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Chemical Composition in Kernels of Ten Grafted Pecan (*Carya illinoensis*) Varieties in Southeastern China

Xiaodan Zhang [1,2], Jun Chang [1,*], Xiaohua Yao [1], Jingru Wang [2], Jiatian Zhang [2], Yang Yang [2], Shuiping Yang [2], Kailiang Wang [1] and Huadong Ren [1]

[1] Research Institute of Subtropical Forestry Chinese Academy of Forestry, Fuyang, Hangzhou 311400, China; zhang_xiaodan_swu@163.com (X.Z.); yaoxh168@163.com (X.Y.); wangkl163@163.com (K.W.); renhd@163.com (H.R.)

[2] College of Resources and Environment, Southwest University, Beibei, Chongqing 400715, China; wjr4869@163.com (J.W.); zjt990305@163.com (J.Z.); yangyang20220508@163.com (Y.Y.); yang-sp@163.com (S.Y.)

* Correspondence: ylschj@caf.ac.cn

Abstract: As woody oil crop, pecan [*Carya illinoinensis* (Wangenh.) K. Koch] may be a solution to the shortage of edible oil in the future. In this study, fruit traits, kernel nutrition and fatty acid composition of 10 pecan varieties were determined to assess the potential of pecans for exploitation as edible oil, as well as to further screen varieties that could be used as edible oil resources and to understand their development prospects for cultivation in mountainous hills. The study showed that all the fruit trait indicators measured, including green-fruit weight (mean 28.47 g), nut weight (10.33 g), kernel weight (5.25 g), nut percentage (36.83%) and kernel percentage (50.50%), showed highly significant differences among the 10 varieties. Among the main nutritional indicators of the kernels, the crude fat content was stable (mean 70.01%) with non-significant differences, while protein (67.50 $mg \cdot g^{-1}$), soluble sugar (10.7 $mg \cdot g^{-1}$) and tannin (6.07 $mg \cdot g^{-1}$) showed highly significant differences between varieties. The oil percentage of nuts (kernel percentage * crude fat) averaged 35.36%, with highly significant differences between varieties. The fatty acid composition was dominated by unsaturated fatty acids (mean 91.82%), with unsaturated fatty acids being 11.24 times more abundant than saturated fatty acids. Among the monounsaturated fatty acids, oleic acid was the highest (mean 70.02%), with highly significant differences between varieties, followed by cis-11-eicosanoic acid (0.25%), with non-significant differences between varieties; among the polyunsaturated fatty acids, linoleic acid was the highest (19.58%), followed by linolenic acid (0.97%), both of which showed highly significant differences between varieties; monounsaturated fatty acids were 2.42 times more abundant than polyunsaturated fatty acids. Compared to other oilseed crops, pecan has the potential to produce "nutritious, healthy and stable" edible oil, while its wide habitat and good productivity benefits offer broad prospects for development in the hills and mountains of subtropical China.

Keywords: pecans; fatty acids; nutritional composition; production potential; edible oil

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1. Introduction

Food shortages are a worldwide problem, and China is a country with a shortage of edible oil. In 2020, China imported 11.677 million tonnes of edible oil, in addition to 16.972 million tonnes of edible oil extracted from imported oilseeds, with domestically produced oil crops providing only 33.17% of its edible oil consumption needs and a 66.83% foreign dependence [1]. To ensure self-sufficiency in edible oil, the production of soybeans, canola, peanuts and some other oilseeds in China has been increasing year by year, with the total production of the eight major oilseeds in China increasing by 18.85% in 2020, compared to 2016 [1]. However, most of these oil crops involve the occupation of arable land, which can have a negative impact on the cereal supply. In recent years, scholars have turned their attention to woody oil crops, such as *Camellia oleifera* and walnut [2–5].

Although the acreage of the above-mentioned crops is developing rapidly, it is still difficult to effectively solve the shortage of edible oil in China in the short term. China is a vast country with a diverse ecological climate and abundant mountain resources, so the search for new potential woody oil crops is significant.

Pecan [*Carya illinoinensis* (Wangenh.) K. Koch], a defoliate tree of *Carya* in Juglandaceae, is one of the world's most famous nut and oil trees, and popular for its delicious, nutritious kernels. Pecan has a long history of cultivation in America and has formed a large dried-nut industry. In China, the history of pecan cultivation is shorter and the scale is smaller, and most of the current research focuses on fruit traits [6–8], nutrients [9–11], growth regularities and selection of variety [12–15]. In addition to the kernels being consumed as dried fruit, the oil of pecans has multiple exploitative values, not only as a food additive [16] to enhance anti-fatigue effects by increasing the tissue glycogen [17], but also as a biofuel that can be developed as a sustainable energy alternative [18]. More importantly, the oil from pecans can be exploited as a healthy edible oil, and its components and effects have been studied by scholars worldwide. The possibility of using pecan oil as an edible oil "high in unsaturated fatty acids" was reported as early as the 1920s [19]. Toro-Vazquez studied the fatty acid composition and physicochemical stability of pecan oil, which was found to be stable and high in unsaturated fatty acids, and Su found that pecan oil fully met the international nutritional standards of "omega meals" [20,21]. The fatty acid content of the kernels of pecans grown in China was determined by Zhang and Yu, respectively, and both showed: oleic acid > linoleic acid > palmitic acid > stearic acid > linolenic acid, with a predominance of unsaturated fatty acids [9,10]. The production of ready-to-eat kernels from pecans has a long history; however, there have been no reports of edible oil production from pecans, nor has there been any work done to select varieties of pecans specifically for use in the production of edible oil. We have been focusing on the edibility of the oil of pecan kernels for a long time, and obtained 41 candidates from a preliminary screening of hundreds of varieties, which were re-evaluated [22], and then combined with the growth, yield, and adaptability indicators to finally select 10 varieties with high oil productivity. In this study, the fruit traits, kernel nutrition and fatty acid composition of the ten selected varieties were further determined to evaluate their oil content and stability while assessing the potential of pecans to be grown in mountainous areas of China and developed as an edible oil species.

2. Materials and Methods

2.1. Study Area

The pecan experimental forest is located in Hongzhai, Jiande, Zhejiang (29°28′ N, 119°23′ E). The area has an elevation of 100 m, with average annual temperature and rainfall of 16.7 °C and 1500 mm, respectively. The pecan trees were planted in purple soil with pH of 5.39. According to a previous chemical analysis of the soil, the following results were found ($mg \cdot kg^{-1}$): 908 total N, 14.8 olsen-P, 98 avail-K, 872 Ca^{2+}, 5550 Mg^{2+}, 26,600 Fe^{2+}, 405 Mn^{2+}, 61 Zn^{2+} and 27.9 Cu^{2+}.

2.2. Plant Materials

The varieties in this study were No.104, No.11, No.1, No.20, No.21, No.28, No.29, No.32, No.34 and No.35. The grafted seedlings of each variety were planted (8 m × 8 m) in 2005 in one plot of 16 m × 24 m, with 6 plants per plot. A randomized complete block experimental design with three replicates was used, and a total of 30 plots. Thirty fruits were randomly taken from each plot at fruit maturity in 2018. The individual weights of green-fruits, nuts and kernels were weighed using an electronic balance with 0.01 accuracy, and the percentage of nut and kernel were calculated. The weighed samples were placed in an oven until completely dry, after which the dried samples were pulverized and stored in airtight containers for further extraction.

2.3. Proximate Composition

The crude fat, protein, soluble sugar and tannin contents of the samples were determined according to the official methods of the People's Republic of China (National Standards of the People's Republic of China #GB 5009.6-2016, GB 5009.5-2010; Agricultural Industry Standards of the People's Republic of China #NY/T 1278-2007, NY/T 1600-2008). Crude fat content was determined by Soxhlet extractor method [23], protein content was determined by Kjeldahl method (the factor was 6.25) [24], soluble sugar content was determined by Shaffer-Somogyi [25] and tannin content was determined by Spectrophotometry method [26]. All chemicals used in this study were of analytical grade and the reagents used were standardized.

2.4. Fatty Acid Composition

Oil extraction of samples was performed according to the Soxhlet extractor method (National Standards of the People's Republic of China #GB 5009.6-2016) [21,27]. Approximately 2 g kernels was accurately weighed into the filter paper cylinder, followed the filter paper cylinder was put into the extraction cylinder of Soxhlet extractor. The oil was extracted with n-hexane in a Soxhlet for 8 h, and the solvent was removed with a rotary vacuum evaporator at 40 °C. Then residue was dried at 100 °C ± 5 °C for 1 h and cooled in the desiccator for 0.5 h before weighing. The drying procedure was repeated to achieve constant weight.

Fatty acid methyl esters (FAMEs) from oil samples were obtained by alkaline treatment (2.0 M KOH in methanol). The GC–MS analysis for the FAMEs was conducted using an Agilent 7890A gas chromatograph (Agilent Technologies) equipped with a flame ionization detector and an HP-INNOWAX fused silica capillary column (30 m × 0.25 mm × 0.25 μm). The capillary column temperature was programmed from 140 to 250 °C by starting from 140 °C for 1 min, and then increasing to 250 °C at a rate of 4 °C min^{-1}. Helium was used as the carrier gas, and the injection and detector temperatures were 220 °C and 275 °C, respectively, with a split ratio of 1:100. The normalization method was used to quantify the samples. The individual fatty acid composition was expressed as percentages of total fatty acid.

2.5. Statistical Analysis

The statistical significance of the data was calculated by one-way analysis of variance with SPSS 19.0. A value of $p \leq 0.05$ indicated statistical significance, using Duncan's multiple range tests. Nut percentage, kernel percentage and oil percentage data were calculated in accordance with the formula.

$$\text{Nut percentage (\%)} = 100\% \times \text{nut weight (g)}/\text{green-fruit weight (g)} \quad (1)$$

$$\text{Kernel percentage (\%)} = 100\% \times \text{kernel weight (g)}/\text{nut weight (g)} \quad (2)$$

$$\text{Oil percentage (\%)} = \text{kernel percentage (\%)} \times \text{crude fat (\%)} \quad (3)$$

3. Results

3.1. Fruit Traits of Different Varieties

There were highly significant differences in green-fruit weight, nut weight and percentage and kernel weight and percentage among 10 varieties (Table 1). The average green-fruit weight of the total 10 varieties was 28.49 g, ranging from 23.74 g (No.21) to 36.55 g (No.104). The average nut weight was 10.33 g, from 7.86 g (No.11) to 12.80 g (No.28). Kernel weight averaged 5.25 g, with the largest values of 7.08 g (No.28) and 6.94 g (No.104), respectively, significantly higher than that of other varieties, and 1.92 and 1.89 times higher the lowest of 3.68 g (No.11). The variable coefficient of kernel weight (CV = 24.37%) was higher than the other indexes. The nut percentage averaged 36.52%, ranging from 26.78% (No.34) to 41.67% (No.29 and No.32). The average kernel percentage was 50.50%, with a maximum of

55.59% (No.34) and a minimum of 45.40% (No.20), and a minimum coefficient of variation of 7.65%.

Table 1. Fruit traits of 10 pecan varieties.

Trait	Green-Fruit Weight (g)	Nut Weight (g)	Kernel Weight (g)	Nut Percentage (%)	Kernel Percentage (%)	Oil Percentage (%)
104	36.55 ± 0.11 ^{A}	12.64 ± 0.23 ^{A}	6.94 ± 0.19 ^{A}	34.80 ± 0.53 ^{AB}	54.33 ± 0.59 ^{AB}	38.99 ± 0.78 ^{AB}
11	23.96 ± 1.31 ^{CD}	7.86 ± 0.33 ^{B}	3.68 ± 0.14 ^{E}	33.03 ± 0.59 ^{BC}	46.81 ± 1.17 ^{CD}	31.57 ± 1.06 ^{D}
1	29.16 ± 0.88 ^{BCD}	11.93 ± 0.32 ^{A}	6.31 ± 0.33 ^{AB}	41.16 ± 2.19 ^{A}	52.86 ± 1.43 ^{ABC}	36.93 ± 1.22 ^{ABC}
20	25.54 ± 0.74 ^{BCD}	8.44 ± 0.21 ^{B}	3.84 ± 0.14 ^{E}	33.23 ± 1.32 ^{BC}	45.40 ± 0.57 ^{D}	31.90 ± 0.23 ^{CD}
21	23.74 ± 2.93 ^{D}	8.03 ± 1.02 ^{B}	3.81 ± 0.41 ^{E}	33.96 ± 1.18 ^{AB}	47.58 ± 1.46 ^{BCD}	32.48 ± 1.24 ^{BCD}
28	31.21 ± 5.98 ^{AB}	12.80 ± 1.77 ^{A}	7.08 ± 0.71 ^{A}	41.53 ± 2.37 ^{A}	55.33 ± 2.21 ^{A}	40.32 ± 0.69 ^{A}
29	26.10 ± 4.36 ^{BCD}	10.64 ± 1.12 ^{A}	5.48 ± 0.66 ^{BCD}	41.67 ± 3.39 ^{A}	51.62 ± 0.79 ^{ABCD}	35.79 ± 1.44 ^{ABCD}
32	29.11 ± 3.36 ^{BCD}	12.08 ± 1.43 ^{A}	5.73 ± 0.17 ^{BC}	41.67 ± 0.13 ^{A}	47.98 ± 5.81 ^{BCD}	35.02 ± 1.06 ^{BCD}
34	30.76 ± 2.42 ^{ABC}	8.15 ± 0.44 ^{B}	4.52 ± 0.26 ^{DE}	26.78 ± 0.73 ^{C}	55.59 ± 0.29 ^{A}	38.59 ± 0.48 ^{AB}
35	28.79 ± 0.16 ^{BCD}	10.72 ± 0.37 ^{A}	5.09 ± 0.61 ^{CD}	37.35 ± 1.25 ^{AB}	47.47 ± 4.16 ^{BCD}	32.20 ± 3.24 ^{BCD}
Average	28.49	10.33	5.25	36.52	50.5	35.38
CV(%)	13.64	19.63	24.37	13.79	7.65	9.21
F-valued	6.73 **	14.63 **	22.91 **	10.23 **	6.16 **	6.31 **

Weight in indexed refers to the weight of per-fruit/per-nut/per-kernel. Letters A, B, C, D, E indicate statistically significant differences at the $P_{0.01}$ level for the same column of data. ** indicates highly significant differences.

3.2. Content of Crude Fat, Protein, Soluble Sugar and Tannin of Different Varieties

The average crude fat content of the 10 varieties was 70.01%, with a minimum of 67.44% (No.11) and a maximum of 72.99% (No.32). The crude fat content was not significantly different between the 10 varieties and the coefficient of variation (2.84%) was lower than the other nutritional indicators.

Protein, soluble sugar and tannin are also important indicators of nut quality and showed highly significant differences between the 10 varieties (Table 2). The average protein content was 67.50 $mg \cdot g^{-1}$, ranging from 53.33 $mg \cdot g^{-1}$ (No.29) to 84.33 $mg \cdot g^{-1}$ (No.20). The average soluble sugar content was 10.7 $mg \cdot g^{-1}$, with a minimum of 5.6 $mg \cdot g^{-1}$ (No.1) and a maximum of 27.4 $mg \cdot g^{-1}$ (No.35). The highest content was 4.89 times higher than the lowest content, with the highest degree of variation (CV 59.16%). The average tannin content was 6.07 $mg \cdot g^{-1}$, with a range of 4.69 $mg \cdot g^{-1}$ (No.104) to 9.23 $mg \cdot g^{-1}$ (No.29).

3.3. Composition of Fatty Acid of Different Varieties

All 10 varieties showed dominant unsaturated fatty acid content (Table 3), with an average of 91.82%, ranging from 91.50% (No.20 and No.29) to 92.58% (No.34), showing high significant difference among all varieties. The average content of monounsaturated fatty acid was 71.26%, ranging from 67.10% to 76.63%, with the highest No.1 and the lowest No.104, and the difference among the varieties was high significant. Oleic acid was the major monounsaturated fatty acid, with an average content of 70.02%, ranging from 66.85% (No.104) to 76.33% (No.1), with extremely significant difference among the 10 varieties. The second was cis-11-docosenoic acid, with an average content of only 0.25% and a range of 0.20~0.30%, with no-significant difference among all varieties. The average content of polyunsaturated fatty acids was 20.56%, ranging from 15.33% (No.1) to 24.75% (No.104), with high significant difference among the varieties. Linoleic acid was the most predominant polyunsaturated fatty acid, with an average content of 19.58%, ranging from 14.57% (No.104) to 23.65% (No.1). Followed by linolenic acid with an average content of 0.97%, ranging from 0.77% (No.1) to 1.17% (No.11). Both linoleic acid and linolenic acid showed high significant difference among the varieties.

Table 2. Nutritional composition and content of kernels of 10 pecan varieties and some common oil crops.

Composition	Crude Fat (%)	Protein (mg·g^{-1})	Soluble Sugar (mg·g^{-1})	Tannin (mg·g^{-1})
104	71.77 ± 2.02 ^{A}	54.30 ± 0. 60 ^{B}	10.7 ± 1.30 ^{B}	9.23 ± 0.75 ^{A}
11	67.44 ± 3.05 ^{A}	80.03 ± 5.67 ^{A}	11.8 ± 0.05 ^{B}	5.51 ± 0.09 ^{C}
1	69.87 ± 1.17 ^{A}	54.80 ± 6.20 ^{B}	5.6 ± 0.05 ^{C}	5.33 ± 0.30 ^{C}
20	70.27 ± 1.56 ^{A}	84.33 ± 6.33 ^{A}	10.7 ± 0.17 ^{B}	5.01 ± 0.52 ^{CD}
21	68.27 ± 3.75 ^{A}	83.70 ± 13.52 ^{A}	9.7 ± 0.08 ^{BC}	4.69 ± 0.40 ^{CD}
28	72.88 ± 1.41 ^{A}	56.40 ± 1.51 ^{B}	5.9 ± 0.13 ^{C}	7.92 ± 0.79 ^{B}
29	69.33 ± 6.40 ^{A}	53.33 ± 3.17 ^{B}	6.0 ± 0.05 ^{C}	3.81 ± 0.52 ^{D}
32	72.99 ± 0.91 ^{A}	60.13 ± 13.09 ^{B}	9.2 ± 0.29 ^{BC}	7.45 ± 0.51 ^{B}
34	69.42 ± 0.50 ^{A}	79.95 ± 1.05 ^{A}	9.6 ± 0.21 ^{BC}	5.04 ± 0.12 ^{CD}
35	67.83 ± 4.94 ^{A}	68.00 ± 3.80 ^{AB}	27.4 ± 0.41 ^{A}	6.70 ± 0.16 ^{B}
Average	70.01	67.5	10.7	6.07
CV(%)	2.84	19.58	59.16	27.86
F-valued	1.14	10.80 **	36.12 **	33.72 **
Camellia oleifera [1]	53.71	64.5	4.2	-
Olive [2]	Oil percentage: 14.25%	2.25	-	-
Walnut [3]	68.83	155	22.9	-
Peanut [4]	55.4	242	29.3	-
Soybean [5]	21.5	449	50.6	-

The nutritional composition and content of all crops were derived from their kernel. [1] Zhang et al., Shi et al. [28,29], [2] Deng et al. [30], [3] Li [31], [4] Xu [32], [5] Zhang [33]. Letters A, B, C, D indicate statistically significant differences at the $P_{0.01}$ level for the same column of data. ** indicates highly significant differences.

The average content of saturated fatty acids was 8.17%, ranging from 7.45% (No.34) to 8.57% (No.29), with significant difference among the varieties. Palmitic acid was the main saturated fatty acid with an average content of 5.73%, followed by stearic acid with an average content of 2.38% and arachidic acid with an average content of 0.05%, all of which showed extremely significant difference among all varieties. Overall, the order of fatty acid components contents of the 10 varieties was as oleic acid > linoleic acid > palmitic acid > stearic acid > linolenic acid > cis-11-docosenoic acid > arachidic acid, and unsaturated fatty acid were 11.24 times more than saturated fatty acids.

Table 3. Fatty acids composition and content of kernels of 10 pecan varieties and some common oil crops.

Composition (%)	PA (C16:0)	SA (C18:0)	AA (C20:0)	OA (C18:1)	LA (C18:2)	LNA (C18:3)	Cis-11-Eicosenoic Acid (C20:1)	MFA	PFA	UFA	SFA
104	5.85 ± 0.15 ^{AB}	2.25 ± 0.35 ^{BC}	-	66.85 ± 1.65 ^{D}	23.65 ± 1.75 ^{A}	1.10 ± 0.10 ^{AB}	0.25 ± 0.05 ^{A}	67.10 ± 1.60 ^{C}	24.75 ± 1.85 ^{A}	91.85 ± 0.25 ^{AB}	8.10 ± 0.20 ^{AB}
11	5.87 ± 0.23 ^{AB}	2.40 ± 0.20 ^{ABC}	0.10 ± 0.00 ^{A}	66.97 ± 0.38 ^{D}	23.23 ± 0.21 ^{A}	1.17 ± 0.06 ^{A}	0.20 ± 0.00 ^{A}	67.17 ± 0.38 ^{C}	24.40 ± 0.20 ^{A}	91.57 ± 0.25 ^{B}	8.37 ± 0.31 ^{A}
1	5.60 ± 0.20 ^{ABC}	2.43 ± 0.15 ^{ABC}	0.07 ± 0.06 ^{AB}	76.33 ± 0.55 ^{A}	14.57 ± 0.51 ^{C}	0.77 ± 0.06 ^{D}	0.30 ± 0.00 ^{A}	76.63 ± 0.55 ^{A}	15.33 ± 0.47 ^{C}	91.97 ± 0.38 ^{AB}	8.10 ± 0.35 ^{AB}
20	5.93 ± 0.06 ^{AB}	2.43 ± 0.06 ^{ABC}	0.10 ± 0.00 ^{A}	68.40 ± 2.92 ^{CD}	21.73 ± 2.84 ^{AB}	1.10 ± 0.17 ^{AB}	0.27 ± 0.06 ^{A}	68.67 ± 2.87 ^{BC}	22.83 ± 2.97 ^{AB}	91.50 ± 0.10 ^{B}	8.47 ± 0.06 ^{A}
21	5.60 ± 0.20 ^{ABC}	2.27 ± 0.15 ^{BC}	0.10 ± 0.00 ^{A}	69.77 ± 1.25 ^{BCD}	20.87 ± 1.27 ^{AB}	1.10 ± 0.10 ^{AB}	0.20 ± 0.00 ^{A}	69.97 ± 1.25 ^{BC}	21.97 ± 1.23 ^{AB}	91.94 ± 0.32 ^{AB}	7.97 ± 0.32 ^{AB}
28	5.77 ± 0.23 ^{AB}	2.60 ± 0.17 ^{AB}	0.07 ± 0.06 ^{AB}	73.27 ± 3.65 ^{ABC}	17.27 ± 3.37 ^{BC}	0.80 ± 0.10 ^{D}	0.23 ± 0.06 ^{A}	73.50 ± 3.67 ^{AB}	18.07 ± 3.46 ^{BC}	91.57 ± 0.25 ^{B}	8.43 ± 0.23 ^{A}
29	6.07 ± 0.15 ^{A}	2.50 ± 0.17 ^{ABC}	-	72.27 ± 0.91 ^{ABC}	18.07 ± 0.84 ^{BC}	0.87 ± 0.06 ^{CD}	0.30 ± 0.00 ^{A}	72.57 ± 0.91 ^{AB}	18.93 ± 0.81 ^{BC}	91.50 ± 0.17 ^{B}	8.57 ± 0.21 ^{A}
32	6.00 ± 0.35 ^{AB}	2.10 ± 0.00 ^{BC}	-	69.37 ± 1.96 ^{CD}	21.40 ± 2.00 ^{AB}	0.93 ± 0.06 $^{BC D}$	0.27 ± 0.06 ^{A}	69.63 ± 2.00 ^{BC}	22.33 ± 2.04 ^{AB}	91.96 ± 0.29 ^{AB}	8.10 ± 0.35 ^{AB}
34	5.45 ± 0.25 ^{BC}	2.00 ± 0.10 ^{C}	-	72.30 ± 0.20 ^{ABC}	19.00 ± 0.50 ^{ABC}	1.05 ± 0.05 ^{ABC}	0.23 ± 0.06 ^{A}	72.53 ± 0.15 ^{AB}	20.05 ± 0.55 ^{ABC}	92.58 ± 0.40 ^{A}	7.45 ± 0.35 ^{B}
35	5.15 ± 0.15 ^{C}	2.85 ± 0.35 ^{A}	0.10 ± 0.00 ^{A}	74.65 ± 2.25 ^{AB}	16.05 ± 1.65 ^{C}	0.85 ± 0.05 ^{CD}	0.20 ± 0.00 ^{A}	74.85 ± 2.25 ^{A}	16.90 ± 1.70 ^{C}	91.75 ± 0.55 ^{AB}	8.10 ± 0.50 ^{AB}
Average	5.73	2.38	0.05	70.02	19.58	0.97	0.25	71.26	20.56	91.82	8.17
CV(%)	4.91	10.3	89.36	4.57	15.7	15.02	15.73	4.56	15.6	0.36	3.94
F-valued	5.23 **	4.89 **	9.68 **	8.24 **	8.35 **	8.74 **	2.95 *	8.27 **	8.55 **	2.98 **	3.10 *
Camellia oleifera [1]	11.92	2.95	-	83.19	0.08	0.45	-	84.43	0.53	84.96	15.04
Olive [1]	13.5	4.46	-	72.71	6.07	0.72	-	74.54	6.79	81.33	18.66
Walnut [2]	6.23	2.57	-	23.39	51.34	9.89	-	23.65	65.58	89.95	10.05
Peanut [1]	12.6	5.14	-	42.24	31.37	0.11	-	43.42	31.48	74.9	25.09
Soybean [1]	12.45	4.91	-	26.38	47.4	6.95	-	26.82	54.35	81.17	18.82
Canola [1]	4.82	2.1	-	48.68	17.92	8.67	-	64.82	26.78	91.6	8.4

PA—Palmitic acid; SA—Stearic acid; AA—Arachidic acid; OA—Oleic acid; LA—Linoleic acid; LNA—Linolenic acid; MFA—Monounsaturated fatty acid; PFA—Polyunsaturated fatty acid; UFA—Unsaturated fatty acid; SFA—Saturated fatty acid. [1] Liu et al. [34], [2] Zheng et al. [35]. Letters A, B, C, D indicate statistically significant differences at the $P_{0.01}$ level for the same column of data. ** indicates highly significant differences, * indicates significant differences.

4. Discussion

4.1. Comparison and Screening among 10 Varieties

At present, there are few cultivars suitable for cultivation in China, which is one of the factors that restrict the development of pecan planting. The 10 varieties in this study showed little variation in crude fat content, did not differ significantly from each other and did not change significantly compared to the results of previous studies [22], which demonstrated a high degree of stability over time and geography, and they could be used as varieties for edible oil production, particularly No.32, No.28, No.104 and No.20. A combined analysis of kernel percentage and fat content revealed that No.28 had the highest oil percentage (40.32%), followed by No.104 (38.99%) and No.34 (38.59%), which are the most suitable cultivars for efficient production of edible oil. The monounsaturated fatty acid content of No.1, No.35, No.28, No.34 and No.29 exceeded the average of the 10 varieties (71.26%). Among them, No.1 has the highest oleic acid content (76.33%), which is close to *Camellia oleifera* seed oil and higher than olive oil, with better oil quality and stability, and can be exploited as a variety for the production of high-quality edible oil. All indicators except crude fat differed significantly among the 10 varieties, which demonstrated the genetic diversity of the germplasm and provided a basis for the evaluation and selection of multiple target varieties of pecan. Among them, No.104 and No.28 were extremely significantly higher in green-fruit weight, nut percentage and kernel percentage than the other varieties and were large-fruited varieties. In terms of the nut market, the large-fruited types are more popular with consumers, so they can also be used as cultivars for nut production. Although tannin has high application in the food industry [36], it can make the kernels astringent, and tannin is the main substance affecting the taste, as is soluble sugar. Due to the high soluble sugar content and low tannin content of No.21, No.20 and No.34 in this study, they can be considered for exploitation as unprocessed food varieties.

4.2. Fatty Acid Composition and Evaluation for Edible Oil

The fatty acid composition of pecan kernels was mainly oleic acid and linoleic acid, followed by palmitic acid, stearic acid, linolenic acid, and with traces of cis-11-docosenoic acid and arachidic acid. The oleic acid with average content of 70.02% (from 66.85% to 76.33%) is the main monounsaturated fatty acid, comparable to olive oil (72.71%), lower than *Camellia oleifera* seed oil (83.19%), much higher than peanut oil (42.24%) and canola oil (48.68%), 2.99 times higher than walnut oil (23.39%) and 2.65 times higher than soybean oil (26.38%). Feng evaluated the effects of unsaturated fatty acid on the immune status of mice using three edible oils (*Camellia oleifera* seed oil, corn oil and fish oil), which were found to have greater benefits on the immune system due to the higher oleic acid content in *Camellia oleifera* seed oil [37]. Oleic acid was also effective in improving hyperlipidemia [38], limiting the development of coronary heart disease [39] and helping to prevent cardiovascular disease, cancer, hypertension and autoimmune disorders [40]. Linoleic acid is the major polyunsaturated fatty acid with an average content of 19.58%, ranging from 14.57% to 23.65%, much higher than *Camellia oleifera* seed oil (0.08%), olive oil (6.07%) and canola oil (17.92%), and lower than walnut oil (51.34%), soybean oil (47.40%) and peanut oil (31.37%). As a "vascular scavenger", linoleic acid can lower serum cholesterol levels, inhibit the formation of arterial thrombosis; prevent and fight cancer; participate in the control of cardiovascular disease, immune regulation, cell growth and apoptosis in humans [41–43]; and can also be used as a pharmaceutical ingredient to treat seborrhea and acne, which can effectively improve skin conditions [44]. In addition, Rodrigues found that linoleic acid had a significant inhibitory effect on inflammation [45]. The average content of linolenic acid was 0.97%, ranging from 0.77% to 1.17%, higher than peanut oil (0.11%), *Camellia oleifera* seed oil (0.45%) and olive oil (0.72%), and lower than walnut oil (9.89%), canola oil (8.67%) and soybean oil (6.95%). Zou studied the pecan nut and found that α-linolenic acid is the main component of linolenic acid [46], α-linolenic acid is one of the omega-3 polyunsaturated fatty acid, which is closely related to human growth and development [47], and has a role in the prevention of diabetes [48] and inhibition of tumor growth [49]. In addition, the ratio balance between omega-3 and omega-6 has been studied by some scholars [50,51] and were found to be strongly associated with cardiovascular disease, depression in pregnancy and breast cancer [52–54]. As one of the omega-6 unsaturated fatty acid, linoleic acid can be transformed into α-linolenic acid in plants, but the two cannot be converted to each other in animals, and the body cannot synthesize them on its own, so they are both essential fatty acids for the human body.

The content of each fatty acid component varied significantly, not only between the 10 pecan varieties, but also between species. The fatty acid composition and content are essential indicators for the selection of edible oil varieties, and the differences in fatty acid content suggest that pecan oil has the potential to become a specialty edible oil. The average unsaturated fatty acid content of pecan oil was 91.8%, dominating the fatty acids, which is the same conclusion as that of Zhang [9]. It was higher than that of *Camellia oleifera* seed oil (84.96%), olive oil (81.33%), peanut oil (74.90%) and soybean oil (81.17%), and comparable to that of walnut oil (89.95%) and canola oil (91.60%). The average monounsaturated fatty acid content of 71.26% is comparable to that of olive oil (74.54%), lower than *Camellia oleifera* seed oil (84.43%) and higher than peanut oil (43.42%) and canola oil (64.82%), while being 3.01 times higher than that of walnut oil (23.65%) and 2.66 times higher than that of soybean oil (26.82%). The average polyunsaturated fatty acid content is 20.56%, much higher than that of *Camellia oleifera* seed oil (0.53%) and olive oil (6.79%), lower than that of walnut oil (65.58%), soybean oil (54.35%), peanut oil (31.48%) and canola oil (26.78), and only about one-third that of walnut oil. Of these, No.35 and No.34 have the same level of oleic acid compared to olive oil, while their unsaturated fatty acid content is higher than that of olive oil due to the greater difference in linoleic acid content.

The quality of edible oil depends mainly on the composition of fatty acid. It can be seen that the pecan oil is one of the best healthy edible oils with high-quality characteristics of "low saturated fatty acids and high unsaturated fatty acids", especially with the high oleic acid level. Edible oils with a high proportion of polyunsaturated fatty acid are not storable due to their susceptibility to oxidation [55]. Compared to walnut oil, peanut oil, soybean oil and canola oil, pecan oil has a lower polyunsaturated fatty acid content and a more stable oil profile. The polyunsaturated fatty acid content of pecan oil is higher than that of *Camellia oleifera* seed oil and olive oil, making it relatively richer in nutritional value. Wu measured the antioxidant properties of common foods and vegetables in the United States and showed that pecans are one of the strongest foods in terms of antioxidant activity [56]. In addition, the blended oils with more nutritious value and stability, made in certain proportions according to the different edible oils, are favored by the public and have more market prospect [57]. Pecan oil, with monounsaturated fatty acid as the main component, has the potential to be utilized in blending with soybean oil (or walnut oil), which are high in linoleic acid and linolenic acid, in certain proportions to produce "high stability, high quality" blended oils; Su came to a similar conclusion [21].

4.3. Potential Productivity of Pecan

The development of pecan in China is relatively slow. In recent years, the yield of pecan is less than 200 $t \cdot A^{-1}$, but the cultivation area has a trend of accelerating expansion. At present, the cultivation area in China is about 66,700 ha. In this study, the average kernel percentage of the 10 pecan varieties was 50.5%, much less than the value reported by Cruz-Alvarezet [58]. The crude fat content of kernel averaged 70.01%, approximately equal to Yu's 62.53~70.95% [59]. According to kernel percentage and crude fat content, the oil percentage of nut could reach 35.4% (from 31.57% of No.11 to 40.32% of No.28), which was 2.48 times higher than that of olive's 14.25%. It means that less than three kilograms of pecan nuts are required to produce one kilogram of oil. Shi and Liu reported that the kernel percentage of *Camellia oleifera* was 67.8% and kernel crude fat was 53.7%, and the consequent oil percentage was the same as that of pecan approximately. The crude fat content of pecan kernels was the highest compared to other oil crops, comparable to walnuts (68.83%), and higher than *Camellia oleifera* kernels (53.71%), peanuts kernels (55.40%), and soybeans (21.50%). The protein content of the 10 varieties averaged 67.50 mg·g^{-1}, which was equivalent to the 64.50 mg·g^{-1} of *Camellia oleifera*, with the highest protein content (No.20) being 1.31 times higher than that of *Camellia oleifera* and 30.00 times higher than that of olive (2.25 mg·g^{-1}), but much lower than that of soybeans (44.90%), peanuts (24.20%) and walnuts (15.50%). The soluble sugar content of the 10 varieties averaged 1.07%, which was higher than 0.42% of *Camellia oleifera*, but lower than 2.29% of walnut and 2.93% of peanut, and only 21.1% of 50.6 mg·g^{-1} of soybeans.

Based on an average of 20 kg of per-plant of nuts harvested in 2018 from the 10 varieties sampled in this experiment, the yield per pecan plant could produce approximately 7.07 kg crude fat, 0.68 kg protein, and 0.11 kg soluble sugars, respectively, which could be converted to 1060 kg·ha^{-1} crude fat, 102 kg·ha^{-1} protein, and 16.30 kg·ha^{-1} soluble sugars. Although soybeans and peanuts have a higher oilseed yield per unit area than pecans, their potential productivity of fat is much lower than pecans, and their occupation of arable land can have a negative impact on cereal production. Moreover, pecan wood is of good quality [60] and sells for USD900·m^3 in the international market, while other oil crops do not have this advantage.

From this study, pecan is no less prospective a crop with high productivity of edible oil. China's topography is diverse, with a vast mountainous area of about 4.3 million km^2 of mountains and hills, and insufficient arable land resources. This is exactly the advantage for forestry to develop woody oil crops, such as pecan. If 1% of the area of mountains and hills is planted with pecans, about 13.0 million tons of nuts, 4.60 million tons of fat and 0.443 million tons of protein can be harvested annually, which can meet 13.10% of the domestic edible oil consumption (in 2018) and reduce foreign dependence by 17.26%, and to some extent make up for the gap of edible oil in China. The production potential in the rest of the world should be comparable. If about 5.02% of the hilly mountainous land, the pecan could fill up our entire edible oil consumption gap in China.

5. Conclusions

Pecan is a promising woody oil tree that not only has good potential for edible oil exploitation, but also has a large production capacity benefit. The 10 pecan varieties in this study have stable nutritional traits and can be put into production with good returns. As their nut oil percentage can reach 35.36%, they are also a good resource for producing edible oil, which can provide a potential opportunity to effectively alleviate the shortage of edible oil in China. Pecan oil has a high oleic acid content and is characterized by "low saturated fatty acids and high unsaturated fatty acids". Among the 10 varieties, No.104, No.28 and No.34 have a higher oil percentage and can be used as cultivars that can produce high yields of edible oil. Compared to olive oil, No.35 has comparable oleic acid and much higher linoleic acid, which gives it more quality advantages and can be developed as a high-quality edible oil resource.

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