored Whachunchajo and Jaeraejo (Fig. 6).

The concentration of phenolic compounds in common millet was the highest in the Norangchalgijang ($337.0 \mu\text{g}\cdot\text{g}^{-1}$). Hwanggumgijang ($250.0 \mu\text{g}\cdot\text{g}^{-1}$) was also relatively higher contents. Next order were Jaeraegijang ($144.4 \mu\text{g}\cdot\text{g}^{-1}$), Jaeraegijang (pocheon) ($105.6 \mu\text{g}\cdot\text{g}^{-1}$), Bulgeungijang ($87.1 \mu\text{g}\cdot\text{g}^{-1}$). Especially, Jaeraegijang deviation was larger in the

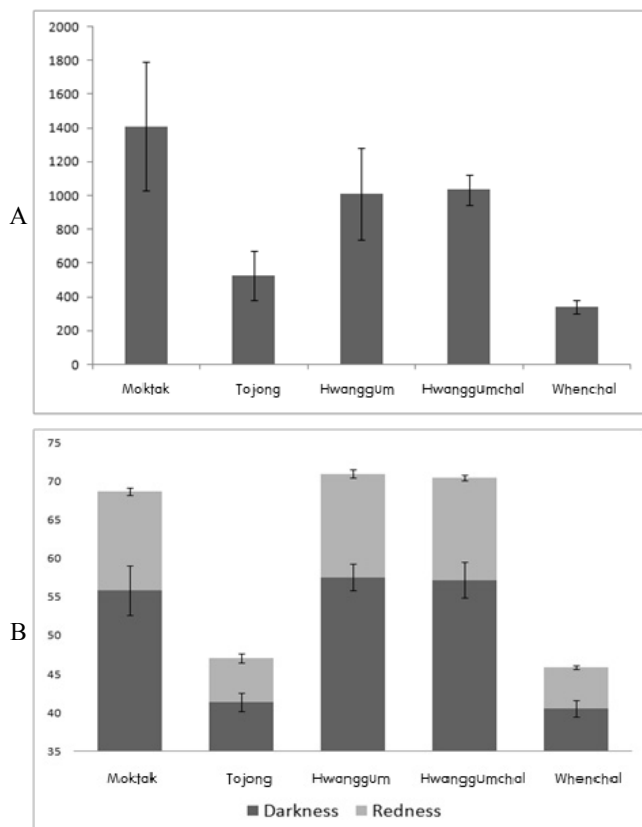


Fig. 5. Comparison of phenolic compounds concentrations in five sorghums.

A: Phenolic compounds concentrations of each varieties (Each vertical bar indicates the standard error values.), B; The chromaticity of the samples

case of varieties. And the correlation between color and phenolic compounds contents was not observed in this study (Fig. 7).

Sorghum had the highest concentration of phenolic compounds among three different varieties (sorghum, foxtail millet, common millet). Specially, (+)catechin ($429.6 \mu\text{g}\cdot\text{g}^{-1}$) concentrations showed the highest in Moktaksusu. Moktaksusu had higher contents of (+)catechin than other sorghum cultivars. In addition, Moktaksusu ($180.4 \mu\text{g}\cdot\text{g}^{-1}$) contained higher contents of chlorogenic acid. However, individual substances of phenolic compounds were showed significant variation according to regional differences. Tojongusu revealed higher contents of benzoic acid ($88.8 \mu\text{g}\cdot\text{g}^{-1}$) and (+)catechin ($62.0 \mu\text{g}\cdot\text{g}^{-1}$). Hwanggum and Hwanggumchalsusu contained β -resorcylic acid, vanillic acid, salicylic acid and naringin. 5 sorghums were contained high concentrations of homogentisic acid, protocatechuic acid, chlorogenic acid, caffeic acid,

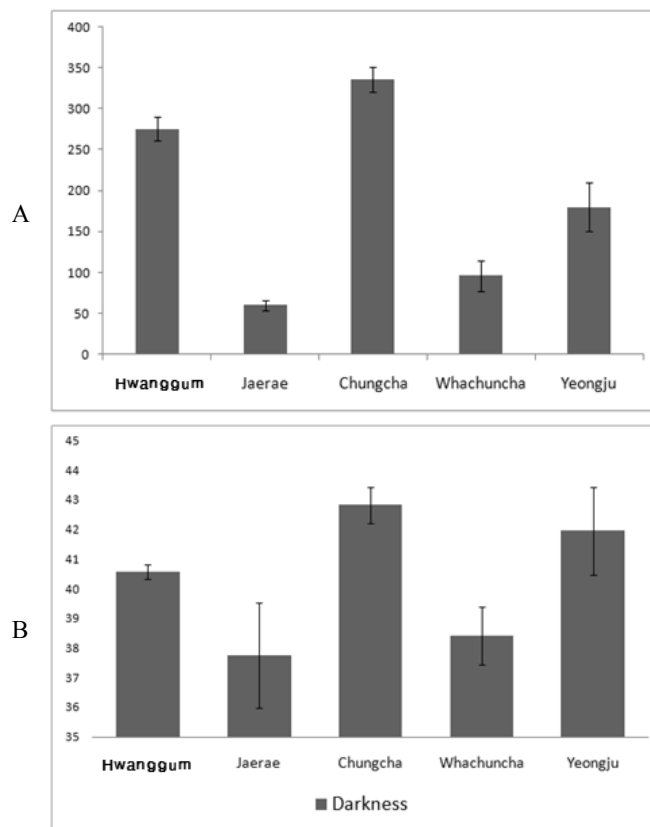


Fig. 6. Comparison of phenolic compounds concentrations in five foxtail millets.

A: Phenolic compounds concentrations of each varieties (Each vertical bar indicates the standard error values.), B; The chromaticity of the samples

myricetin, and quercetin. Specially, *p*-coumaric acid, formononetin and biochanin A were not detected in sorghums.

The phenolic compounds concentrations in foxtail millet showed similar contents that of common millet. Every foxtail millet varieties had much higher concentration of quercetin ($50.8 \mu\text{g}\cdot\text{g}^{-1}$). They contained gallic acid ($10.9 \mu\text{g}\cdot\text{g}^{-1}$), homogentisic acid ($28.1 \mu\text{g}\cdot\text{g}^{-1}$), protocatechuic acid ($30.9 \mu\text{g}\cdot\text{g}^{-1}$), chlorogenic acid ($35.4 \mu\text{g}\cdot\text{g}^{-1}$), caffeic acid ($29.8 \mu\text{g}\cdot\text{g}^{-1}$), ferulic acid ($13.4 \mu\text{g}\cdot\text{g}^{-1}$) and benzoic acid ($11.9 \mu\text{g}\cdot\text{g}^{-1}$). Also, β -Resorcylic acid, syringic acid, vanillin, *p*-coumaric acid, *m*-coumaric acid, *o*-coumaric acid, kaempferol and formononetin were not detected in foxtail millets.

Concentrations of phenolic compounds showed big differences among sorghums, foxtail millets, and common millets. Total phenolic compounds concentrations of sorghums were higher than that of foxtail millets and common millets. These

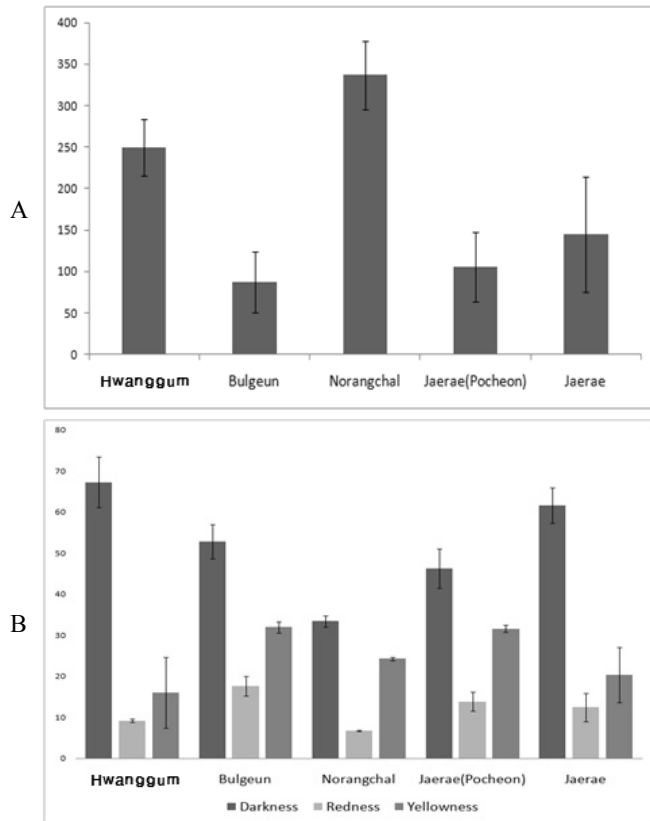


Fig. 7. Comparison of phenolic compounds concentrations in five common millets.

A: Phenolic compounds concentrations of each varieties (Each vertical bar indicates the standard error values.), B; The chromaticity of the samples

variations may caused by their genetic differences according to different species.

The relationship between color and phenolic compounds concentrations was similar to that of Lee *et al.* (2010). It was reported that the total phenolic compounds concentration in black and brown crops higher contained than that of green or yellow colored crops. In this study, sorghums and foxtail millets showed significant relationship between color and phenolic compounds concentrations. However, common millets did not significant differences of phenolic compounds according to different colors.

In case of sorghums, dark and red color varieties showed higher concentrations than others. The difference of colored sorghum and colorless sorghum showed significant differences in phenolic compounds concentrations. Foxtail millet also showed significant relationship color and phenolic compounds concentrations. Dark color varieties had higher amount of

phenolic compounds concentrations. Therefore, this factor will be used in further studies on variety selection with high contained phenolic compounds.

The contribution of phenolic compounds for human health was reported of phenolic compounds in previous study (Lee *et al.*, 2007). In this study, sorghums had higher concentration of phenolic compounds than others (foxtail millet, common millet). Moktaksusu, Hwanggumsusu and Hwanggumchalsusu had higher concentration of phenolic compounds. According to Dykes and Rooney (2007), there was relationship between phenolic compounds and antioxidant activities. From this study, Moktaksusu, Hwanggumsusu, Hwanggumchalsusu were may have strong antioxidant activities.

Some phenolic compounds such as (+)catechin, chlorogenic acid and quercetin were well known for their specific functional effects. Moktaksusu, Tojongsusu and 5 common millets were had much of (+)catechin which contained special effects such as prevention of obesity and suppression of skin aging due to UV radiation (Silvina *et al.*, 1998).

Every varieties that used in this study contained higher contents of chlorogenic acid. Chlorogenic acid had an influence on the gallstone and liver disease and was known to the cytotoxic activities (Kweon *et al.*, 2001; Paynter *et al.*, 2006). Large amount of quercetin was detected in all cultivars. Specially, quercetin was famous for their effects to heart disease ana various cancers (Murakami *et al.*, 2008; Davis *et al.*, 2009).

In conclusion, this study suggests that variation of phenolic compounds exist among sorghums, foxtail millets and common millets in different regions. Further investigation is needed to select varieties high contained phenolic compounds under field condition and to analyze the phenolic compounds involved in biological activity which facilitate selection and breeding of varieties with high contained biofunctional compounds and biological activity.

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