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Component Characteristics of *Xanthoceras sorbifolium* Seeds for Bioenergy Plant Utilization

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Abstract

Xanthoceras sorbifolium is considered as bio-energy crops owing to the high oil content from kernel. This study was performed to analyze calorific value, crude ash content, ultimate ratio, crude lipid and fatty acid composition among seed sources. Calorific values ranged from 4,526.0 cal g^{-1} to 7,377.2 cal g^{-1} in seeds and kernels showed the highest value. Calorific values and crude ash contents were observed as significant difference among plantations and/or individuals ($p>0.05$). Kernel from SD-F plantation showed the highest calorific value and lower crude ash content. C content comprised 63.4%, the highest levels was detected from SD-F (64.8%). Crude lipid content in kernel observed as 54.5 g 100 g^{-1} from SD-F. In contrast it was determined the lowest value from LN-JARS as 46.5 g 100 g^{-1}. The fatty acid composition of kernel was determined to those of oleic acid (31.3%) and linoleic acid (38.1%) from SD-F and LN-JARS. These results will be offered to useful information for breeding materials selection.

Key Words: bio energy, calorific value, FAME, oil content, *Xanthoceras sorbifolium*

Introduction

Plant sources of bioenergy are divided into several categories: oil crops such as rape, soy, palm, and jatropha; solid biomass such as corn and potato; sugar-rich crops such as sugarcane; cellulose biomass from agricultural by-products such as grass, trees, rick straw, and chaff; and protein biomass such as muck and microbial cell matter (Kim et al. 2007a). *Xanthoceras sorbifolium* is considered an important bio-oil crops owing to the high oil content of its seeds. Oil crops such as *X. sorbifolium*, *Jatropha curcas*, *Cornus wilsoniana*, and *Pistacia chinensis* were planted for forest biomass crop on a trial basis by the State of Forest Administration, but their commercialization as bioenergy crops will be difficult without genetic improvement (Yao et al. 2013). Therefore, the selection of superior populations and/or clones and propagation research is needed.

Fatty acid methyl ester (FAME) analysis has shown that the seed oil from *X. sorbifolium* is comparable to that of cottonseed oil as a bio-diesel fuel (Wang et al. 2010). It is mainly composed of C16 to C18 fatty acid around 75% which is kind of 13 component (Yu and Zhou 2009). Seed kernel oil concentrations among several populations in China varied from a minimum of 57% to a maximum of 67%, while oil composition varied by approximately 47% among populations (Ao 2009). The correlation between oil concentration and seed weight was poor (e.g., the seeds with a high concentration of oil were below the average

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weight and the number of seeds level (Zhang et al. 2011a). Other results reported that fatty acid compositions of linoleic acid, linolenic acid, and oleic acid varied in accordance with the latitude and longitude of the nursery (Mou et al. 2007). Generally, palmitic acid, stearic acid (a saturated fatty acid), and oleic acid (a monounsaturated fatty acid) show good oxidative stability. In contrast, linoleic acid and linolenic acid (polyunsaturated fatty acids) are very prone to oxidation (Jang et al. 2010).

Jatropha and palm are widely known as bioenergy plants but are disadvantageous in that they only grow in tropical temperature zones. In contrast, *X. sorbifolium* is resistant to cold and can withstand temperatures down to 30°C～41°C below 0°C. In addition to being cold-hardy, this species is drought-tolerant and grows in alkaline soil (Liu et al. 2013), making it a good choice for temperate climates. *X. sorbifolium* has been previously studied as a way to stabilize vegetation on Chinese Loess plateau, which experiences localized heavy rain and subsequent soil erosion (Shen 2010).

In this study, we compared seed oil concentration, fatty acid composition, and calorific value to determine variations in populations of *X. sorbifolium*. The results will be used to develop new bioenergy resources and make genetic improvements in the breeding process.

Materials and Methods

General information

Seeds of *X. sorbifolium* were obtained from four discontiguous plantations in Inner Mongolia, Liaoning, and Shandong Province in China (Table 1). The samples were air-dried and were milled.

Calorific value and crude ash

From each of the milled samples, 0.6～1 g seeds or plants powder was analyzed for gross calorific value using a 6300 Bomb Calorimeter (Parr Instrument Corp., USA). Crude ash content was determined by heating at 550°C until light gray to white color ash was achieved. Three replications were performed for each sample. Data were analyzed using a one-way ANOVA in SPSS Statistics v. 21 (IBM corp., USA).

Ultimate analysis

Carbon (C), hydrogen (H), nitrogen (N), and sulfur (S) ratios were determined using ultimate analyzer (FlashEZ 1112, Thermo Fisher Scientific, Italy). A standard based on sulfanilamide ($C_6H_8N_2O_2S$; 177.2 g mol^{-1}) 4-aminobenzenesulfonamide was examined. Analyses were performed using a thermal conductivity detector for CHNS-O at an initial temperature of 1,000°C. Samples were combusted for 20 min. Data were analyzed using Eager300 software (Thermo Fisher Scientific). The oxygen (O) content was estimated by subtracting the difference of the sum of the percentages of C, H, N and S from 100%.

Crude lipid and fatty acid analysis

Crude lipid content was determined by hexane extraction using a Soxhlet extractor (2050 Soxtec; Foss, Hoganas, Sweden). Fatty acid methyl ester (FAMEs) were prepared by combining 100 mg freeze-dried samples with 340 μl methylation reagent containing methanol (MeOH); benzene; 2,2-dimethoxypropane; (DMP); sulfuric acid (H_2SO_4) (39:20:5:2); and 200 μl heptane. Mixtures were incubated at 80°C for 2 h. The extracts were cooled at room

Table 1. Location of plantations for seeds collection

Province	Plantation name	Location
Inner Mongolia	Jinjilinchang (IM-J)	Ongniud Banner, Chifeng
Inner Mongolia	Lindonglinchang (IM-L)	Baarin Left Banner, Chifeng
Inner Mongolia	No. 38 (IM-38)*	Ar Khorqin Banner, Chifeng
Inner Mongolia	No. 160 (IM-160)*	Ar Khorqin Banner, Chifeng
Liaoning	Jianping Agriculture Research Station (LN-JARS)	Jianping county, Chaoyang
Shandong	Forest farm (SD-F)	Beizhuangcun, Weifang

*superior tree.

Table 2. Calorific value of various parts in *X. sorbifolium*

Parts	Plants				Seeds		
	Leave	Shoot	Stem	Withered	Total	Kernel	Coat
Calorific value* ($cal\ g^{-1}$)	$4,712.9^{c}$	$4,402.2^{e}$	$4,306.9^{f}$	$4,397.1^{e}$	$5,874.2^{b}$	$7,377.2^{a}$	$4,526.0^{d}$
S.E.	12.7	27.5	23.5	5.9	46.0	0.8	21.7

*Duncan's test $p < 0.05$.

temperature temperature and the supernatant was discarded for gas liquid chromatography analysis. FAMEs were analyzed using an Agilent 7890A (Agilent Technologies, USA) with a FID at 280°C. A DB-Wax column (30 mm x 0.25 mm x 0.25 μm; Agilent Technologies) was used. Analyses were performed under the injector temperature of 250°C and gas flow was adjusted to 35 ml min^{-1} H_2, 350 ml min^{-1} air, and 35 ml min^{-1} He.

Results

Calorific values ranged from 4,306.9 cal g^{-1} to 4,712.9 cal g^{-1} in plant parts including leaves, shoot, stem and withered shoot and from 4,526.0 cal g^{-1} to 7,377.2 cal g^{-1} in seeds (Table 2). Kernels showed the highest value (7,377.2 cal g^{-1}) followed by total seed, leaf, bark, shoot, and withered. Samples that contained seed coats showed a reduced calorific value, ranging from 7,377.2 cal g^{-1} to 4,526.0 cal g^{-1}. However, the value of total seed, (5,874.2 cal g^{-1}) was higher than that reported for plants parts, which may be attributed to the high oil content in the seeds.

A significant difference was observed in the calorific value of seeds from the various plantations ($p < 0.05$) (Table 3). Total seeds and kernels from plantation SD-F displayed the highest values (6,396.5 cal g^{-1} and 7,774.6 cal g^{-1}, respectively). Plantations LN-J, IM-38, and IM-160 displayed the highest calorific value in seed coats. Seeds from IM-J and LN-JARS were determined to have the lowest level of calorific value for all seeds parts. Kernels, which contain the highest oil content, and main parts were ranked from highest to lowest as SD-F, IM-160, IM-38, IM-J, LN-JARS and IM-L in that order. Based on this result, seeds from plantation SD-F may be considered superior seeds, selecting for high calorific value. Additionally, seeds from IM-38 and IM-160 may also be considered superior along with those of SD-F.

Table 3. Calorific value of seeds among plantations and tree in *X. sorbifolium*

Plantations	Calorific value* ($cal\ g^{-1}$)		
	Total	Kernel	Seed coat
IM-J	$5,532.4^{d}$	$7,580.6^{c}$	$4,484.8^{a}$
IM-L	$5,698.9^{c}$	$7,402.9^{e}$	$4,273.6^{b}$
IM-38	$6,083.2^{b}$	$7,670.1^{b}$	$4,466.6^{a}$
IM-160	$6,099.9^{b}$	$7,699.4^{ab}$	$4,524.2^{a}$
LN-JARS	$5,590.5^{d}$	$7,499.3^{d}$	$4,134.9^{c}$
SD-F	$6,396.5^{a}$	$7,774.6^{a}$	$4,271.4^{b}$
Mean	5,900.2	7,604.5	4,359.3
S.E.	140.4	56.1	63.2

*Duncan's test $p < 0.05$.

Crude ash content among plantations was significantly different ($p < 0.05$) (Table 5). The crude ash contents of plant parts from highest to lowest are as follows: leaves, shoots, stem, and withered shoot in that order. The values from seeds were consistently lower than those from plant parts, with seed coats displaying the lowest value. Among plantations, seed ash contents were the lowest in seeds from plantation LN-JARS with a value of 0.9 cal g^{-1} and highest in seeds from IM-L (Table 5). Kernels from plantation SD-F, which were measured as having the highest calorific value, were included in lower group at 1.3 cal g^{-1}. A comparison of calorific value and crude ash yields a Pearson's coefficient value of 0.90, indicating a strong linear relationship between the two variables ($p < 0.05$) which was higher coefficient value (data not shown). As the calorific value of seed parts increased, crude ash contents also increased among plantations (Table 5).

C content comprised 63.4%, which was the highest value among the samples analyzed (Table 6). The remaining values, in descending order, are for O, H, and N. S was not detected. C, H, and O contents constituted 93.9～95.2%. The highest levels of C were detected from plantation SD-F (64.8%), and the lowest value from IM-160 was 62.1%.

Crude lipid content analysis determined that the highest value was observed in seeds from plantation SD-F (54.5 g 100 g^{-1}). On the other hand, seeds from LN-JARS displayed the lowest value at 46.5 g 100 g^{-1} (Table 7). The average lipid content among plantations was shown to be 51.15 g 100 g^{-1}. The gap between the highest value and the lowest value was 8 g 100 g^{-1} with crude lipid content differing significantly among plantations ($p < 0.05$). Based on our analysis of crude lipid contents, trees from SD-F are considered to select for seeds with high oil content. In addition, seeds from plantations IM-J and IM-L will be considered as superior to those of other trees and/or populations.

An analysis of the fatty acid composition of kernels showed that linoleic acid comprised the highest percentages of total fatty acids, ranging from 38.0% to 41.5% amongst the different plantations (Table 8). The major components of total fatty acids were oleic acid (38.0～41.5%), followed by erucic acid, eicosenoic acid, palmitic acid, and stearic acid. Oleic acid, an unsaturated fatty acid, is known to be oxidatively stable, but linoleic acid is known to be prone to

Table 4. Crude ash contents of various parts in *X. sorbifolium*

Parts	Plants				Seeds		
	Leave	Shoot	Stem	Whthered shoot	Total	Kernel	Coat
Calorific value* (cal g^{-1})	5.4^{a}	3.1^{b}	2.2^{c}	1.9^{cd}	1.2^{e}	1.7^{d}	0.6^{f}
S.E.	0.1	0.1	0.2	0.1	0.1	0.1	0.1

*Duncan's test $p < 0.05$.

Table 5. Crude ash of seed parts among plantations and trees in *X. sorbifolium*

Plantations	Calorific value* (cal g^{-1})		
	Total	Kernel	Seed coat
IM-J	1.2	1.9	0.6
IM-L	1.4	2.2	0.6
IM-38	1.1	1.6	0.8
IM-160	1.4	1.6	0.8
LN-JARS	0.9	1.8	0.3
SD-F	1.0	1.3	0.7
Mean	1.2	1.7	0.6
S.E.	0.1	0.1	0.1

*Kruskal-Wallis test, $p < 0.05$, F=52.717.

Table 6. Ultimate analysis of kernel among collected plantations and trees

Plantations	Organic element ratio (%)				
	C	H	N	S	O
IM-J	63.9	9.5	5.0	0.0	21.6
IM-L	62.6	9.3	5.9	0.0	22.2
IM-38	64.0	9.3	5.4	0.0	21.2
IM-160	62.1	9.0	6.1	0.0	22.8
LN-JARS	63.2	9.4	5.4	0.0	22.0
SD-F	64.8	9.5	4.7	0.0	20.9
Mean	63.4	9.4	5.4	0.0	21.8
SE	0.4	0.1	0.2	0.0	0.3

Table 7. Crude lipid content of kernels from each plantation and tree in *X. sorbifolium*

Plantation	IM-J	IM-L	IM-38	IM-160	LN-JARS	SD-F
Crude lipid (g 100 g^{-1})	52.3	52.1	52.2	49.2	46.5	54.5
S.E.	0.3	0.4	0.1	0.2	0.4	0.6

Table 8. Fatty acid composition of kernels (% total fatty acid)

Fatty acid (n:m)*	Percentage of total fatty acid					
	IM-J	IM-L	IM-38	IM-160	LN-JARS	SD-F
Palmitic (C16:0)	5.2	5.2	5.2	5.2	5.2	5.4
Palmitoleic (C16:1)	0.0	0.1	1.0	0.0	0.0	0.0
Stearic (C18:0)	2.0	2.0	2.0	2.0	2.1	2.2
Oleic (C18:1)	27.4	27.6	28.4	27.9	32.2	31.3
Linoleic (C18:2)	41.5	41.2	40.7	41.4	38.0	38.1
γ-Linolenic (C18:3 n6)	0.1	0.1	0.1	0.1	0.1	0.0
α-Linolenic (C18:3 n3)	0.3	0.3	0.3	0.3	0.3	0.3
Arachdic (C20:0)	0.2	0.2	0.4	0.2	0.3	0.3
Eicosenoic (C20:1)	6.9	6.6	7.0	6.9	7.1	7.1
Eicosadienoic (C20:2)	0.5	0.5	0.5	0.5	0.4	0.4
Behenic (C22:0)	0.5	0.5	0.5	0.5	0.5	0.6
Erucic (C22:1 n9)	9.1	8.8	9.1	9.1	8.7	8.8
Lignoceric (C24:0)	0.4	0.4	0.3	0.4	0.4	0.4
Nervonic (C24:1)	3.4	3.5	3.3	3.3	2.9	2.9
Total	97.7	97.0	98.9	97.7	98.1	97.8

*n:m=number of carbon atoms: unsaturated carbon.

oxidative stress (Jang et al. 2010). Trees from LN-JARS might be good candidates as bio-diesel plants because their seeds were shown to have the highest oleic acid content at 32.2% and the lowest linoleic acid at 38.0%. In addition, the fatty acid composition of seeds from plantation SD-F were similar to those of LN-JARS in that they have higher contents of oleic acid (31.3%) and lower linoleic acid (38.1%). When compared to SD-F and LN-JARS, IM plantations contain lower concentrations of oleic acid (27.4～28.4%) and higher concentrations of linoleic acid (40.7～41.5%). The contributions of palmitic acid and stearic acid, which are mainly saturated fatty acids, were analyzed to be 5.2～5.4% and 2.0～2.2%, respectively. No significant difference was detected among plantations ($p<0.05$). When comparing erucic acid and eicosenoic acid between populations, no significant difference was found ($p<0.05$).

Discussion

In order to produce wood pellets using by-products such as empty fruit bunches (EFBs) or mesocarp fibers (MFs) remaining after extraction of seed oil and to meet economic demands for wood pellets, we investigated the heating values of different materials. EFBs isolated after palm oil extraction have been reported to show quality characteristics similar to those of the existing pellets produced by using bagasse fibers isolated after extraction of crude liquid from sugar cane (Erlich and Fransson 2011). Therefore, if bagasse isolated after extraction of oil from seeds is used for production of wood pellets or is used in a mixture, the supply and demand rate of wood pellets would be increased. The heating value of seed coats of *Xanthoceras sorbifolium* was measured as 4,526.0 kcal g^{-1}, which is higher than the heating value of grade 1 pellets (4,300 kcal kg^{-1}) based on the dimension-quality standard of wood pellets recommended by the Korea Forest Research Institute (Korea Forest Research Institute 2013). Therefore, this material can be used for the production of wood pellets alone or in a mixture. In addition to seeds, all heating values of leaves, shoots, stem parts, and withered shoot of *X. sorbifolium* were greater than 4,300 kcal kg^{-1}; thus, this material appeared to exceed the standard of grade 1 pellets based on heating values. Since high ash contents in produced pellets make it difficult to use the pellets at home, the dimension-quality standard of grade 1 pellets requires 1.0% or less ash contents in wood pellets (Korea Forest Research Institute 2013). Seed coats of *X. sorbifolium* were found to contain 0.6% ash content. Because ash content is increased by 0.01～0.1% after production of wood pellets (Ahn et al. 2013), ash contents of seed coats may be suitable for application in wood pellet production. In addition, since the heating value of seeds with intact seed coats was found to be as high as 5,874.2 kcal g^{-1}, a use of wood pellets in a mixture with seeds would be expected to improve the heating value compared with that of wood alone. The ash content of seeds was 1.2%, which was relatively lower than that (1.6%) of existing pellets produced from mixed hardwoods (Ahn et al. 2013) but comparable to that of standard grade 2 pellets (≤1.5%); therefore, the use of this material combined with wood would reduce the ash contents in pellets, allowing the production of grade 1 pellets. Pellets made of only wood are likely to absorb moisture, which increases moisture content, decreases heating value, and allows the pellets to be spoiled by bacteria. To address these issues, one study examined the effects of added soybean oil, waste soybean oil, ozonized soybean oil, and ozonized waste soybean oil to pellets and showed that this combination improved the heating value by 60 kcal kg^{-1}, yielding pellets with a heating value of 4,552 kcal kg^{-1} (Lee et al. 2011).

Seeds lacking seed coats but having high heating values that were collected from forest farms had higher carbon contents than seeds collected from other production areas. In general, pellets with high carbon content and low oxygen content have been shown to have high heating values. Moreover, pellets made from corn stovers have been shown to have a higher carbon content and a lower oxygen content than pellets made from *Populus alba × P. glandulosa*, resulting in a higher heating value; this higher heating value is correlated with higher oxygen contents in cellulose and hemicellulose and relatively lower oxygen contents in lignin (Han et al. 2009). However, in the present study, we found no correlation between the heating values of seeds and organic elements, providing a reference for the ratio of organic elements in wood pellet production. According to the quality standard of wood pellets (Korea Forest Research Institute 2013), the standard for grade 1 pellets is 0.05% or less; however, this element was not detected in our experiment. Additionally, the nitrogen content was 4.7～6.1%, which was higher than 1.0%, the maximum of the standard for grade 4 pellets. The higher nitrogen content seemed to be generated during the heating and oxidation of oil due to the high lipid contents in grains. Therefore, if *X. sorbifolium* grains are mixed in pellets, nitrogen contents would be compatible with the standards for wood pellet composition. The heating value of soybeans was 4,983.3 kcal g^{-1}, whereas that of *X. sorbifolium* seeds without seed coats was as high as 7,774.6 kcal g^{-1}. Accordingly, using these seeds in a mixture with wood pellets would raise the efficiency compared with that of existing oil plants.

The heating values of seeds with intact seed coats by collection group/individual were between 5,532.4 and 6,396.5 kcal g^{-1}, showing a maximum different of 800 kcal g^{-1}; these data indicated that it is essential to select superior groups or individuals. Because there was a correlation between heating values and ash contents, seeds collected from forest farms where seeds had high heating values also had a low ash content, showing superior characteristics for use a bioenergy materials.

The mean oil contents of *X. sorbifolium* seeds were 51.15 g 100 g^{-1} from six groups/individuals, and the fatty acids contents of seeds were similar to or higher than those found in materials from markets in South Korea, e.g., 17.8% mean fat content in soybeans (Kim et al. 2007b), 43.9 wt% mean fat content in canola seeds (Hwang et al.

2009), 47.8% mean fat content in castor beans (Lee et al. 2010), 50% mean fat content in oil palm, and 28～39% mean fat content in Jatropha (Aranda-Rickert et al. 2011). A study of castor beans and soybeans reported that oil contents of seeds were different depending on the growing area and collection area, likely owing to differences in genotypes and cultivation environments (Kim et al. 2007a). In addition, oil contents may depend on the maturity of the samples (Kim et al. 2008).

The composition of fatty acids extracted from plants is an important factor determining the qualities of biodiesel raw materials. An ideal fatty acid composition includes low degrees of saturation and unsaturation and a high rate of unsaturated fatty acids having only one double bond (Roh and Park 2007). Of the major fatty acids in plants, saturated fatty acids without double bonds, e.g., palmitic acid (C16:0) and stearic acid (C18:0), exhibit stable oxidation, and oleic acid (C18:1), which exists as geometric isomers in the cis- and trans- forms, also exhibits stable oxidation. In contrast, lenoleic acid (C18:2) and lenolenic acid (C18:3), which are unsaturated fatty acids with double bonds, do not have stable oxidation status, and the composition ratio of each component should to be considered (Jang et al. 2010). Saturated fatty acids have high oxidation stability and high melting points, allowing these materials to be used as fuels in tropical areas but not in temperate or cold areas where they may become solid, even at room temperature (Roh and Park 2007). Based on these characteristics of major fatty acids, oleic acid rates in oils extracted from tree species that can be used as raw materials for biodiesel are considered important. Oleic acid rates in major plant species are as follows: 27.4% in corn oil, 42.6% in Jatropha oil, 22.3% in palm oil, 27.5% in soybean oil, 18.7% in sunflower seed oil, 63.4% in native varieties of rapeseed oil, and 9.5% in improved varieties of rapeseed oil (Jang et al. 2010). In comparison, in *X. sorbifolium* seeds, oleic acid contents ranged from 27.4% to 32.2% depending on the collection area/individual; this was similar to or higher than those of corn oil, oil palm oil, soybean oil, and sunflower seed oil. Although the oleic acid content of rapeseed oil was only 9.5% in improved varieties, first generation hybrid varieties of rapeseed, such as Chungpoong, Sunmang, and Chungram, were developed by growing male sterility strains and creating hybrid strains using the hybrid vigor phenomenon to increase productivity (Jang et al. 2002a; Jang et al. 2002b). Varieties such as Naehan, Youngsan, Yongdang, Tamra, Tammee, and Hanla were also developed by breeding to increase oleic acid contents up to 65% (Jang et al. 1998). In addition, for seed gathering, seed production was induced by isolation and crossing in order to maintain purity of plants selected by F1 cross combinations of rapeseed (Jang et al. 2002c).

Raw materials for production of biodiesel in South Korea are mainly produced by soybeans and waste cooking oil; however, rapeseed cultivation has recently been attempted for biodiesel production as well (Kim et al. 2008). Unfortunately, this crop is sensitive to cold weather, and if temperature is continuously -5°C or less, the underground parts of the plant will wither (Roh and Park 2007), making cultivation in the central north area of South Korea difficult. Thus, further studies of bioenergy crop production using seeds of forest trees with cold resistance are necessary. In a study on analysis of the characteristics (including oil contents and fatty acid compositions) in several tree species that are usable as biodiesel fuels in South Korea, oil contents and oleic acid contents of the camellia were 70.3% and 85.93%, respectively (Kim et al. 2013). However, camellia is also only distributed in the southern temperate region and the warm temperate zone of the northern hemisphere and is found on islands along the southern coast of South Korea (Kim et al. 2005; Chung et al. 2011). Hence, it is difficult to use this plant as a source of raw materials for biodiesel owing to these limitations in the cultivation area. In contrast, *X. sorbifolium* can grow in regions with annual average temperatures between 3°C and 15.6°C, average temperature in January of between －19.4°C and 0.2°C, and average temperature in July of between 13.6°C and 3.2°C; accordingly, this tree species may represent a novel species for production of bioenergy materials (Mou et al. 2008).

Therefore, since seeds of *X. sorbifolium* from forest farms in the Shandong area (SD-F) of China have high oil contents and high oleic acid contents, these seeds can be selected and used as breeding materials. Seeds of Jinjilinchang and Lindonglinchang from Neimenggu, for which oil contents were the second highest after that of forest farms, and of JARS from Liaoning province, China, which have high oleic acid contents but low oil contents, can also be used as breeding materials.

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