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RESEARCH ARTICLE

Variation in Antioxidant Activity and Polyphenol Content in Tomato Stems and Leaves

Xiang-Min Piao, Eun-Kyu Jang, Jong-Wook Chung, Gi-An Lee, Ho-Sun Lee, Jung-Sook Sung, Young-Ah Jeon, Jung-Ro Lee, Yeon-Gyu Kim, Sok-Young Lee*

National Agrobiodiversity Center, NAAS, RDA, Suwon, 441-853, Republic of Korea

ABSTRACT Tomato was considered as one of the most widely cultivated vegetable crops in the world. Tomato plant has high antioxidant capacity which can be attributed to the high levels of carotenoids, phenols, vitamins C and E. However, most of tomato plants have been discarded as waste after fruit harvesting. In order to identify genetic resources with high antioxidant level for use in food or as feed additives, we investigated the ABTS, DPPH antioxidant activity and polyphenol content in tomato leaves and stems. A total of 112 tomato accessions were classified into three groups by latitude of their collected countries: 30°~60° North (50 accessions), 0°~30° North (40 accessions), and 0°~30° South (22 accessions). Stem and leaf extracts showed wide variation in ABTS antioxidant activity ranging from 1.6 ± 1.0 to 48.4 ± 6.1 μg Trolox mg^{-1} dw. The antioxidant activity of DPPH was in the range of 6.3 ± 0.2 to 40.0 ± 0.3 μg ASC mg^{-1} dw. Total polyphenol content ranged from 6.1 ± 0.2 to 38.9 ± 0.7 μg GAE mg^{-1} dw. ABTS, DPPH antioxidant activities and polyphenol content in accessions from 30°~60°N latitude were significantly higher ($P<0.05$) than those from 0°~30°N latitude. ABTS values showed a significant positive correlation ($r = 0.700^{**}$) with DPPH activity. IT100506 (KOR) and 702959 (UKR) were recommended as potential sources of natural antioxidants due to their highest antioxidant activity among accessions. This study will provide valuable information for tomato breeders in developing and producing functional food or feed additives resources.

Keywords Antioxidant activity, Polyphenol, Tomato, Stems and leaves

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) was considered as one of the most widely cultivated vegetable crops in the world (Hanson *et al.* 2004; Borguini and Torres 2009). Tomato plant has high antioxidant capacity which can be attributed to the high levels of carotenoids, phenols, vitamins C and E (Kotkov *et al.* 2009). Antioxidants act to both reduce the content of toxic components in foods and to supply the human body with exogenous antioxidant (Block and Langseth 1994). Antioxidant capacity depends on the tomato variety, environmental growth conditions, production techniques used, and post-harvest storage conditions (Dumas *et al.* 2003). Low temperatures and northern latitudes have been reported to increase the amounts of antioxidants in berries and walnuts (Åkerstöm *et al.* 2010; Ghasemi *et al.* 2011). Methods using the stable 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid) (ABTS) or 1,1-diphenyl-2-picryl-hydrazil (DPPH) radicals are used widely to evaluate the free radical scavenging ability of antioxidant substances (Nabavi *et al.* 2009). Both methods are characterized by excellent reproducibility under certain assay conditions, but also show significant differences in their responses to antioxidants. The $ABTS^{\cdot+}$ can be dissolved in aqueous and organic media due to the hydrophilic and lipophilic nature of the compounds present in samples. In contrast, DPPH is soluble only in organic media, especially ethanol, this being an important limitation when interpreting the role of hydrophilic antioxidants (Arnao 2000).

Previous studies revealed that ethanol extracts of tomato, eggplant, and sweet potato leaves have higher antioxidant activity, phenolic components and flavonol content than their fruits (Zornoza and Esteban 1984; Truong *et al.* 2007; Jung *et al.* 2011; Munir *et al.* 2012). Hence, these leaves

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***Corresponding author** Sok-Young Lee, lsy007@korea.kr, Tel: +82-31-299-1821, Fax: +82-31-294-6029

represent a potential source of natural antioxidants. However, during the harvest period, 95−98% of tomato leaves and stems are discarded while the remaining 2−5% is used as animal food (Mcgee 2009). The reason is that foliage of the tomato plant has long been considered potentially toxic because of the alkaloid tomatine. However, levels of tomatine in leaves and stems are generally too small to be dangerous unless large amounts are consumed (Barceloux 2009). The recent research found that tomatine binds to cholesterol molecules in the digestive system. In fact, ingesting the leaves can lower the levels of undesirable LDL cholesterol in humans and animals (Mcgee 2009). Research into the antioxidant capacity of tomato stems and leaves compared to fruits is limited, and little research has aimed to determine the influence of collection latitudes on the antioxidant activity in tomato stems and leaves. In this study, the DPPH and ABTS activities and polyphenol contents of the leaves and stems of 112 tomato accessions originating from 18 countries were investigated to determine the effects of collection latitudes on antioxidant activity and polyphenol content, and also to identify high antioxidant activity tomato germplasm which can be used as a source of feed additive.

MATERIALS AND METHODS

Materials

One hundred and twelve tomato accessions were obtained from the National Agro-biodiversity Center. All accessions collected from 18 countries were classified into three groups by latitude of their origins: 30°～60° North (n=50), 0°～30° North (n=40), and 0°～30° South (n=22). The 30°～60° N latitude area is composed of nine countries: NLD, DEU, HUN, BGR, UKR, ARM, UZB, KOR, and JPN. The 0°～30° N latitude area included six countries: ETH, IND, TWN, PHL, HND, and CUB. The 0°～30° S latitude area is composed of three countries: ZWE, PER, and BRA (Fig. 1, Table 1). The accessions were grown in an experimental field in Suwon during April 2012. Plant spacing was 50 cm between rows and 40 cm between plants.

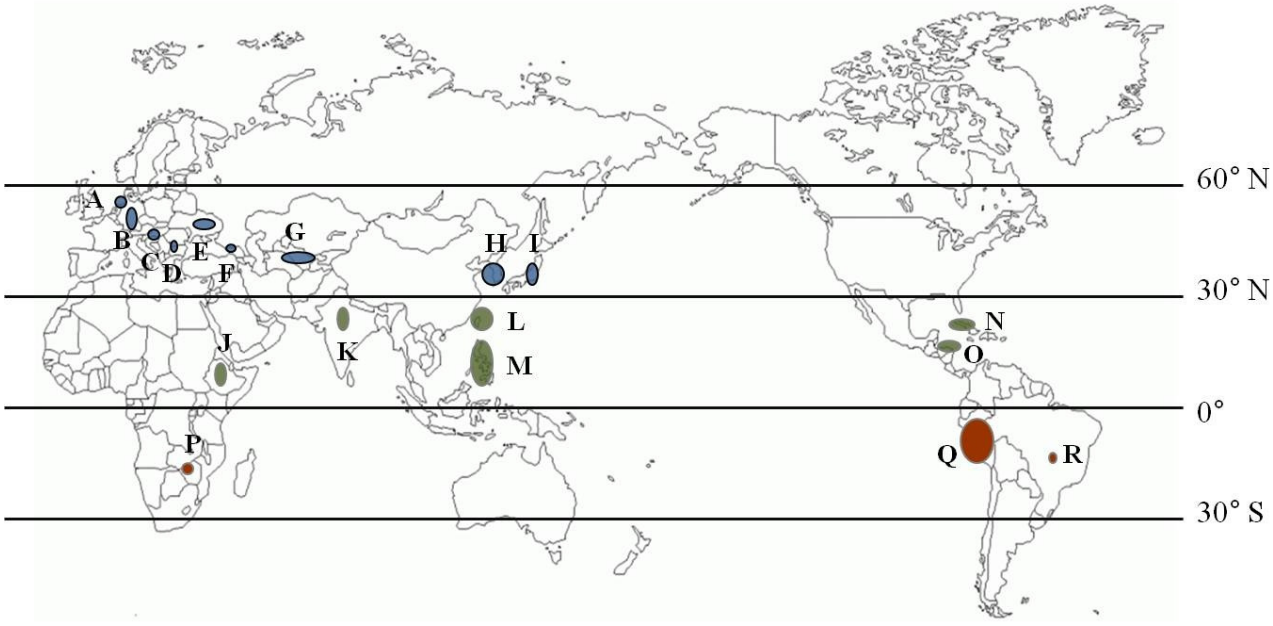

Fig. 1. Distribution of 112 tomato accessions according to country of origin.
A: NLD(n=4), B: DEU(n=2), C: HUN(n=1), D: BGR(n=2), E: UKR(n=3), F: ARM(n=2), G: UZB(n=10), H: KOR(n=22), I: JPN(n=3), J: ETH(n=1), K: IND(n=2), L: TWN(n=10), M: PHL(n=23), N: HND(n=1), O: CUB(n=1), P: ZWE(n=1), Q: PER(n=20), R: BRA(n=1)

Table 1. NAC registration numbers and origins of 112 tomato accessions investigated in this study.

NAC registration number	Country of origin	NAC registration number	Country of origin	NAC registration number	Country of origin	NAC registration number	Country of origin
1. IT203258	ARM	29. K012913	KOR	57. IT173888	PER	85. IT116970	PHL
2. IT203272	ARM	30. K012916	KOR	58. IT173901	PER	86. IT201662	PHL
3. IT199436	BGR	31. K012920	KOR	59. IT173955	PER	87. IT201664	PHL
4. K047416	BGR	32. K012924	KOR	60. IT174011	PER	88. IT116989	TWN
5. K047418	BRA	33. K012934	KOR	61. IT203416	PER	89. K000872	TWN
6. IT199463	CUB	34. K012970	KOR	62. K057603	PER	90. K000893	TWN
7. 803106	DEU	35. K047488	KOR	63. IT116894	PHL	91. K177639	TWN
8. K004846	DEU	36. K047491	KOR	64. IT116895	PHL	92. K177641	TWN
9. 805811	ETH	37. K047500	KOR	65. IT116897	PHL	93. K177642	TWN
10. K047588	HND	38. K047503	KOR	66. IT116898	PHL	94. K177644	TWN
11. K020958	HUN	39. K004905	NLD	67. IT116899	PHL	95. K177645	TWN
12. IT136595	IND	40. K020956	NLD	68. IT116901	PHL	96. K177646	TWN
13. IT203407	IND	41. K019075	NLD	69. IT116902	PHL	97. K177647	TWN
14. IT186735	JPN	42. K019076	NLD	70. IT116903	PHL	98. IT203255	UKR
15. IT186736	JPN	43. IT119947	PER	71. IT116904	PHL	99. 702959	UKR
16. IT100506	KOR	44. IT119953	PER	72. IT116905	PHL	100. 702977	UKR
17. K012777	KOR	45. IT173727	PER	73. IT116907	PHL	101. K020933	UKR
18. K012781	KOR	46. IT173730	PER	74. IT116908	PHL	102. IT199433	UZB
19. K012793	KOR	47. IT173733	PER	75. IT116910	PHL	103. IT203240	UZB
20. K012798	KOR	48. IT173742	PER	76. IT116912	PHL	104. IT203248	UZB
21. K012807	KOR	49. IT173749	PER	77. IT116913	PHL	105. IT203252	UZB
22. K012827	KOR	50. IT173750	PER	78. IT116914	PHL	106. IT203253	UZB
23. K012841	KOR	51. IT173758	PER	79. IT116916	PHL	107. IT203254	UZB
24. K012851	KOR	52. IT173759	PER	80. IT116918	PHL	108. IT203261	UZB
25. K012859	KOR	53. IT173760	PER	81. IT116919	PHL	109. 805835	UZB
26. K012888	KOR	54. IT173772	PER	82. IT116955	PHL	110. 908870	UZB
27. K012893	KOR	55. IT173804	PER	83. IT116957	PHL	111. K014621	UZB
28. K012904	KOR	56. IT173812	PER	84. IT116961	PHL	112. 805750	ZWE

Methods

Chemicals

1,1-diphenyl-2-picryl-hydrazil (DPPH•), L-ascorbic acid, 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid) (ABTS•), 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox), Folin−Ciocalteu reagent, and gallic acid were obtained from Sigma-Aldrich (USA). All other reagents were of analytical grade.

Sample preparation

Crude extracts were produced using 7 g of oven-dried tomato stems and leaves using an ASE-200 (Dionex) extractor. Extractions were performed in 40-ml 75% ethanol under nitrogen gas at a pressure of 1,500 psi and at 70°C. Extracted samples were dried using a Genevac HT-4X vacuum concentrator.

DPPH assay

The free radical scavenging activity of the extracts was assessed by the DPPH• method proposed by Lee and Lee (2004), with slight modification. DPPH solution (150 μl; 150 μM, in anhydrous ethanol) was added to 100 μl of sample solution. The mixture was shaken vigorously and left to stand at 25°C in the dark for 30 min. Absorbance at 517 nm was then measured in a spectrophotometer. DPPH free radical scavenging activity was calculated using the following equation:

DPPH• scavenging effect (%) =
[1 - (A0 - A1)/(A2 - A3)] × 100,

where A0 is the absorbance of the sample, A1 is the absorbance of the sample blank, A2 is the absorbance of the control, and A3 is the absorbance of the control blank. Finally, the radical scavenging effect was expressed as μg L-ascorbic acid equivalent antioxidant capacity (ASC) per 1-mg dried extract (μg ASC mg^{-1} dw).

ABTS assay

ABTS radical scavenging activity was estimated using the method of Re *et al.* (1999) with some modifications. ABTS radical cation was generated by adding 7 mM ABTS to 2.45 mM potassium persulphate followed by overnight incubation of the mixture in the dark at room temperature. The ABTS radical cation solution was diluted with methanol to obtain an absorbance of 0.7 ± 0.02 at 735 nm. Diluted ABTS radical cation solution (190 μl) was added to 10 μL of sample solution. After 6 min, absorbance at 735 nm was determined using a spectrophotometer. The capability to scavenge the ABTS radical was calculated using the following equation:

ABTS scavenging effect (%) =
[1 - (A0 - A1)/(A2 - A3)] × 100,

where A0 is the absorbance of the sample, A1 is the absorbance of the sample blank, A2 is the absorbance of the control, and A3 is the absorbance of the control blank. The free radical-scavenging effect of each sample was reported as the Trolox equivalent antioxidant activity obtained by comparing the changes in absorbance at 735 nm in reaction mixtures containing a sample tomato extract or a Trolox equivalent.

Polyphenol assay

Total polyphenol content was measured using the modified Folin-Ciocalteu method (Waterhouse 2002). Folin-Ciocalteu reagent (100 μl) was added to 100 μl of sample solution and allowed to react at room temperature for 3 min. After addition of 100 μl of 2% sodium carbonate, the mixture was incubated at room temperature for 30 min. Absorbance was measured at 750 nm using an ELISA reader with distilled water as a blank. Total phenolic content was reported as milligrams of gallic acid equivalents (GAE) per gram dried weight sample (μg GAE mg^{-1} dw).

Statistical analysis

Each sample was analyzed in triplicate and data were reported as means. Duncan's multiple range test (DMRT) were carried out to test any significant differences among tomato accessions collected from different latitudes by the SAS program (Software version 9.1, SAS Institute Inc.). Correlation coefficients were calculated to describe the relationship between DPPH and ABTS activity.

RESULTS

ABTS, DPPH antioxidant activity and polyphenol content in stem and leaf extracts of 112 tomato accessions were investigated to identify genetic resources with high antioxidant level for use in food or as feed additives. ABTS antioxidant activity showed wide variation from 1.6 ± 1.0 μg Trolox mg^{-1} dw (IT116898 from PHL) to 48.4 ± 6.1 μg Trolox mg^{-1} dw (IT100506 from KOR). DPPH antioxidant activity was found to be in the range 6.3 ± 0.2 μg ASC mg^{-1} dw (IT116898) to 40.0 ± 0.3 μg ASC mg^{-1} dw (702959 from UKR). Total polyphenol content ranged from 6.1 ± 0.2 μg GAE mg^{-1} dw (IT116898) to 38.9 ± 0.7 μg GAE mg^{-1} dw (K12913 from KOR) in extracts of the stems and leaves of various tomato accessions (Table 2).

Duncan's multiple range test indicated that the ABTS,

DPPH antioxidant activities and total polyphenol content in accessions from 30°～60°N latitude (33.4 Trolox mg^{-1} dw, 31.6 ASC mg^{-1} dw and 26.8 μg GAE mg^{-1} dw, respectively) were significantly higher ($P<0.05$) than those from 0°～30°N latitude (27.3 Trolox mg^{-1} dw, 26.4 ASC mg^{-1} dw and 23.2 μg GAE mg^{-1} dw, respectively) (Table 3). It is considered that low latitude or high temperature of the geographical origins may lead to the low antioxidant activity and phenolic compounds accumulation. It is reported that the cultivated tomato is native to the Peru-Ecaudor area, and spread throughout the world following the Spanish colonization of the Americas (Pinela *et al.* 2012). In this study, DPPH antioxidant activity and total polyphenol content in accessions from Peru and Brazil (0°～30°S latitude) were found to be significantly higher ($P<0.05$) than those from 0°～30°N latitude (Table 3).

The ABTS and DPPH activities showed skew-normal distributions (Figs. 2, 3). ABTS activity in two accessions from 30°～60°N latitude were more than 45 μg Trolox mg^{-1} while in one accession from 0°～30°N latitude was less than 5 μg Trolox mg^{-1}. 84% of accessions from 30°

Table 2. ABTS and DPPH antioxidant activities and polyphenol contents of stem and leaf extracts of 112 tomato accessions.

No.	ABTS[z)]	DPPH[y)]	Polyphenol[x)]	No.	ABTS	DPPH	Polyphenol	No.	ABTS	DPPH	Polyphenol	No.	ABTS	DPPH	Polyphenol
1	25.5±3.9	25.1±2.1	23.2±1.0	29	14.4±0.1	21.9±0.1	38.9±0.7	57	23.3±1.6	29±0.2	34.3±0.5	85	24.9±4.9	25.2±0.6	38.4±1.5
2	29.8±3.8	17.8±1.8	22.1±2.0	30	36.7±0.9	36.1±0.8	28.7±4.3	58	28.4±0.7	32.5±0.5	31.4±1.0	86	36±2.7	23.0±2.2	17.1±0.5
3	27.5±2.1	20.9±3.7	21.9±0.5	31	21.5±4.5	7.3±0.3	7.8±0.2	59	22.6±1.2	21.7±2.2	34.0±1.4	87	43.5±6.4	30.2±1.7	26.7±2.4
4	37.5±0.8	39.9±0.2	29.6±1.1	32	33.1±1.5	28.6±0.5	30.2±1.1	60	24.7±0.3	29.6±0.5	31.9±1.8	88	19.2±1.8	21.5±0.4	16.2±0.9
5	38.1±1.2	34.0±1.5	31.0±0.7	33	41.3±2.6	37.3±0.9	23.9±0.8	61	27.9±1.6	32.0±0.9	33.0±2.3	89	31.0±0.3	26.7±0.3	22.1±1.0
6	15.2±3.2	17.1±0.3	18.8±0.7	34	31.5±0.8	33.8±0.5	33.8±1.0	62	27.6±0.2	36.7±0.6	33.9±1.8	90	42.6±3.1	29.5±4.1	25.6±1.6
7	30.2±5.4	27.0±3.7	19.5±0.3	35	33.2±1.8	33.8±0.5	31.5±0.2	63	28.0±4.8	25.4±1.4	29.9±1.5	91	39.3±1.1	38.8±0.4	28.8±1.2
8	31.6±2.1	26.7±1.3	20.6±0.4	36	41.4±1.0	37.4±0.9	29.1±0.7	64	34.8±6.7	31.5±1.3	23.8±0.8	92	31.8±1.6	33.8±0.6	31.5±1.7
9	33.8±4.7	31.4±0.3	21.4±0.7	37	22.1±0.9	26.9±1.2	37.5±0.6	65	21.5±5.8	27.1±0.4	17.3±1.1	93	30.6±4.1	35.9±0.6	34.3±1.0
10	27.1±3.8	35.3±0.8	31.2±0.8	38	30.0±0.6	31.8±0.8	31.6±1.7	66	1.6±1.0	6.3±0.2	6.1±0.2	94	44.9±0.7	20.4±0.3	27.9±1.2
11	40.2±0.6	38.2±0.4	25.3±1.9	39	26.7±3.3	23.1±5.3	18.7±1.0	67	21.8±3.8	25.5±0.2	21.0±1.4	95	22.2±0.4	27.5±0.9	35.0±1.0
12	24.1±4.4	22.7±2.1	20.0±2.1	40	43.1±2.7	37.9±1.2	27.3±1.4	68	23.1±0.8	19.9±1.2	20.6±0.8	96	28.0±1.4	30.7±0.8	30.9±0.1
13	19.0±3.6	21.4±4.4	20.6±0.7	41	26.5±1.2	32.5±0.8	34.3±0.4	69	32.7±2.6	29.3±1.6	20.9±2.6	97	36.6±1.6	36.8±2.0	27.2±2.7
14	36.4±7.2	37±2.4	23.2±1.8	42	38.3±0	27.8±0.3	28.6±1.2	70	31.2±3.6	29.7±0.6	25.1±0.8	98	31.6±5.2	31.2±1.0	22.3±2.8
15	29.3±3.9	22.9±2.7	18.8±0.7	43	25.1±3.5	18.1±3.3	17.5±0.1	71	28.2±2.1	28.5±4.1	13.9±0.7	99	45.9±5.9	40.0±0.3	27.6±1.0
16	48.4±6.1	38.3±0.9	29.5±3.1	44	20.5±3.1	17.6±4.4	15.9±0.9	72	20.4±2.1	22.2±0.4	20.5±1.7	100	29.6±3.1	24.5±4.2	19.5±0.8
17	37.6±1.5	38±0.7	27.3±1.3	45	27.3±1.7	23.8±0.8	35.0±1.2	73	20.6±3.3	21.3±3.3	18.1±0.8	101	39.2±3.1	37.8±0.1	25.6±1.1
18	40.1±2.8	38.2±0.2	26.9±4.9	46	29.5±2.6	33.4±1	30.8±2.2	74	24.7±6.2	27.2±0.3	21.9±2.2	102	44.7±4.4	32.1±11	27.3±0.8
19	39.1±0.7	38.2±0.5	25.9±2.3	47	29.5±1.4	35.9±0.6	31.1±0.6	75	18.9±3.2	22.4±0.1	20.0±1.0	103	42.3±5.9	31.2±2.2	27.6±2.8
20	21.6±1.3	30.2±0.6	35.0±0.7	48	15.1±1.2	20.8±1.3	37.3±0.6	76	29.9±2.0	26.3±2.1	19.8±0.4	104	22.1±1.2	24.6±1.1	17.1±0.9
21	29.8±2.9	21.8±5.3	26.9±0.8	49	36.2±1.9	35.2±0.4	29.3±1.3	77	18.8±5.9	15.9±1.1	24.0±0.4	105	45.0±6.1	39.2±1.1	28.1±2.4
22	33.5±1.7	33.2±0.4	28.6±3.0	50	23.4±0.6	33.8±1.0	31.8±2.1	78	21.1±1.8	18.9±2.5	20.7±2.6	106	28.8±2.9	25.1±2	24.5±1.2
23	28.8±1.4	32.5±0.2	33.0±1.0	51	32.2±2.7	36.5±0.6	30.4±0.5	79	29.1±3.0	28.7±1.2	21.4±0.6	107	32.1±1.6	29.0±1.0	23.5±0.9
24	35.6±1.5	36.8±0.6	28.2±2.4	52	27.9±0.7	35.5±0.7	31.0±1.8	80	40.2±3.5	36.2±1.3	27.0±1.4	108	38.6±4.6	37.7±0.3	20.6±0.6
25	41.8±2.7	38.7±0.1	25.0±5.3	53	27.3±1.8	32.4±1.4	31.3±0.9	81	27.3±2.6	28.3±0.4	21.0±1.7	109	36.9±1.2	33.7±1.4	22.3±2.4
26	28.1±2.3	31.2±1.9	36.3±0.8	54	34.8±1.1	34.1±2.4	32.8±0.3	82	29.0±4.9	27.3±1.5	20.8±1.4	110	36.9±6.2	30.6±1.9	27.7±1.9
27	24.4±0.7	33.3±0.4	35.2±1.4	55	36.5±3.5	37.3±0.4	29.9±1.3	83	24.7±4.0	26.3±2.6	21.7±1.8	111	32.4±3.5	36.4±0.4	31.8±1.2
28	25.7±1.3	32.6±0.5	31.6±0.8	56	20.7±2.8	31.5±1.8	34.3±1.2	84	15.8±3.0	25.9±1.4	18.1±0.9	112	31.2±0.9	30.1±0.4	23.8±1.5

[z)] μg Trolox mg^{-1}; [y)] μg ASC mg^{-1}; [x)] μg GAE mg^{-1}

~60°N latitude were distributed between 25 and 45 μg Trolox mg^{-1}, while 80% of accessions from 0°~30°N latitude were assembled in the range of 15~35 μg Trolox mg^{-1}. DPPH value was greater than 40 μg ASC mg^{-1} for one accession from 30°~60°N latitude and less than 10 μg ASC mg^{-1} for two other accessions. 64% of accessions from 30°~60°N latitude were clustered in 30~40 μg ASC mg^{-1}, while 60% of accessions from 0°~30°N latitude were distributed from 20 to 30 μg ASC mg^{-1}. The total polyphenol content showed normal distribution with 90% of the accessions having values in the range of 15 to 35 μg GAE mg^{-1} dw. Twenty accessions from 30°~60°N latitude were distributed from 25 to 30 μg GAE mg^{-1}, while 15 accessions from 0°~30°N and 0°~30°S were assembled in 20~25 GAE mg^{-1} and 30~35 GAE mg^{-1}, respectively (Fig. 4). These results suggested that ABTS, DPPH antioxidant activities and polyphenol content in tomato leaves and stems are

Table 3. Mean, standard deviation and range of antioxidant activity and polyphenol content classified by collection latitudes in stems and leaves extract of 112 tomato germplasm.

Latitude	ABTS (ug Trolox mg^{-1})		DPPH (ug ASC mg^{-1})		Polyphenol (ug GAE mg^{-1})	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
30°~60° N (n=50)	33.4±7.4a[z)]	14.1~48.4	31.6±6.8a	7.3~40.0	26.8±5.9b	7.8~38.9
0°~30° N (n=40)	27.3±8.7b	1.6~44.9	26.4±6.4b	6.3~38.8	23.2±6.2c	6.1~38.4
0°~30° S (n=22)	27.7±5.7b	15.1~38.1	30.5±6.2a	17.6~37.3	30.5±5.2a	15.9~37.3

[z)] same letter in each column are not significantly different by duncan's multiple range test, $p<0.05$

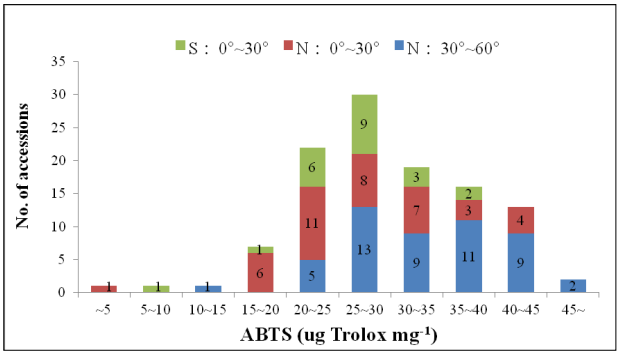

Fig. 2. Distribution of ABTS antioxidant activities in stem and leaf extracts of 112 tomato accessions.

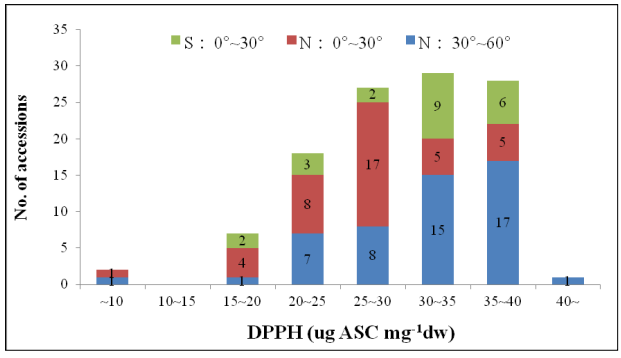

Fig. 3. Distribution of DPPH antioxidant activities in stem and leaf extracts of 112 tomato accessions.

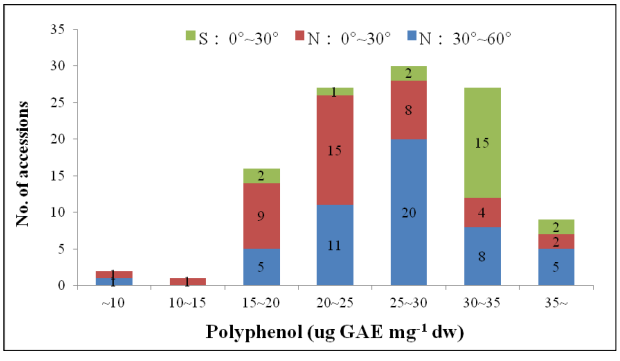

Fig. 4. Distribution of polyphenol contents of stem and leaf extracts of 112 tomato accessions.

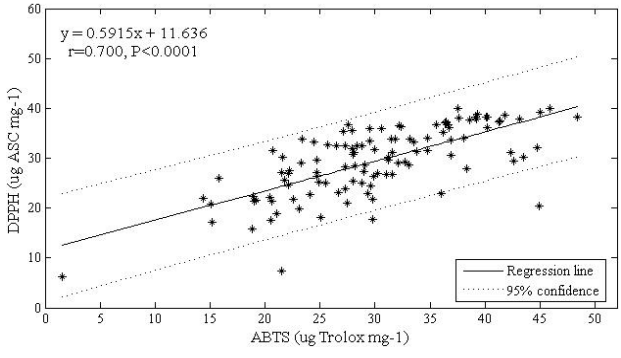

Fig. 5. Relationship between DPPH and ABTS antioxidant activities in stem and leaf extracts of 112 tomato accessions.

influenced by collection latitudes.

ABTS values showed a significant positive correlation ($r = 0.700^{**}$) with DPPH activity in the 112 tomato germplasm stem and leaf extracts; only three observations fell outside the 95% confidence interval (dotted lines) (Fig. 5). From the results, IT100506 (KOR) and 702959 (UKR) were recommended as potential sources of natural antioxidants for use in food or feed additives due to their highest antioxidant activity among accessions.

DISCUSSION

Tomato contains antioxidant, anti-allergic, anti-inflammatory, and anti-bacterial activities (Hanson *et al.* 2004). The presence of polyphenol might contribute to protective properties in tomato stems and leaves. Phenolics are important mainly due to their function in scavenging free radicals in the human body (Islam *et al.* 2003). The Folin-Ciocalteau method is commonly used to determine the total polyphenol contents of various samples; gallic acid is typically used as the standard. The color of Folin-Ciocalteau reagent changes from yellow to blue upon detection of phenolics in an extract due to the chemical reduction of the tungsten and molybdenum oxides mixture in the reagent (Waterhouse 2002). The stable ABTS and DPPH radicals provide the bases of methods of evaluating the free radical scavenging ability of antioxidant substances (Nabavi *et al.* 2009). In our study, ABTS, DPPH antioxidant activity and polyphenol contents in stem and leaf extracts of the tomato accessions showed wide variations ranging from 1.6 ± 1.0 to 48.4 ± 6.1 μg Trolox mg^{-1} dw, 6.3 ± 0.2 to 40.0 ± 0.3 μg ASC mg^{-1} dw, and 6.1 ± 0.2 to 38.9 ± 0.7 μg GAE mg^{-1} dw, respectively. As the result, IT100506 (KOR) and 702959 (UKR) were recommended as potential sources of natural antioxidants for use in food or feed additives due to their highest antioxidant activity among accessions (Table 2). The antioxidant capacity in plants was found to be influenced by genotypes, environmental conditions, use of production techniques and storage conditions after post harvesting (Dumas *et al.* 2003; Kacharava *et al.* 2009). Northern latitudes have been reported to increase the amounts of phenolics in berries and walnuts (Åkerstöm *et al.* 2010; Ghasemi *et al.* 2011). Also in the present study, the ABTS, DPPH antioxidant activities and total polyphenol content in accessions from 30°～60°N latitude were significantly higher ($P<0.05$) than those from 0°～30°N latitude (Table 3). It is considered that low latitude or high temperature of the geographical origins may lead to the low antioxidant activity and phenolic compounds accumulation. These results were in conformity with other findings that temperature of plant collecting place showed negative correlation with antioxidant activities and total phenolic content (Ghasemi *et al.* 2011). Pasko *et al.* (2009) reported a strong positive correlation between ABTS and DPPH antioxidant activity in amaranth and quinoa seeds. Similar result was found in the current study. ABTS values showed a significant positive correlation ($r = 0.700^{**}$) with DPPH activity in the stem and leaf extracts of 112 tomato germplasm (Fig. 5). This study will provide valuable information for tomato breeders and growers in developing and producing functional food or feed additives resources.

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