Korean J. Plant Res. 30(6):590-600(2017)
https://doi.org/10.7732/kjpr.2017.30.6.590

Print ISSN 1226-3591
Online ISSN 2287-8203

Original Research Article

Variation in Agronomic Traits and Fatty Acid Compositions of the Seed Oil in Germplasm Collection of *Brassica* spp.

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Abstract - A total of 447 accessions consisting of seven *Brassica* spp.; *Brassica carinata* (34), *B. juncea* (199), *B. rapa* subsp. *dichotoma* (18), *B. rapa*. subsp. *oleifera* (14), *B. rapa* subsp. *rapa* (36), *B. rapa* subsp. *trilocularis* (56) and *B. alba* subsp. *alba* (90) were studied for their morphological characters and fatty acid compositions. There was a wide variation for morphological traits, oil content and fatty acid composition among Brassica species. Seed number/silique and yield/plant were varied from 4.2 (*B. alba*) to 25.1 (*B. rapa* subsp. *trilocularis*) and from 170.7 g (*B. rapa* subsp. *oleifera*) to 351.9 g (*B. juncea* L. Czern.), respectively. Among *Brassica* species, *B. rapa* subsp. *trilocularis* exhibited the highest oil (29.2%), stearic (20.4%) and erucic acid (45.3%) content. *B. carinata* had the highest content of palmitic (5.2%), oleic (21.2%) and linolenic acid (11.1%). *B. rapa* subsp. *dichotoma* and *B. rapa* subsp. *oleifera* exhibited the highest content of linoleic (8.1%) and behenic (26.9%) acid, respectively. *B. rapa* subsp. *trilocularis* exhibited the highest (45.3%) erucic acid content and significant positive relationship was observed between oleic acid and linoleic acid. This variation of agronomic and fatty acid compositions in *Brassica* species can be utilized to develop new varieties.

Key words - *Brassica*, Fatty acid, Silique, Variation, Yield

Introduction

The genus *Brassica,* a member of the Brassicaceae family, includes a diverse group of species comprising of major vegetables, oilseed crops and fodder crops (Christopher *et al*., 2005; Rakow, 2004). The genus *Brassica* includes 41 species and among them, *B. carinata* A. Braun, *B. juncea* L. Czern., *B. rapa* L. and *Brassica* (*Sinapis*) *alba* L. are important. *Brassica* species play an important role in agriculture and overall, it contributes to the economy and health of people (Zhao, 2007).

Variability assessment is important in germplasm characterization and conservation. Morphological variation in plant species is controlled by a single or multiple genes for the traits but the variation in morphological traits are the result of both genetic and environmental attributes (Rohlf, 2000). Generally, morphological traits have been used to assess the genetic variation and relationships among populations of different *Brassica* species (Balkaya *et al*., 2005; El-Esawi *et al*., 2012). *B. juncea* L. and *B. rapa* L. are the most important source of vegetable oil in world (Friedt and Lauhs, 1995). In addition, palmitic, stearic, oleic, linoleic, linolenic, eicosanoic and erucic acids are major fatty acids extract in genus *Brassica* but *Brassica* oil has more variation in fatty acid compositions than other vegetable oils (Sovero, 1993). Oils containing high erucic acid content are suitable for industrial application. Therefore, screening of *Brassica* species for high erucic acid content and free erucic acid have a present need to develop new varieties. In the study of Velasco *et al*. (1998), the highest erucic acid content (>55% of the total fatty acids) was reported in *B. napus L., B. oleracea* L., *B. rapa* L., and *B. incana* Ten. Highest content of linolenic (20%) and linoleic (19%) acid had also been reported in *B. juncea* (Sharafi *et al*., 2015). Generally, fatty acid composition controls functional and nutritional values of vegetables oils but it varies on the

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plant species. In Korea, previous studies were focused mainly on growth and flowering characters (Kim *et al*. 2015) and fatty acid compositions (Lee *et al*., 2014) on rapeseed (*Brassica napus* L.) cultivars but information on agronomic and fatty acid compositions in the germplasm of different *Brassica* species are not documented yet. National Agrobiodiversity Center (NAC) of Rural Development Administration (RDA), Korea has been collected many germplasm of *Brassica* species for few years and these germplasm may contain the valuable traits for breeding new cultivars. Therefore, this study was conducted to investigate the variation for agronomic characters and fatty acid compositions in different *Brassica* species.

Materials and Methods

Plant materials

Seeds of 447 accessions of *Brassica* species consisting of *B. carinata* A. Braun (34), *B. juncea* (L). Czern (199), *B. rapa* subsp. *dichotoma* (Roxb.) Hanelt (18), *B. rapa* L. subsp. *oleifera* (DC.) Metzg (14), *B. rapa* L. subsp. *rapa* (36), *B. rapa* L. subsp. *trilocularis* (56) and *B. alba* L. subsp. *B. alba* (90) were received from NAC, Korea. For raising the seedlings, seeds were sown in the plug trays, contained horticultural soil (Bio-media Co., Ltd., Seoul, Korea) in January 2013 at Pyeongtaek. Twenty-four seedlings were transplanted at 20 × 20 ㎝ spacing in the plastic house in March 5, 2013 at each plot. Accessions from each species were isolated by nylon net during flowering period to prevent cross-pollination among species, and RDA recommendation for agronomic practices and plant protection measures were followed in the field. Fertilizers were applied at the rate of 25-20-20 N-P_2O_5-K_2O ㎏/10a and irrigation was applied uniformly at each plot through drip system.

Observation on agronomic characters

Days to 50% flowering were recorded by counting number of days from seed sowing until 50% plants have at least one flower in each accession. Silique length (㎜) was measured as the distance from the base to the tip of individual silique whereas width (㎜) measured as distance across the widest point of the same silique. Peduncle length (㎜) was measured using measuring scale and number of seeds/silique was counted after harvesting. Seed yield (g) was recorded at five randomly selected plants for each accession and maintained moisture content at 13%. Weight of 100 random dried seed was calculated and, then converted to 1000 seed weight by multiplying 10.

HPLC analysis for fatty acids

The mature seeds were used for fat content and fatty acid analysis. Bulk seed samples from each accession were taken, dried to 5% moisture level in oven at 108°C for 16-18 h. Samples of *Brassica* were freshly ground through homogenizer and weighted. Oil content and fatty acid compositions (palmitic, stearic, oleic, linoleic, linolenic, behenic and erucic acid) were analyzed using Gas Chromatography (Hewlett-packard, HP5890, USA) with an HPLC as the procedure described by Velasco *et al*. (1998).

Statistical analyses

The data on agronomic characters and fatty acid compositions of a seed from all the accessions were subjected to R Program (Version 3.2.0). Descriptive statistics (mean, minimum, maximum and standard deviation) was used to interpret the data. Pearson correlation coefficient was calculated among the agronomic characters and the fatty acid compositions using SPSS Statistics 17.0 (SPSS Inc., Chicago, IL, USA) and Principal component analysis (PCA) was used to analyze the agronomic and biochemical variables using Microsoft Excel (version 10.0, Microsoft, Redmond, WA, USA), Multibase program (http://www.numericaldynamics.com).

Results and Discussion

Variation of agronomic characters in different accessions of different *Brassica* species is presented in Table 1. Flowering days of *Brassica* species varied from 55.0 (*B. rapa* subsp. *dichotoma*) to 124.0 (*B. rapa* subsp. *dichotoma*). Days to flowering in *B. rapa* subsp. *rapa* varied from 25.0 to 200.0 with an average of 114.0. The average silique length was the highest (47.5 ㎜) in *B. carinata* but variation for silique length was the highest in *B. rapa subsp. rapa*. The highest silique width was observed in *B. rapa* subsp. *trilocularis* with an average of 6.3 ㎜. *B. rapa* subsp. *trilocularis* had the highest peduncle length (22.1 ㎜) followed by *B. alba* subsp. *alba* (22.0 ㎜). The highest (25.1 ㎜) seed number/silique was recorded in *B. rapa* subsp. *trilocularis* while *B. alba* subsp. *alba* was the lowest (4.2 ㎜). The highest seed yield (351.9 g) was recorded in *B. juncea* followed by *B. carinata* (336.9 g) while 1000 seed weight was higher in *B. alba* subsp.

Table 1. Agronomic traits and seed yield of 447 accessions in different *Brassica* species

Traits	*Brassica* group						
	B. carinata A. Braun	*B. juncea* (L.) Czern.	*B. rapa* L. subsp. *dichotoma*	*B. rapa* L. subsp. *oleifera*	*B. rapa* L. subsp. *rapa*	*B. rapa* L. subsp. *trilocularis*	*B. alba* L. subsp. *alba*
Days to flowering							
N[z]	34	199	18	14	36	56	90
Mean	123.0	116.0	55.0	124.0	114.0	99.0	106.0
Min[y]	115.0	101.0	14.0	112.0	25.0	23.0	25.0
Max[x]	196.0	216.0	109.0	196.0	200.0	116.0	119.0
SD[w]	13.2	16.8	42.5	21.0	26.4	24.3	10.6
Silique length (㎜)							
Mean	47.5	36.9	43.9	47.02	41.8	46.4	12.78
Min.	37.4	20.8	33.3	38.6	18.5	33.2	8.9
Max.	71.6	48.7	60.5	58.0	60.1	65.7	22.8
SD	7.1	5.1	6.9	4.9	8.9	7.2	2.4
Silique width (㎜)							
Mean	5.6	3.8	4.1	3.8	3.7	6.3	4.4
Min.	3.4	2.5	2.9	2.7	1.6	2.5	1.6
Max.	8.4	7.3	5.1	5.6	7.8	10.3	7.0
SD	1.3	0.7	0.7	0.8	1.2	1.7	0.8
Peduncle length (㎜)							
Mean	5.9	9.0	20.4	18.1	18.1	22.1	22.0
Min.	3.4	4.7	12.2	11.4	7.1	9.2	8.1
Max.	9.0	15.2	29.8	22.8	35.3	39.9	40.9
SD	1.2	1.6	5.0	3.2	5.9	5.3	5.9
Seeds/silique (no.)							
Mean	17.4	16.0	20.9	18.3	17.5	25.1	4.2
Min.	10.0	7.2	3.6	10.0	5.0	9.8	1.2
Max.	22.0	25.2	37.6	25.8	29.6	43.2	9.0
SD	2.8	3.1	7.8	4.2	6.7	6.4	1.2
Seed yield (g/plant)							
Mean	336.9	351.9	243.6	170.7	195.6	270.5	268.5
Min.	118.8	108.8	149.1	53.3	87.7	156.6	101.6
Max.	572.6	554.0	388.0	296.1	357.8	429.7	422.8
SD	113.4	104.3	61.4	69.5	70.3	61.3	63.4
Wt. 1000 seed (g)							
Mean	3.8	2.9	2.9	2.6	2.3	4.2	6.6
Min.	2.9	1.0	1.8	2.1	0.8	2.5	1.7
Max.	5.4	5.3	4.0	3.6	5.5	6.8	9.8
SD	0.5	0.7	0.6	0.5	0.8	1.2	1.3

[z]Number of accessions, [y]Minimum, [x]Maximum, [w]Standard deviation.

alba (6.6 g) compared to *Brassica* species.

The morphological traits used in this study showed wide variation among *Brassica* species. The breeding program of any crop relies on the magnitude of morphological variability (Koffi *et al*., 2008). Variation for days to flowering in the varieties of *B. campestris* was also reported by Yousuf *et al*. (2011). Asghari *et al*. (2011) reported that seed yield/plant was varied among the cultivars of *B. napus* L. In the study of Zada *et al*. (2013), they reported the variation in seed yield/ plant and 1,000 seed weight in different accessions of *B. carinata* A. Braun. Variation for morphological traits had also been reported in the accession of *B. carinata* (Muthone, 2010) and *B. oleracea* (El-Esawi *et al*., 2012). Variation in morphological traits could be attributed to differences in accessions and species, which might be influenced by environmental factors, geographical origin and soil fertility.

Variation in oil compositions

HPLC method was used to evaluate the lipid composition of seed in *Brassica* plants and fatty acid compositions of different *Brassica* seeds were separated and quantified. This method allowed the separation of seven (palmitic acid, stearic acid, oleic acid, linoleic acid, linolenic acid, behenic acid and erucic acid) with different peaks (Fig. 1). Beermann et al. (2003) were established a reliable HPLC method to evaluate the lipid composition of useful plants in different *Brassica napus* L. varieties.

The oils extracted from different *Brassica* species were analyzed to determine oil content and their fatty acid compositions and the result showed inter and intra-specific variability for the oil content and fatty acid composition (Table 2). Oil content was the highest (29.2%) in *B. rapa* subsp. *trilocularis* while oil content was ranged from 14.0 to 39.4%. in *B. juncea*. *B. carinata* exhibited the highest (5.2%) palmitic acid. Variation for palmitic acid was the highest in *B. alba* subsp. *alba*, ranged from 0.0 to 8.3%. Stearic acid was the highest (20.4%) in *B. rapa* subsp. *trilocularis* whereas the lowest (12.7%) was in *B. carinata*. *B. carinata* had the highest (21.2%) oleic acid content followed by *B. juncea* (20.5%). *B. rapa* subsp. *dichotoma* exhibited higher linoleic acid (8.1%) but the most remarkable variation for linoleic acid content was in *B. alba* subsp. *alba*, ranged from 0.0 to 20.9%. The highest (11.1%) linolenic acid content was recorded in *B. carinata* but *B. alba* subsp. *alba* exhibited the highest variation of linolenic acid ranging from 1.1 to 23.2%. *B. rapa* subsp. *rapa* showed the highest (20.5%) behenic acid content followed by *B. alba* (15.5%). Erucic acid was the highest (45.3%) in *B. rapa* subsp. *trilocularis* with a ranged from 7.3 to 53.9%. *B. alba*

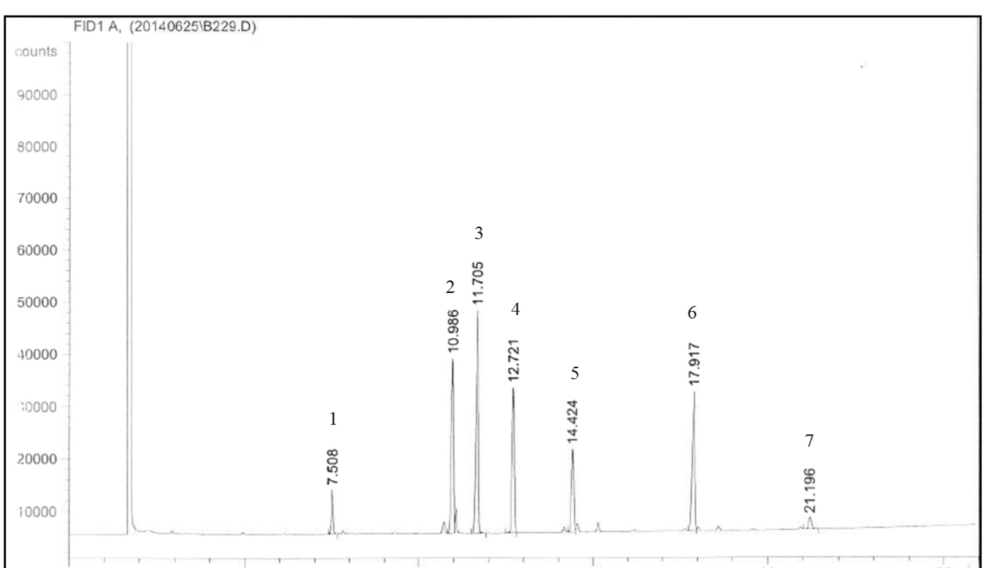

Fig. 1. HPLC identification of fatty acid composition from seed oil in *Brassica* species. Peak refers to following identified compounds; 1 = Palmitic acid, 2 = Stearic acid, 3 = Oleic acid, 4 = Linoleic acid, 5 = Linolenic acid, 6 = Behenic acid and 7 = Erucic acid.

Table 2. Oil content and fatty acid compositions in seed oil of 447 accessions in different *Brassica* species

Traits	*Brassica* group						
	B. carinata A. Braun	*B. juncea* L. Czern.	*B. rapa* L. subsp. *dichotoma*	*B. rapa* L. subsp. *oleifera*	*B. rapa* L. subsp. *rapa*	*B. rapa* L. subsp. *trilocularis*	*B. alba* L. subsp. *alba*
Oil content (%)							
N[z]	34	199	18	14	36	56	90
Mean	21.9	24.7	28.6	24.5	27.8	29.2	16.7
Min[y]	18.5	14.0	23.2	19.2	21.3	22.7	9.1
Max[x]	29.9	39.4	32.2	27.2	55.8	38.1	28.3
SD[w]	2.5	3.2	2.2	2.3	5.1	3.2	3.1
Palmitic acid (%)							
Mean	5.2	3.0	2.2	2.1	2.2	2.2	2.5
Min.	3.4	2.3	1.3	1.2	1.1	1.5	0.0
Max.	7.1	4.8	2.9	3.1	3.0	3.7	8.3
SD	0.9	0.4	0.5	0.6	0.5	0.4	0.9
Stearic acid (%)							
Mean	12.7	13.2	19.3	16.4	17.2	20.4	17.8
Min.	9.0	2.0	13.3	9.6	7.9	8.7	3.2
Max.	26.3	28.1	25.3	33.4	31.9	33.5	36.7
SD	3.3	3.0	3.4	6.3	5.5	3.9	6.0
Oleic acid (%)							
Mean	21.2	20.5	11.7	12.9	12.6	13.2	9.3
Min.	14.4	12.3	7.9	8.3	5.4	8.9	2.3
Max.	24.4	31.1	15.3	17.8	19.4	21.5	26.7
SD	2.3	2.5	2.2	3.0	3.1	2.4	3.3
Linoleic acid (%)							
Mean	6.2	6.5	8.1	6.7	7.2	7.8	6.1
Min.	5.4	3.9	5.5	1.4	0.7	4.2	0.0
Max.	7.3	13.6	11.0	10.4	10.1	10.6	20.9
SD	0.5	1.4	1.6	2.4	2.4	1.4	2.7
Linolenic acid (%)							
Mean	11.1	10.8	5.9	5.3	5.9	5.9	7.8
Min.	8.3	5.0	3.2	2.4	0.0	3.9	1.1
Max.	15.1	16.9	7.9	7.1	8.4	10.1	23.2
SD	1.8	1.6	1.4	1.5	1.7	1.3	2.7
Behenic acid (%)							
Mean	3.2	2.5	12.0	26.9	20.5	5.0	15.5
Min.	2.5	1.4	1.4	2.6	1.6	0.8	0
Max.	4.0	8.5	40.8	52.1	64.9	52.3	74.1
SD	0.3	0.5	14.5	17.8	19.5	10.1	14.9
Erucic acid (%)							
Mean	40.5	43.4	40.6	29.6	34.3	45.3	40.2
Min.	34.1	17.1	26.0	2.7	8.6	7.3	0.0
Max.	44.3	49.8	50.2	43.4	48.9	53.9	58.1
SD	2.2	6.2	8.8	11.1	10.7	8.2	14.0

[z]Number of accessions, [y]Minimum, [x]Maximum, [w]Standard deviation.

subsp. *alba* exhibited wide variation for erucic acid which ranged from 0.0 to 58.1%.

This study showed the variation in oil and fatty acid compositions in different *Brassica* species. The nutritional properties of *Brassica* seed oil depend on the contents of oleic, linoleic, linolenic and erucic acid which constitute unsaturated fatty acid, have great importance in human nutrition. High oleic acid has cholesterol lowering properties while saturated fatty acid including palmitic and stearic acid tend to raise blood levels (Rakow and Raney, 2003). High oleic acid has heat stability properties and it can be heated to a higher temperature without smoking so that the cooking time can be reduced and as a result, foods take up less oil (Miller *et al*., 1987). In our study, *B. carinata* showed the highest content of oleic acid but Sharafi *et al.* (2015) have reported as high as 61% oleic acid in *B. napus.* Our study showed the highest linoleic acid content in the collections of *B. rapa* subsp. *dichotoma* whereas the highest linoleic acid have reported in the accessions of *B. juncea* (Sharafi *et al.*, 2015). We found the highest linolenic acid ranged from 8.3 to 15.1% in *B. carinata* but it was ranged from 52.7 to 58.9% in the varieties of *B. botrytis* (Velasco *et al*., 1998).

Erucic acid is the most important fatty acid, found in *Brassica* but it is harmful to human health. In this study, some accessions in *B. alba* showed zero-erucic acid and most of *Brassica* species exhibited more than 40% erucic acid except *B. rapa* subsp. *oleifera* (29.6%) and *B. rapa* subsp. *rapa* (34.3%). But in the study of Sharafi *et al*. (2015), they have reported the highest (>40%) erucic acid in the accession of *B. rapa* whereas Mandal *et al*. (2002) have reported 23.64% erucic acid in *Sinapis alba* which contradicts to our findings. High erucic acid is a valuable raw material to manufacture industrial products such as plasticizers, detergents, surfactants, polyesters (Beare-Rogers *et al*., 1971). The accessions containing high erucic acid content is a priority in *Brassica* breeding because of its industrial value (Friedt and Lauhs, 1995). Recently, rapeseed genotypes with 78% erucic acid are developed and recommended them for emollient industries (Nath *et al*., 2016). Our study also identified some accessions containing high erucic acid content which might be useful for breeding new cultivar and industrial usages.

Correlation among the agronomic characters

Correlation among the agronomic characters in each *Brassica* group was analyzed and results are presented in Table 3. Silique length had a significant positive correlation with seeds/silique whereas a significant negative association was observed between seeds/silique and wt. 1000 seed in *B. carinata*. In *B. juncea*, silique length was a significant positive association with silique width, peduncle length, seeds/silique and wt. 1000 seed but seed yield had a significant negative correlation with wt. 1000 seed. In *B. rapa* subsp. *dichotoma*, silique length had highly significant positive correlation with seeds/silique. In *B. rapa* subsp. *oleifera*, significant positive relationship was observed between silique length and seeds/silique, and silique length and wt. 1000 seed. In *B. rapa* subsp. *rapa*, silique length had a significant positive correlation with silique width, peduncle length, seeds/silique, and seed yield. Likewise, silique width was also a significant positive association with peduncle length, seeds/silique and wt. 1000 seed. Seeds/silique was significantly positively associated with seed yield and wt. 1000 seed. Silique length and width were significantly positively correlated with seeds/silique and wt. 1000 seed in *B. rapa* subsp. *trilocularis*. Silique length had a significant and positive association with seeds/silique but peduncle length was significantly negatively associated with seeds/silique and seed yield in *B. alba* subsp. *alba*. In this study, silique length was significantly positively correlated with seeds/silique in all the *Brassica* species which is close to the finding of Khan and Khalil (2008). Seeds/silique was not significantly associated with seed yield except *B. juncea*, *B. rapa* subsp. *rapa* and *B. alba* subsp. *alba* and Malik *et al.* (2000) reported the similar results. Correlation between seed yield and wt. 1000 seed was non-significant in all the *Brassica* species except *B. juncea* subsp. but seed yield was significantly negatively correlated with wt. 1000 seed in *B. juncea* and this result was agreed with the findings of Malik *et al*. (2000). Sandhu and Gupta (1996) reported negative correlation between days to flowering and seed yield in *Brassica* species but our study showed the similar results in *B. juncea*. Zhang and Zhou (2006) observed that number of seeds/silique and 1000 grain weight positively correlated with seed yield and our study agreed to this finding in the result of *B. juncea*, *B. rapa* and *B. alba* but wt. 1000 seed were mostly non-significantly

Table 3. Correlation co-efficient between agronomic characters in germplasm collections of different *Brassica* species

Characters	Pair of characters	*Brassica* group						
		B. carinata A. Braun	*B. juncea* L. Czern.	*B. rapa* L. subsp. *dichotoma*	*B. rapa* L. subsp. *oleifera*	*B. rapa* L. subsp. *rapa*	*B. rapa* L. subsp. *trilocularis*	*B. alba* L. subsp. *alba*
Days to flowering								
	Silique length	-0.029	-0.185**	-0.188	-0.172	-0.324	0.100	0.220*
	Silique width	-0.108	-0.031	0.063	-0.105	-0.255	0.527**	0.296**
	Peduncle length	0.035	-0.038	-0.143	0.114	-0.243	0.087	-0.301**
	Seeds/silique	-0.118	0.076	0.364	0.060	-0.293	0.294*	0.309**
	Seed yield	-0.202	-0.232**	0.396	-0.234	-0.170	0.272*	0.350**
	Wt. 1000 seed	0.072	-0.236**	-0.400	-0.362	-0.307	0.439**	-0.093
Silique length								
	Silique width	-0.074	0.209*	0.207	0.037	0.339*	0.179	0.039
	Peduncle length	0.017	0.368**	0.254	0.422	0.732**	0.243	-0.205
	Seeds/silique	0.406*	0.339**	0.567*	0.698**	0.773**	0.564**	0.734**
	Seed yield	-0.137	-0.090	0.122	0.122	0.491**	0.205	0.194
	Wt. 1000 seed	0.225	0.387**	0.293	-0.038	0.212	0.549**	-0.227*
Silique width								
	Peduncle length	-0.138	0.156*	0.177	0.342	0.409*	0.083	0.042
	Seeds/silique	-0.174	-0.145*	0.283	0.190	0.589**	0.635**	0.041
	Seed yield	-0.305	-0.049	-0.006	0.403	0.311	0.153	0.209*
	Wt. 1000 seed	0.070	0.394**	0.157	0.610*	0.743**	0.459**	0.367**
Peduncle length								
	Seeds/silique	0.200	0.058	-0.097	0.441	0.678**	0.024	-0.411**
	Seed yield	-0.262	-0.071	-0.157	-0.081	0.429**	0.194	-0.373**
	Wt. 1000 seed	-0.367*	0.139	0.400	0.046	0.246	0.040	0.374**
Seeds/silique								
	Seed yield	0.181	0.140*	0.426	0.304	0.461**	0.146	0.240*
	Wt. 1000 seed	-0.369*	-0.362**	0.086	-0.187	0.371*	0.128	-0.368**
Seed yield								
	Wt. 1000 seed	0.081	-0.151*	0.048	0.420	0.285	0.117	0.058

*, and ** means significant at $P \leq 0.05$ and $P \leq 0.01$, respectively.

associated with seed yield which contradicts with the findings of Zhang and Zhou (2006). Our result of correlation among the agronomic traits was not consistent in *Brassica* species. Generally, seed yield is complex trait determined by many characters have positive or negative effects on this trait and association of traits with seed yield would be great importance to select the particular trait of interest.

Relationship among fatty acid compositions

Relationship among the fat content and fatty acid compositions among *Brassica* species is shown in Table 4. Fat content had positively correlated with palmitic acid in *B. juncea* and *B. rapa* subsp. *trilocularis*. The association between fat content and stearic acid was positive in *B. carinata* and *B. rapa* subsp. *trilocularis*. However, a negative correlation was found between fat content and oleic acid in the germplasm of *B. carinata*, *B. juncea* and *B. rapa* subsp. *trilocularis*. For the association between palmitic and stearic acid, significant positive relationship was observed in all the *Brassica* species except *B. alba* L. subsp. *alba*. Significant positive correlation has reported between palmitic and stearic acid in *B. rapa* var. tori (Mandal *et al*., 2002). Significant negative correlation was observed between palmitic and oleic acid in the *B*. species except *B. carinata*. Palmitic acid had a significant positive association with linoleic and linolenic acid in all *B*. species

Table 4. Correlation co-efficient between individual fatty acids present in the oils of germplasm collections in different *Brassica* species

Fatty acids	Pair of fatty acids	*Brassica* group						
		B. carinata A. Braun	*B. juncea* L. Czern.	*B. rapa* L. subsp. *dichotoma*	*B. rapa* L. subsp. *oleifera*	*B. rapa* L. subsp. *rapa*	*B. rapa* L. subsp. *trilocularis*	*B. alba* L. subsp. *alba*
Oil content								
	Palmitic acid	0.056	0.361**	-0.361	0.267	0.157	0.373**	-0.127
	Stearic acid	0.565*	0.077	0.094	0.332	0.203	0.304*	-0.093
	Oleic acid	-0.567**	-0.300**	-0.329	0.066	0.138	-0.415**	-0.208*
	Linoleic acid	0.304	0.032	-0.122	-0.049	0.150	-0.341*	-0.084
	Linolenic acid	-0.043	-0.142*	-0.345	0.335	0.177	0.184	0.150
	Behenic acid	-0.443**	-0.095	0.127	-0.126	-0.233	-0.143	0.148
	Erucic acid	-0.235	0.146*	-0.065	-0.054	0.210	0.225	-0.023
Palmitic acid								
	Stearic acid	0.675**	0.410**	0.629**	0.647*	0.748**	0.331*	0.206
	Oleic acid	-0.413*	0.630**	0.858**	0.632*	0.869**	0.704**	0.228*
	Linoleic acid	0.089	0.563**	0.874**	0.594*	0.739**	0.648**	0.258*
	Linolenic acid	-0.679**	0.396**	0.775**	0.894**	0.758**	0.283*	0.480**
	Behenic acid	0.060	-0.268**	-0.777**	-0.838**	-0.893**	-0.430**	-0.123
	Erucic acid	-0.471**	-0.728**	0.485*	0.502	0.654**	-0.211	-0.284**
Stearic acid								
	Oleic acid	-0.624**	0.372**	0.433	0.511	0.781**	-0.036	0.546**
	Linoleic acid	0.223	0.880**	0.821**	-0.053	0.441**	-0.144	0.158
	Linolenic acid	-0.653**	-0.051	0.251	0.408	-0.603**	-0.499**	0.173
	Behenic acid	-0.278	-0.478**	-0.624**	-0.398	-0.714**	-0.623**	-0.424**
	Erucic acid	-595**	-0.810**	0.311	-0.150	-0.335*	0.058	-0.151
Oleic acid								
	Linoleic acid	0.085	0.405**	0.596**	0.417	0.575**	0.786**	0.116
	Linolenic acid	0.200	0.180*	0.796**	0.564*	0.839**	-0.169	-0.003
	Behenic acid	-0.023	-0.196**	-0.841**	-0.774**	-0.801**	-0.281*	-0.509**
	Erucic acid	-0.098	-0.745**	-0.685**	0.476	-0.463**	-0.218	0.023
Linoleic acid								
	Linolenic acid	-0.127	0.228**	0.580*	0.558*	0.577**	-0.060	0.276**
	Behenic acid	-0.578**	-0.505**	-0.677**	-0.844**	-0.763**	-0.354**	-0.406**
	Erucic acid	-0.461**	-0.872**	0.328	0.951**	0.673**	0.007	-0.072
Linolenic acid								
	Behenic acid	0.066	-0.198**	-0.790**	-0.762**	-0.803**	-0.473**	0.047
	Erucic acid	0.259	-0.365**	0.697**	0.534*	0.580**	0.307*	-0.415**
Behenic acid								
	Erucic acid	0.314	0.415**	-0.904**	-0.839**	-0.874**	-0.659**	-0.643**

*, and ** means significant at $P \leq 0.05$ and $P \leq 0.01$, respectively.

except *B. carinata*. A positive and significant correlation has been reported between palmitic and oleic acid (Islam *et al*., 2009; Lee *et al*., 1974; Sharafi *et al*., 2015) and palmitic and linoleic acid (Islam *et al*., 2009) in *Brassica* species. Palmitic acid exhibited a significant negative association with behenic acid in all *B.* species except *B. carinata* and *B. alba*. Collections of *B. carinata*, *B. juncea* and *B. alba* exhibited a significant negative association between palmitic and erucic acid.

Relationship between stearic and oleic was positive for the *B. juncea*, *B. rapa* subsp. *rapa* and *B. alba* subsp. *alba* but negative for *B. carinata*. Stearic acid had positively correlated with linoleic acid in the collections of *B. juncea*, *B. rapa* subsp. *dichotoma, B. rapa* subsp. *rapa* but it had negatively correlated with linolenic acid in *B. carinata*, *B. rapa* subsp. *rapa* and *B. rapa* subsp. *trilocularis*. Association between stearic and behenic acid was negative for the collections of *B. juncea*, *B. rapa* subsp. *dichotoma*, *B. rapa* subsp. *rapa* and *B. rapa* subsp. *trilocularis*. Similar positive relationship was observed between oleic and linoleic acid in the collections of *B. juncea*, *B. rapa* subsp. *dichotoma*, *B. rapa* subsp. *rapa* and *B. rapa* subsp. *trilocularis.* Significant positive correlation was observed between oleic and linolenic acid among the collections under *B. juncea*, *B. rapa* subsp. *dichotoma*, *B. rapa* subsp. *oleifera*, and *B. rapa* subsp. *rapa*. While the association between oleic and behenic acid was negative in all the *B*. species except *B. carinata*. But unlike, *B. juncea*, *B. rapa* subsp. *dichotoma* and *B. rapa* subsp. *rapa* collections, correlation between oleic and erucic acid was negative in nature.

Except *B. carinata* and *B. rapa* subsp. *trilocularis*, all the collections of *B*. species exhibited significant positive association between linoleic and linolenic acid but relationship between linoleic and behenic acid was negative in the collections of entire *B*. species. Except *B. carinata* and *B. alba*, linolenic and behenic acids of *B. species* oil were found negatively associated. Significant negative correlation was also found between behenic and erucic acid in all the *B*. species except *B. carinata* and *B. juncea*. In this study, mean individual fatty acid concentrations among different species of *Brassica* are not similar and therefore, we observed different kinds of significant relationship among the individual fatty acids. Mandal *et al*. (2002) have reported the similar result in the study of different cruciferous species and the relationship between various pairs of fatty acids has also been studied by many researchers (Genet *et al*., 2004; Mandal *et al*., 2002).

PCA on agronomic characters and fatty acid compositions

PCA on morphological and fatty acid compositions revealed that the first four principal components accounted 96.0% of the variation (Table 5). The first principal component (PC1) accounted for 39.0% of the total variance, the second a further 28.0% and the third 17.0% of the total variance. The first component had high positive loadings from behenic acid, stearic acid, and linoleic acid while it had high negative loadings from linolenic acid, oleic acid, palmitic acid and silique length. The second principal component (PC2) received higher contributions from weight of 1000 seed, number of seeds/silique, peduncle length, erucic and stearic acid. The third principal component (PC3) received higher contributions from linoleic, silique length and erucic acid while it had high negative loadings from silique width, fat content and seed yield. Four groups were identified by reducing the number of variables. For the first group, linolenic acid would be best choice; weight 1000 seed would be the best in the second group, silique width for the third and flowering days for the fourth. Multivariate statistical analysis including PCA has been used by previously (Dawood *et al*., 2009; El-Esawi *et al*., 2012; Jatoi *et al*., 2011; Zada *et al*., 2013) to study morphological traits and fatty acid compositions.

This study found the variation in agronomic characters and fatty acids composition in different *Brassica* species. Wide variation was observed in days to flowering, silique length and width, seed number/silique, seed yield and weight of 1000 seed among *Brassica* species. Wide variation encountered in fatty acid composition of *Brassica* species will be a high potential to improve the varieties. Palmitic acid had positively correlated with stearic, oleic, linoleic and linolenic acid in most of the *Brassica* species. The first three principal components together explained 84.0% of the variation. *Brassica* species containing high oleic and linoleic acid content are useful for nutrition while *Brassica* species germplasm having high erucic acid content can be a potential value for breeding program and industry as well.

Table 5. Eigenvectors and eigenvalues generated by PCA applied on agronomic characters and fatty acid composition of 447 accessions in different *Brassica* species

Characters	Eigenvectors			
	PC1	PC2	PC3	PC4
Flowering days	-0.17	-0.15	0.08	-0.62
Silique length	-0.36	0.10	0.18	0.23
Silique width	-0.08	-0.02	-0.61	-0.04
Peduncle length	-0.17	0.37	-0.07	-0.16
No of seeds/silique	0.17	0.43	-0.09	-0.13
Seed yield	-0.02	-0.34	-0.39	0.26
Wt. of 1000 seed	-0.01	0.47	-0.06	-0.19
Oil content	0.08	0.12	-0.56	0.18
Palmitic acid	-0.36	-0.10	0.04	-0.02
Stearic acid	0.32	0.30	-0.05	0.10
Oleic acid	-0.38	-0.11	-0.15	0.01
Linoleic acid	0.27	-0.13	0.25	0.42
Linolenic acid	-0.41	0.02	-0.01	0.06
Erucic acid	-0.21	0.34	0.12	0.34
Behenic acid	0.33	-0.22	-0.02	-0.28
Eigenvalues				
Eigenvalue	2.76	1.97	1.17	0.82
Total variance (%) explained	39.0	28.0	17.0	12.0
Cumulative percent of Total variance (%) explained	39.0	68.0	84.0	96.0

Acknowledgment

This study was carried out with the support of "Research Program for Agricultural Science & Technology Development (Project No. PJ01192203)" National Institute of Agricultural Sciences, Rural Development Administration, Republic of Korea.

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(Received 27 April 2017 ; Revised 7 August 2017 ; Accepted 18 August 2017)