Characterization of Chionanthus retusus fruits: contents and composition of oil, fatty acids, phytosterols, and tocopherols

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Abstract

Chionanthus retusus is a deciduous shrub or small tree in the *Oleaceae* with important ornamental and economic value. In this study, fruits were collected from 22 individual *C. retusus* plants to study their morphological characteristics, oil content, and the contents and composition of fatty acids, phytosterols, and tocopherol. The average fruit fresh biomass, grain dry biomass, kernel dry biomass, and kernel percentage were 76.432 ± 20.75 g, 24.370 ± 6.52 g, 12.122 ± 3.21 g, and 50.16%, respectively. The average oil content of the kernels was 36.55%, ranging between 28.90% and 47.50%.The average total phytosterols content was 280.33 ± 43.96 mg/100 g. The average total tocopherols content was 578.31 ± 101.29 µg/g. In correlation analyses, the oil content was negatively correlated with the total phytosterols content ($r = -0.653$, $P < 0.01$) and positively correlated with kernel weight ($r = 0.762$, $P < 0.01$). In principal component analyses, the first two principal components explained 77.1%,72.2%, and 91.2% of the total variance of fatty acid, phytosterol, and tocopherol composition, respectively. These results allowed us to identify germplasm resources with high oil yield, high oleic acid content, high phytosterol content, and high tocopherol content.

Introduction

Chionanthus retusus is a deciduous shrub or small tree in the *Oleaceae* family. *C. retusus* is widely distributed in East Asia, and is an excellent landscaping tree species. It is resistant to saline, alkaline, and low-nutrient soils, and shows strong adaptability. Because this species produces a variety of bioactive compounds such as flavonoids, it also has a high practical value. Previous reports have elucidated the chemical components of *C. retusus* flowers and leaves[1, 2]. *C. retusus* flowers contain flavonoids and lignans that have significant therapeutic effects against a range of inflammatory and neurological diseases [3]. The buds, leaves, roots, and bark of *C. retusus* contain glycosides, coumarins, and polysaccharides that have important medicinal value. Thus, this plant is recognized as a medicinal plant [4]. Because the flowers, leaves, and fruits of *C. retusus* contain phenols and other compounds with antioxidant activity, they can effectively remove free radicals. Extracts from this plant are used as a functional ingredient in foods. Most previous studies on the chemical components of tassels have focused on the flowers and leaves, while little is known about the components of the seeds. Chien (2004) studied changes in the contents of volatile components and nutrients in seeds during germination [5], but no previous studies have explored changes in the secondary metabolite contents and composition in the seeds of *C. retusus*. In this study, the contents and composition of fatty acids, phytosterols, and tocopherols (tocopherols) in oil extracted from *C. retusus* kernels were determined to establish whether *C. retusus* has potential as an oil crop.

Plant oils contain a variety of fatty acids, most of which are unsaturated fatty acids, therefore, compared with animal fats, plant oils are better for human health. Unsaturated fatty acids include oleic acid, linoleic acid, and linolenic acid, with the latter two produced only by plants. Because they cannot synthesized by the human body and must be obtained from the diet, they are known as essential fatty acids [6, 7]. Unsaturated fatty acids play a very important role in human physiological processes and are essential nutrients for growth [8]. Studies have shown that many unsaturated fatty acids can reduce cholesterol, regulate blood lipids, reduce blood viscosity, and improve immunity [9]. Oleic acid can reduce the amount of total cholesterol and low-density cholesterol (harmful cholesterol) in human blood to a certain extent, while maintaining the levels of high-density cholesterol (beneficial cholesterol), which is conducive to reducing blood lipid levels. Thus, it can effectively prevent or ameliorate cardiovascular and cerebrovascular diseases [10, 11]. Linolenic acid, eicosapentaenoic acid, and docosahexaenoic acid can improve the activity of brain cells and play a role in the development of retina and nerve tissue [12, 13]. Unsaturated fatty acids such as linoleic acid and linolenic acid can also enhance human immune function, reduce the production of proinflammatory factors, prevent infarction, and inhibit allergic reactions [14–21].

Phytosterols are plant metabolites in the triterpene family, with a structure similar to that of cholesterol. They are essential biomolecules for human health that must be obtained from food [22–24]. Vegetable oils and cereals are the best natural sources of dietary phytosterols [25]. Phytosterols have been shown to reduce the incidence of cardiovascular disease through effectively reducing cholesterol absorption [26, 27]. They also have anti-inflammatory and anticarcinogenic properties [28, 29]. Tocopherols is a fat-soluble compound that is important for human health. It cannot be synthesized by humans and animals, so it must be obtained from the diet [30]. Among several natural types of tocopherols, α-tocopherol has the highest absorption and metabolism efficiency in the human body, while γ-tocopherol has the strongest antioxidant capacity [31]. Tocopherols can reduce the incidence of cancer, cardiovascular disease, coronary heart disease, nervous system disease, and lung disorders [32–34]. It can also delay human aging and protect against ultraviolet radiation [35–37].

C. retusus is used as a traditional Chinese medicine to treat inflammation and heatstroke[1]. Although *C. retusus* contains a variety of phytochemicals, there are few reports on these compounds in its seeds. Therefore, it is necessary to comprehensively analyze the seeds of different *C. retusus* accessions to determine their contents and composition of fatty acids, phytosterols, and tocopherols. In this work, we assessed the variability of berry morphology, oil content, and fatty acids, phytosterols, and tocopherols contents and composition among different *C. retusus* accessions. The relationships among berry morphology, fatty acid composition, and contents of oil, phytosterols, and tocopherols in the seed kernels of *C. retusus* accessions were analyzed. The results will facilitate the selection of high-quality edible oil varieties of *C. retusus* to promote an oil industry based on this species in China.

Materials And Methods

Plant materials

Shandong Province is the main distribution area of ancient *C. retusus* trees in China. Therefore 22 superior and ancient trees of *C. retusus* with high yield and vigorous growth were selected for these analyses. The trees were growing in the cities of Anqiu, Yinyuan, Qingzhou, Tai'an, and Zibo in Shandong Province (Table A1, Appendix A). In late August 2020, approximately 2 kg mature fruits were collected from each grafted accession. The fruits were picked randomly from different infructescences in the crown to ensure that the samples were representative. First, the fruit morphology parameters were measured (fresh weight, transverse diameter, and longitudinal diameter), and then the pulp was removed and seeds of each accession were dried to constant weight at 65 °C.

Grain morphology

For measurements of morphological parameters, 300 undamaged fruits were randomly selected from each *C. retusus* accession. The fresh weight of fruit was determined as the weight of 100 seeds, accurate to 0.001 g. This measurement was repeated three times. After removing the pulp from the fruit, the grains were dried at 65 °C and the weight of 100 grains was determined, accurate to 0.001 g. This measurement was repeated three times. The kernels were then removed from the seeds, and the weight of the kernels and seed shells were separately determined for 100 grains, accurate to 0.001 g. This measurement was repeated three times. The fruit characters (fruit vertical diameter, FVD; fruit transverse diameter, FTD; fruit shape index, FSI) and the kernel characters (grain vertical diameter, GVD; grain transverse diameter, GTD; shell thickness, ST) were measured to the nearest 0.001 mm. Fruit shape index(FSI) is the ratio of fruit vertical diameter(FVD) to fruit transverse diameter(FTD). Kernel percentage (Kp) was calculated as the ratio of kernel dry biomass to grain dry biomass. The values of the grain morphological traits are reported as mean ± standard deviation.

Oil extraction

Oil was extracted using the Soxhlet method according to the Chinese National Standard (GB, 5009.6–,2016). For each *C. retusus* accession, approximately 5 g kernels was crushed into a powder and then subjected to Soxhlet extraction using petroleum ether (boiling point 30–60 °C) as the solvent at 60 °C for 8–10 h. After solvent evaporation, the flask containing oil was dried at 105 °C, cooled in a desiccator, and reweighed. Oil extraction was conducted in triplicate, and the data are reported as mean ± standard deviation.

Fatty acid determination

Fatty acid composition was determined by gas chromatography (GC) according to the Chinese National Standard (GB, 5009.168–, 2016). Saponification of fat and methyl esterification of fatty acids was conducted by adding 8 mL 2% sodium hydroxide methanol solution to the fat extract. The mixture was refluxed in a water bath at 80 °C until the oil droplets disappeared; then, 7 mL 15% boron trifluoride methanol solution was added and the mixture was refluxed for 2 min. It was then rapidly cooled to room temperature; 10–30 mL n-heptane was added, and the mixture was shaken for 2 min. Saturated sodium chloride solution was added, followed by static layering. Then, 3–5 g of anhydrous sodium sulfate was added to approximately 5 mL of the n-heptane extraction supernatant solution. The mixture was shaken for 1 min, followed by static layering for 5 min. Finally, the upper layer of the solution was transferred into an injection vial for determination. The fatty acid methyl esters obtained from each *C. retusus* oil sample were analyzed using an Agilent 7890B gas chromatograph (GC) (Agilent Technologies, Little Falls, DE, USA) fitted with a flame ionization detector and equipped with a DM-2560 capillary column (100 m × 0.25 mm i.d., 0.2 μm film thickness). The injector and detector were programmed at 100 °C, increasing at 10 °C min^{-1} to 180 °C, then at 1 °C min^{-1} to 200 °C, and then at 4 °C min^{-1} to 230 °C for 10.5 min. The flow rate of the carrier gas (nitrogen) was 1.0 mL min^{-1} and the split ratio was 1:100. Fatty acids were identified by comparing retention times with those of standard samples (Supelco 37 FAME mix, Supelco, Bellefonte, PA, USA) and their percentage was calculated according to the area of each peak. Each determination was run in triplicate. Data are reported as the mean ± standard deviation.

Phytosterols determination

Phytosterols were determined using a GC according to the Chinese National Standard (GB/T 25223, 1999). The oil sample was saponified with ethanolic potassium hydroxide solution. The unsaponifiable sterol fraction was separated by thin-layer chromatography on a sheet of aluminum foil coated with a thin layer of alumina. Separation and quantification of the silanized sterol fraction were carried out by capillary GC on an Agilent 7890B (Agilent Technologies) instrument equipped with an SE-45 capillary column (length, 50 m; i.d.,0.25 mm; film thickness, 0.1 μm). The working conditions were as follows: injector at 320 °C; initial column temperature at 240 °C, increasing at 4 °C min−1 to 255 °C; sample injection volume, 1 μL; flow rate, 36 cm/s; split ratio 1:20; carrier gas, hydrogen. Phytosterols were identified by comparing retention times with those of standard samples (Betulin, Supelco). These analyses were conducted in triplicate. Data are reported as the mean ± standard deviation.

Tocopherols determination

The contents and composition of tocopherols were determined using a GC according to the Chinese National Standard (GB/T5009, 82-2016). Each *C. retusus* kernel sample was ground into a powder, then 0.2 g was placed in a test tube before adding 0.05 g vitamin C and 4 mL 80% ethanol solution. The mixture was shaken and mixed thoroughly, then subjected to ultrasonic treatment in a low-temperature water bath for 30 min before adding 8 mL n-hexane solution. The mixture was then centrifuged and the supernatant was passed through a 0.22-μM organic phase filter membrane. Tocopherols were identified by comparing retention times with those of standard samples (Betulin, Supelco). Each determination was run in triplicate. Data are reported as the mean ± standard deviation.

2.7 Statistical analyses

Data for fruit characters, kernel characters, yield, Kp, contents of oil, sterols, and tocopherols, and fatty acid and sterols composition were subjected to analysis of variance followed by Tukey's honestly significant difference test using IBM SPSS 19.0 software (IBM Corp., Armonk, NY, USA). Spearman's correlation coefficients were calculated to detect relationships among grain morphological characters, fatty acid composition, and oil, phytosterols, and tocopherols contents. Principal component analysis (PCA) was performed using SAS 9.2 software (SAS Institute, Cary, NC, USA).

Results And Discussion

Fruit morphological diversity

The use of morphological characteristics as phenotypic indicators is important for estimating phenotypic diversity and selecting clonal varieties [38, 39]. The data for fruit characters (fresh weight, FVD, FTD, FSI), kernel characters (grain dry weight, GVD, GTD, ST, GVD/ST), and yield (kernel dry weight, kernel shell dry weight) are summarized in Table 1. The values of morphological characters differed significantly among the 22 *C. retusus* accessions ($P < 0.05$). The mean value for fruit fresh biomass was 76.432 ± 20.75 g, ranging from 49.240 ± 0.94 g (B-1) to 121.303 ± 7.51 g (T-8) with a coefficient of variation (CV) of 27.15%. The mean value of grain dry biomass was 24.370 ± 6.52 g, ranging from 10.085 ± 0.94 g (WS-2) to 36.067±0.98 g (T-8) with a CV of 26.75%. The mean value of kernel dry biomass was 12.122 ± 3.21 g, ranging from 7.751 ± 0.54 g (WS-2) to 16.665 ± 1.80 g (T-8) with a CV of 26.52%. The mean values of FVD, FTD, GVD, and GTD were 12.462 ± 1.39 mm, 9.742 ± 1.04 mm, 10.732 ± 1.51 mm, and 6.831 ± 0.65 mm, respectively. *C. retusus* kernels contain oil and important metabolites, and they are the main organ used by the processing industry. Therefore, Kp is a major economic indicator. The average value for Kp was 50.16%, ranging from 39.90% to 62.59% (Fig. 1). The maximum Kp was in T-2 (62.59%), and this value was significantly higher than those in other accessions ($P < 0.05$).

Oil contents and fatty acid composition

We analyzed the oil content in the kernels of 22 *C. retusus* accessions (Table 2). The mean oil content in the kernels of 22 *C. retusus* accessions was 36.55% ± 5.78%, with a range from 28.3% ± 0.35% (S-3) to 47.5% ± 0.67% (WS-5) and a CV of 15.81% (Table 2). The accession WS-5 had the highest oil content (47.5% ± 0.67%) and S-3 had the lowest (28.3% ± 0.35%), which was not significantly different from those of B-1 (28.9% ± 0.58%), WA-1 (29.0% ± 0.45%), and S-2 (29.2% ± 0.38%) (Table 2). These differences in oil content may be due to variations among accessions and differences in their genetic background [40].

Fatty acid composition is an important index of oil quality. Analyses of the fatty acid composition of vegetable oil from 22 *C. retusus* kernels revealed seven main fatty acid constituents (Table 2). The most abundant fatty acid was oleic acid (C18:1), accounting for 49.53% ± 0.06% to 59.67% ± 0.15% of total fatty acids (average, 52.33% ± 3.22%); followed by linoleic acid (C18:2) (range, 27.00% ± 0.80% to 34.80% ± 0.51%; average, 31.31% ± 3.28%); palmitic acid (C16:0) (range, 3.41% ± 0.02% to 5.09% ± 0.02%; average, 4.30% ± 0.49%); stearic acid (C18:0) (range, 1.45% ± 0.01% to 2.88% ± 0.01%; average, 2.12% ± 0.39%); linolenic acid (C18:3) (range, 0.34% ± 0.03% to 0.51% ± 0.05%; average 0.42% ± 0.05%); arachidonic acid (C20:1) (range, 0.26% ± 0.03% to 0.40% ± 0.04%; average, 0.36% ± 0.08%); and arachidic acid (C20:0) (range, 0.12% ± 0.03% to 0.21% ± 0.04%; average, 0.15% ± 0.03%). Notably, arachidonic acid (C20:0) was only detected in the WA, WS, and S accessions. Compared with saturated fatty acids, unsaturated fatty acids are better for human health. Therefore, the content of unsaturated fatty acids is often used as a quality standard for vegetable oil [21]. According to the number of double bonds in the molecule, fatty acids can be categorized into three groups: saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA) The mean value for SFA was 6.49% ± 0.78%, ranging from 5.13% ± 0.06% (S-6) to 7.64% ± 0.20% (B-1) with a CV of 12.02%. The mean value for MUFA was 52.33% ± 3.23%, ranging from 49.87% ± 0.11% (S-3) to 60.00% ± 0.18% (Z-5) with a CV of 6.17%. The mean value for PUFA was 31.88% ± 3.26%, ranging from 27.39% ± 0.83% (S-6) to 35.14±0.53% (WS-3) with a CV of 10.22% (Table 2). Thus, the main component of vegetable oil from *C. retusus* kernels was unsaturated fatty acids, accounting for 80.55% ± 0.43% to 91.84% ± 0.29%. These findings indicate that *C. retusus* has potential as a high-quality oil crop.

Individual fatty acids have their own specific properties, and they can alter metabolism, gene expression, responsiveness to hormones, and patterns of secondary metabolite production [19]. Unsaturated fatty acids play an important role in human body. They can reduce cholesterol, regulate blood lipids, and enhance immunity [9]. The unsaturated fatty acids content is one of the important indexes for woody oil crops. In fact, the main goal for peanut breeding is to produce varieties with high levels of oleic acid [41]. In this study, the average proportion of unsaturated fatty acids in oil from kernels of *C. retusus* was 88.51%, which is equivalent to the content of unsaturated fatty acids in oils from common woody oil crops such as olive (89.72%), *Camellia oleifera* (83.48%), and *Acer truncatum* (91.71%) [42-44]. Our analyses indicate that the main unsaturated fatty acid in *C. retusus* kernels is oleic acid (55.17% of total fatty acids). Thus, *C. retusus* is a woody oil crop with a high oleic acid content. Oleic acid is the most important unsaturated fatty acid. It is a monounsaturated fatty acid that can reduce cholesterol levels in serum, thereby ameliorating or preventing cardiovascular and cerebrovascular diseases [45, 46]. Oleic acid can reduce the concentrations of total cholesterol and low-density cholesterol (harmful cholesterol) in human blood to a certain extent, while maintaining the concentration of high-density cholesterol (beneficial cholesterol) [10, 11]. In 2018, the Food and Drug Administration (FDA) issued food health guidelines allowing for edible oil with an oleic acid content of > 70% to state, “20 g per day can reduce the risk of cardiovascular disease” on the product label [41]. In this study, the oleic acid contents in kernels were significantly higher ($P < 0.05$) in WS-2 (59.58% ± 0.08%), WS-3 (59.40% ± 0.10%), and WS-5 (59.73% ± 0.18%) than in the other tested accessions (Table 2). Thus, our results identify WS-2, WS-3, and WS-5 as excellent germplasm resources with a high oleic acid content.

Linoleic acid is a biosynthetic precursor of γ-linolenic acid and arachidonic acid, particularly in the skin. The deficiency of this essential fatty acid results in the breakdown of skin integrity and an inability to prevent transdermal water loss [19]. Linoleic acid lowers blood cholesterol and low-density lipoprotein cholesterol concentrations, particularly when it replaces common saturated fatty acids [47, 48]. Other fatty acids detected in *C. retusus* kernels were linolenic acid (0.42% ± 0.05%), arachidonic acid (0.15% ± 0.03%), and arachidonic acid (0.36% ± 0.08%), all of which can enhance human immune function, reduce pro-inflammatory factors, prevent infarction, and inhibit allergic reactions [14-21]. The ratio of saturated fatty acids, monounsaturated fatty acids, and polyunsaturated fatty acids in oil from *C. retusus* kernels was 6:55:33, similar to the composition of rapeseed oil and olive oil. Thus, the oil from *C. retusus* kernels is a potential edible vegetable oil.

Phytosterols composition

Table 3 shows the total phytosterols content and phytosterols composition of oil from the kernels of 22 *C. retusus* accessions. The total phytosterol content in oil from tested accessions varied significantly at $P < 0.05$, ranging from 225.71 ± 1.21 mg/100 g (S-5) to 360.59 ± 1.54 mg/100 g (WA-2) with a mean value of 280.33 ± 43.96 mg/100 g and a CV of 15.68%. Among more than 250 different phytosterols found in plants, the most common ones are β-sitosterol, campesterol, and stigmasterol [22, 24]. Capillary GC analyses of *C. retusus* phytosterols revealed seven phytosterols, with β-sitosterol as the dominant compound (average, 191.14 ± 28.51 mg/100 g; range, 155.93 ± 6.67 mg/100 g (T-10) to 240.67 ± 1.07 mg/100 g (WA-2)), followed by β-sitostanol (average, 36.37 ± 4.56 mg/100 g; range, 31.66 ± 0.02 mg/100 g (B-2) to 49.65 ± 0.64 mg/100 g (T-8). The other detected phytosterols were campestanol (range, 12.09–

42.90 mg/100 g), campesteranol (range, 10.07–19.30 mg/100 g), campesterol (10.99–22.95 mg/100 g), and Δ5, 24-stigmasterol (range, 2.26–9.87 mg/100 g) (Table 3). This is the first report of the phytosterols content and profile in *C. retusus* oil. Although some studies have shown that dietary phytosterols can lower low-density lipoprotein cholesterol, others have shown that the consumption of phytosterols reduces the absorption and plasma concentrations of some fat-soluble vitamins and antioxidants [49]. The FDA tentatively issued a health claim related to phytosterol consumption and coronary heart disease risk; that is, the daily dietary intake to achieve the claimed effect of phytosterols is 2 g per day [50]. The phytosterol content was much higher in *C. retusus* oil than in oils of olive (*Olea europaea* L. subsp. Oleaster) (206.82 mg/100 g), yellow horn (*Xanthoceras sorbifolium* Bunge) (185.3 mg/100 g), and peanut (*Arachis hypogaea*) (135 mg/100 g) [51-53]. Thus, *C. retusus* oil has potential as a functional ingredient to produce foods enriched with phytosterols.

Tocopherols content and composition

This is the first report on the content and composition of tocopherols in *C. retusus* oil. The total tocopherols content and composition in oil varied significantly ($P < 0.05$) among the 22 *C. retusus* accessions (Table 4). The average tocopherols content in oil across the 22 *C. retusus* samples was 578.31 ± 58.66 μg/g, ranging from 480.94 ± 2.11 μg/g (Z-1) to 654.22 ± 1.94 μg/g (T-10), with a CV of 10.14%. Tocopherols is a viscous oily light yellow substance that is soluble in organic solvents. Tocopherols can be classified into eight types according to the saturation of the chain and the number and position of methyl groups. In vegetable oil, tocopherols mainly exists in the form of tocopherols [54]. Among several natural tocopherols, α-tocopherol has the highest absorption and metabolic efficiency in the human body, while γ-tocopherol has the strongest antioxidant capacity [31]. In this study, the types of tocopherols in the 22 *C. retusus* samples were determined by liquid chromatography. Four tocopherols were detected in *C. retusus* oil, with γ-tocopherol being the most abundant (526.90 ± 51.36 μg/g) followed by α-tocopherol (34.1 ± 7.56 μg/g). The concentrations of δ-tocopherol and β-tocopherol were 9.60 ± 3.05 and 7.50 ± 1. μg/g, respectively. Tocopherols helps to prevent or ameliorate a variety of major human diseases, such as cancers, cardiovascular diseases, eye disease, and nervous system diseases [32-34, 55, 56]. The main source of tocopherols in the human body is vegetable oils in the diet [30]. The FDA recommends that adults should consume 30 mg tocopherols per day [57]. Some studies have shown that the absorption of 7–9 mg α-tocopherol per day can ensure the normal function of the human central nervous system and vascular system, and the absorption of 100–1000 mg α-tocopherol per day can delay human aging and protect against ultraviolet radiation [35]. Our analyses show that the tocopherols content is higher in *C. retusus* oil than in oils from soybean (*Glycine max* (Linn.) Merr.) (285 μg/g), olive (*O. europaea* L.) (347.5 μg/g), and *C. oleifera* (280 μg/g) [37, 58, 59]. Thus, *C. retusus* oil has potential applications as an ingredient to produce fortified foods enriched with tocopherols.

Correlations among fruit morphology, fatty acid composition, and oil, phytosterol, and tocopherols contents

Spearman's correlation coefficients between fruit morphology, oil content, SFA, MUFA, PUFA, and total phytosterols content in 22 *C. retusus* accessions are shown in Table 5. The fruit fresh weight was significantly positively correlated with FTD (r=0.589, $P < 0.01$), FSI (r = 0.902, $P < 0.01$), GVD (r = 0.907, $P < 0.01$), GVD/ST (r = 0.810, $P < 0.01$), kernel weight (r=0.794, $P < 0.01$), and kernel rate (r = 0.790, $P < 0.01$). The FTD was significantly positively correlated with FSI (r =0.448, $P < 0.05$), grain weight (r=0.566, $P < 0.01$), GVD (r=0.663, $P < 0.01$), GTD (r=0.953, $P < 0.01$), and GVD/ST (r=0.556, $P < 0.01$). The FSI was positively correlated with GVD (r=0.787, $P < 0.01$), GVD/ST (r=0.844, $P < 0.01$), and kernel rate (r=758, $P < 0.01$); and negatively correlated with grain weight (r=0.478, $P < 0.05$). A very significant positive correlation between GVD/ST and kernel rate (r= 0.763, $P < 0.01$) was detected. These results indicated that fruit fresh weight would be a useful selection trait for high kernel dry biomass and high kernel rate in *C. retusus* breeding. Regarding oil, phytosterols, and tocopherols contents, the total oil content was negatively correlated with the total phytosterols content (r= −0.653, $P < 0.01$) and positively correlated with kernel weight (r=0.762, $P < 0.01$). We detected very significant negative correlations between SFA and PUFA (r=−0.561, $P < 0.01$), between MUFA and PUFA (r= −0.693, $P < 0.01$), between MUFA and total phytosterols content (r= −0.548, $P < 0.01$), and between PUFA and total phytosterols content (r= −0.811, $P < 0.01$). We detected a very significant negative correlation between total phytosterols content and tocopherols content (r= −0.744, $P < 0.01$).

Principal component analyses of fatty acids, phytosterols, and tocopherols composition

Principal component analyses provide data that are useful for breeding improved varieties. For example, Liang et al. (2019) studied the composition of fatty acids and sterols in 22 *Acer truncatum* plants, and used a principal component analysis to separate the plants into groups on the basis of their components [42]. Two-dimensional biplots for the first two principal components (PCs) obtained from PCAs based on fatty acids, phytosterols, and tocopherols composition and contents are shown in Fig. 2. For fatty acids composition and content, the first two PCs explained 71.10% of the total variance of fatty acids composition, and the tested *C. retusus* accessions were separated into four groups (Fig. 2A). Group I included WS-2, WS-3, WS-4, and WS-5, which were characterized by a high oil content and large proportions of PUFA and linoleic acid. Group II consisted of T-2, T-4, T-5, T-9, T-10, T-11, Z-1, Z-4 and Z-5, which were characterized by high proportions of MUFA, SFA, palmitic acid, stearic acid, and oleic acid. Group III included B-1, B-2, WA-1, S-2, S-3, and S-5 which were characterized by high levels of arachidic acid and arachidonic acid. Group IV included WA-2 and S-6, accessions with a medium level of the studied parameters (Fig. 2A). On the basis of these results, WS-2, WS-3, WS-4, and WS-5 were identified as ideal *C. retusus* germplasm resources with high oil content and high linoleic acid content, and T-2, T-4, T-5, T-9, T-10, T-11, Z-1, Z-4, and Z-5 were identified as *C. retusus* germplasm resources with a high oleic acid content.

For phytosterols composition and content, the first two PCs explained 72.2% of the total variance of phytosterols composition, and the tested accessions were separated into three groups (Fig. 2B). Group I included WA-1, WA-2, WS-2, WS-3, WS-4, and WS-5, which were characterized by a high level of total phytosterols, β-sitosterol, campestanol, Δ5-avenosterol, and Δ5, 24- stigmasterol. Group II included T-2, T-4, T-5, T-8, T-9, T-10, T-11, B-1, B-2, Z-1, Z-4, and Z-5, which were characterized by high levels of campesterol, campesteranol, and β-sitostanol. Group III included S-2, S-3, S-5 and S-6, which showed no significant difference in sterol composition and content compared with other groups. The results of the PCA identified WA-1, WA-2, WS-2, WS-3, WS-4, and WS-5 as *C. retusus* germplasm resources with a high phytosterols content.

For tocopherols composition and content, the first two PCs explained 91.2% of the total variance of tocopherols composition and the tested samples were separated into five groups (Fig. 2C). Group I included T-4, T-5, T-8, T-10, WS-4, and WS-5, which were characterized by high contents of total tocopherols, γ-tocopherol, and δ-tocopherol. Group II included T-2, T-9, WS-2, WS-3, and WA-2, which were characterized by a high α-tocopherol content. Group III included B-1, B-2, and T-11, which were characterized by a high β-tocopherol content. Group IV (S-2, S-6, and WA-1) and group V (S-3, S-5, Z-1, Z-4, and Z-5) showed no significant difference in phytosterols composition and content compared with other groups. These results identified T-4, T-5, T-8, T-10, WS-4, and WS-5 as *C. retusus* germplasm resources with a high tocopherols content.

Conclusions

This is the first report on the oil content, and the fatty acids, phytosterols, and tocopherols content and composition in *C. retusus* kernels. There were significant differences in fruit morphological characteristics, oil content, and fatty acids, phytosterols, and tocopherols composition among 22 accessions. Our analyses indicate that the average oil content of *C. retusus* kernels is 36.55% ± 5.78%, and the oil comprises seven different fatty acids, of which oleic acid is the most abundant. The phytosterols content in *C. retusus* oil is significantly higher than that other woody oil crops. Seven phytosterols were detected in *C. retusus* oil, the main one being β-sitosterol. The tocopherols content detected in *C. retusus* oil far exceeded our expectations. The main form of tocopherols is γ-tocopherol, suggesting that *C. retusus* oil may have good antioxidant capacity. Correlation analyses and PCA identified T-2, T-4, T-5, T-9, T-10, T-11, Z-1, Z-4, and Z-5 as accessions with a high oil content and high oleic acid content; WA-1, WA-2, WS-2, WS-3, WS-4 and WS-5 as accessions with a high phytosterols content; and T-4, T-5, T- 8, T-10, WS-4, and WS-5 as accessions with a high tocopherols content. These results will be useful for the genetic improvement and/or selection of varieties that produce abundant high-quality edible oil. Such varieties could be cultivated to promote the development of the *C. retusus* oil industry.

Abbreviations

FTD, fruit transverse diameter;

FSI, fruit shape index;

GVD, grain vertical diameter;

GTD, grain transverse diameter;

GVD/ST, grain vertical diameter/shell thickness;

SFA, saturated fatty acid;

MUFA, monounsaturated fatty acid;

PUFA, polyunsaturated fatty acid

Declarations

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Data Availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Consent to participate Not applicable.

Consent for publication Not applicable.

Ethics approval This article does not contain any unethical subjects.

Conflict of Interest The authors declare that there is not confict of interest in the study.

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Tables

Table 1 Variation of morphological characteristics of 22 *Chionanthus retusus* accessions.

Accessions	Fruit character				Kernel character			
	Fresh weight(hundred grains)/g	Fruit vertical diameter/mm	Fruit transverse diameter/mm	Fruit shape index	Grain weight(hundred grains)/g	Grain vertical diameter/mm	Grain transverse diameter/mm	Shell thickness/mm
T-2	79.360±1.56^{h}	12.255±0.23^{d}	10.376±0.84^{ab}	1.182^{cd}	23.951±0.21^{g}	10.562±1.11^{e}	7.138±0.43^{a}	0.382±0.02^{f}
T-4	90.706±3.81^{e}	12.970±1.12^{cd}	9.420±0.22^{c}	1.389^{b}	32.271±2,14^{c}	11.640±1.31^{cd}	7.300±0.55^{a}	0.680±0.09^{bc}
T-5	47.423±0.76^{m}	10.900±0.25^{ef}	7.809±0.05^{e}	1.398^{b}	14.334±1.11^{k}	10.165±1.04^{e}	5.763±0.72^{bc}	0.386±0.05^{f}
T-8	121.303±7.51^{a}	15.374±0.38^{a}	11.380±0.18^{a}	1.352^{b}	36.067±0.98^{a}	13.568±1.21^{ab}	7.494±0.67^{a}	0.665±0.10^{c}
T-9	89.296±2.79^{e}	12.430±0.56^{d}	10.030±0.47^{b}	1.244^{bc}	26.332±2.21^{de}	10.460±1.03^{ef}	6.880±0.52^{ab}	0.550±0.04^{d}
T-10	69.327±1.52^{ij}	11.262±0.43^{e}	10.301±0.93^{ab}	1.094^{e}	20.148±1.34^{i}	9.596±0.87^{ef}	6.898±0.29^{ab}	0.434±0.03^{de}
T-11	61.024±0.34^{k}	11.990±0.25^{de}	9.030±0.71^{c}	1.331^{b}	19.745±1.23^{i}	10.240±1.98^{e}	6.220±0.54^{ab}	0.510±0.06^{d}
WS-2	39.979±0.63^{n}	9.527±0.72^{g}	7.805±0.60^{e}	1.226^{c}	10.085±0.94^{l}	7.513±3.20^{g}	5.120±0.42^{c}	0.445±±0.07^{de}
WS-3	73.850±2.14^{i}	11.832±0.89^{de}	9.696±0.29^{bc}	1.223^{c}	24.889±2.12^{f}	9.699±1.21^{ef}	7.149±0.71^{a}	0.426±0.02^{de}
WS-4	112.705±3.58^{b}	13.730±0.98^{c}	11.076±1.01^{a}	1.242^{bc}	34.920±3.13^{b}	11.654±0.85^{cd}	7.680±0.66^{a}	0.689±0.08^{bc}
WS-5	60.916±2.81^{kl}	11.125±1.05^{e}	8.996±1.20^{cd}	1.239^{bc}	17.839±1.34^{j}	9.947±0.48^{ef}	6.314±0.52^{ab}	0.449±0.02^{de}
WA-1	72.750±1.90^{i}	15.361±0.45^{a}	9.227±0.54^{c}	1.670^{a}	24.970±2.31^{f}	14.322±1.21^{a}	6.387±0.61^{ab}	0.765±0.13^{b}
WA-2	73.214±1.05^{i}	13.548±0.21^{c}	9.876±1.21^{bc}	1.376^{b}	24.448±2.55^{f}	12.092±1.20^{c}	7.399±0.70^{a}	0.596±0.06^{cd}
S-2	75.254±2.06^{i}	12.342±0.59^{d}	9.713±0.76^{bc}	1.272^{bc}	23.560±2.12^{g}	10.340±0.76^{e}	6.491±0.49^{ab}	0.645±0.04^{c}
S-3	100.756±5.14^{c}	11.679±2.14^{de}	11.189±0.11^{a}	1.042^{e}	31.961±3.02^{c}	9.423±0.81^{ef}	7.705±0.95^{a}	0.671±0.07^{bc}
S-5	89.520±3.84^{e}	13.436±0.78^{c}	10.293±1.00^{ab}	1.308^{b}	31.738±3.08^{c}	11.743±1.53^{cd}	7.411±0.83^{a}	0.571±0.02^{cd}
S-6	63.316±1.81^{k}	11.630±0.37^{de}	8.960±0.51^{cd}	1.300^{b}	18.318±1.51^{j}	9.850±0.49^{ef}	6.120±1.01^{b}	0.511±0.04^{d}
B-1	49.240±0.94^{m}	11.615±0.11^{de}	8.743±0.71^{cd}	1.330^{b}	21.919±1.93^{h}	10.166±1.10^{e}	6.827±1.14^{ab}	0.416±0.05^{e}
B-2	70.547±1.58^{ij}	12.205±0.17^{d}	10.006±1.11^{b}	1.221^{bc}	27.268±2.22^{d}	9.879±0.89^{ef}	6.716±0.72^{ab}	0.417±0.01^{e}
Z-1	58.139±0.47^{l}	14.131±0.26^{bc}	8.859±0.39^{cd}	1.601^{a}	19.814±1.32^{i}	12.670±1.00^{bc}	6.915±0.53^{ab}	0.450±0.03^{de}
Z-4	83.890±2.08^{ef}	12.346±0.62^{d}	9.933±0.64^{bc}	1.244^{bc}	26.836±2.11^{d}	10.854±0.82^{e}	6.945±0.71^{ab}	0.889±0.09^{a}
Z-5	98.982±0.56^{cd}	12.479±0.23^{d}	11.599±1.12^{a}	1.077^{e}	24.718±3.10^{f}	9.715±0.91^{ef}	7.412±0.45^{a}	0.694±0.08^{bc}
Average	76.432±20.75	12.462±1.39	9.742±1.04	1.289±0.15	24.370±6.52	10.732±1.51	6.831±0.65	0.556±0.12
CV(%)	27.15	11.18	10.63	11.48	26.75	14.09	9.53	25.18

Column data marked with different superscripts indicate significant differences among accessions, ($P < 0.05$).

Table 2 Oil content and fatty acid composition of 22 *Chionanthus retusus* accessions.

Accessions	Oil content/%	Fatty acid composition							
		Palmitic acid(C16:0)	Stearic acid(C18:0)	Oleic acid(C18:1)	Linoleic acid(C18:2)	Linolenic acid(C18:3)	Arachidic acid(C20:0)	Arachidonic acid(C20:1)	SFA
T-2	34.9±0.65^{ef}	4.28±0.03^{f}	2.16±0.01^{e}	54.63±0.09^{cd}	31.17±0.05^{cde}	0.41±0.02^{gh}	—	0.28±0.04^{i}	6.57±0.07^{c}
T-4	38.2±0.10^{cd}	4.23±0.12^{f}	2.10±0.01^{e}	54.70±0.17^{cd}	31.33±0.09^{cde}	0.44±0.03^{f}	—	0.35±0.04e^{fg}	6.46±0.31^{d}
T-5	39.2±0.38^{bcd}	4.25±0.05^{f}	2.34±0.06^{cd}	54.67±0.25^{cd}	31.47±0.12^{cd}	0.41±0.03^{gh}	—	0.38±0.03^{cd}	6.72±0.14^{c}
T-8	34.5±0.53^{ef}	4.21±0.12^{f}	2.31±0.09^{cd}	54.73±0.47^{cd}	30.60±0.05^{de}	0.40±0.05^{efg}	—	0.38±0.03^{cd}	6.64±0.24^{c}
T-9	40.3±0.87^{bc}	4.22±0.02^{f}	1.98±0.15^{fg}	54.67±0.45^{cd}	31.30±0.17^{cd}	0.42±0.04^{e}	—	0.38±0.06^{cd}	6.33±0.21^{d}
T-10	35.5±0.60^{ef}	4.21±0.01^{f}	2.04±0.15^{ef}	54.03±0.08^{cd}	31.27±0.16^{cde}	0.40±0.04^{efg}	—	0.38±0.03^{cd}	6.40±0.19^{d}
T-11	39.6±0.64^{bcd}	4.06±0.32^{gh}	1.74±0.08^{gh}	55.77±0.06^{c}	31.30±0.55^{cd}	0.40±0.02^{efg}	—	0.35±0.03^{efg}	5.93±0.42^{g}
Z-1	37.8±1.15^{cd}	4.98±0.06^{ab}	2.52±0.24^{bc}	58.97±0.28^{ab}	31.43±0.11^{cd}	0.47±0.03^{cde}	—	0.32±0.05^{h}	7.63±0.33^{a}
Z-4	37.2±0.96^{cde}	4.28±0.01^{f}	2.53±0.11^{bc}	59.43±0.04^{ab}	30.70±0.06^{de}	0.48±0.05^{cd}	—	0.36±0.09^{e}	6.99±0.16^{b}
Z-5	40.0±0.96^{bc}	4.15±0.01^{fg}	2.64±0.09^{b}	59.67±0.15^{ab}	31.40±0.07^{cd}	0.44±0.04^{f}	—	0.33±0.03^{gh}	7.00±0.14^{b}
B-1	28.9±0.58^{h}	4.76±0.01^{cd}	2.88±0.01^{a}	53.60±0.08^{cd}	31.87±0.35^{cd}	0.49±0.04^{b}	—	0.27±0.02^{j}	7.64±0.20^{a}
B-2	30.5±0.36^{g}	4.69±0.22^{cde}	2.83±0.05^{ab}	53.10±0.11^{cd}	31.40±0.06^{cd}	0.49±0.06^{b}	—	0.28±0.03^{i}	7.52±0.27^{a}
S-3	28.3±0.35^{h}	3.88±0.04^{h}	1.45±0.01^{hij}	49.53±0.06^{ih}	30.27±0.29^{de}	0.41±0.03^{gh}	0.13±0.03^{de}	0.34±0.05^{fgh}	5.33±0.05^{hi}
S-5	31.4±0.95^{g}	3.44±0.08^{i}	1.73±0.08^{gh}	50.17±0.12^{gi}	31.37±1.15^{cd}	0.39±0.03^{ghi}	0.13±0.03^{de}	0.35±0.03^{efg}	5.17±0.16^{ij}
S-6	34.5±1.60^{ef}	3.41±0.02^{i}	1.72±0.04^{gh}	50.30±0.06^{gi}	27.00±0.80^{f}	0.39±0.03^{ghi}	0.13±0.03^{de}	0.40±0.04^{ab}	5.13±0.06^{ij}
S-2	29.2±0.38^{h}	3.42±0.06^{i}	1.58±0.01^{hi}	51.53±0.37^{fg}	30.47±0.81^{de}	0.41±0.04^{ef}	0.12±0.03^{ef}	0.39±0.01^{bc}	5.00±0.07^{jk}
WS-2	42.8±1.01^{b}	5.02±0.31^{ab}	1.80±0.08^{gh}	56.20±0.04^{bc}	33.03±1.01^{b}	0.38±0.04^{hi}	0.13±0.03^{de}	0.38±0.04^{cd}	6.82±0.39^{c}
WS-3	42.4±1.30^{b}	4.63±0.02^{cde}	2.10±0.09^{e}	55.40±0.08^{bc}	34.80±0.51^{a}	0.34±0.02^{k}	0.15±0.03^{c}	0.35±0.03^{efg}	6.73±0.11^{c}
WS-4	42.3±0.49^{b}	5.09±0.02^{ab}	2.09±0.06^{ef}	56.03±0.06^{bc}	34.40±0.46^{a}	0.34±0.03^{k}	0.13±0.02^{de}	0.37±0.04^{ef}	7.18±0.08^{b}
WS-5	47.5±0.67^{a}	4.80±0.32^{cd}	2.15±0.11^{e}	56.37±0.12^{bc}	33.43±1.11^{b}	0.35±0.03^{jk}	0.13±0.03^{de}	0.36±0.06^{ef}	6.95±0.43^{b}
WA-1	29.0±0.45^{h}	4.21±0.02^{f}	2.06±0.01^{ef}	53.53±0.03^{cd}	31.80±0.10^{d}	0.51±0.05^{a}	0.18±0.04^{b}	0.27±0.04^{j}	6.27±0.03^{d}
WA-2	30.8±1.00^{g}	4.48±0.03^{e}	1.93±0.09^{fg}	54.63±0.25^{cd}	27.03±0.15^{f}	0.47±0.04^{cde}	0.21±0.04^{a}	0.26±0.03^{k}	6.41±0.12^{d}
Average	36.55±5.78	4.30±0.49	2.12±0.39	52.33±3.22	31.31±3.28	0.42±0.05	0.15±0.03	0.36±0.08	6.49±0.78
CV/%	15.81	11.40	17.65	5.84	10.07	11.90	20.00	22.22	12.02

Column data marked with different superscripts indicate significant differences among accessions at P < 0.05.

Table 3 Total phytosterol and phytosterol composition of 22 *Chionanthus retusus* accessions.

Accessions	Phytosterols mg/100g							
	Campesterol	Campestanol	Campesteranol	β-Sitosterol	β-Sitostanol	Δ5-Avenosterol	Δ5, 24- Stigmasterol	Total phytosterols
T-2	11.41±0.25^{h}	15.25±0.85^{hi}	18.63±0.31^{ab}	166.19±1.05^{ef}	37.48±0.94^{de}	—	—	248.96±0.93^{de}
T-4	12.95±0.57^{fg}	12.09±1.79^{k}	16.74±0.89^{cd}	178.88±1.98^{de}	36.12±0.74^{e}	—	—	256.78±0.56^{cde}
T-5	11.49±0.05^{h}	12.76±0.79^{jk}	19.50±0.92^{a}	187.63±2.16^{bcd}	35.18±0.50^{ef}	—	—	266.56±0.78^{cd}
T-8	14.13±1.04^{e}	28.10±1.17^{e}	13.44±0.76^{f}	195.13±1.53^{abc}	49.65±0.64^{a}	—	—	290.45±1.93^{c}
T-9	10.99±0.05^{hi}	17.53±0.52^{g}	15.92±0.67^{cd}	167.70±2.91^{def}	42.28±0.20^{b}	—	—	254.42±1.25^{cde}
T-10	11.98±0.50^{g}	23.57±0.70^{f}	14.96±1.13^{de}	155.93±6.67^{fg}	36.26±0.16^{e}	—	—	242.70±1.06^{de}
T-11	16.95±0.13^{d}	17.21±0.28^{n}	18.73±0.58^{ab}	174.53±1.39^{de}	32.57±0.23^{h}	—	—	259.99±0.63^{cde}
Z-1	22.03±0.33^{a}	17.58±0.26^{g}	19.33±0.43^{a}	163.85±1.83^{ef}	33.56±0.89^{g}	—	—	256.35±0.31^{cde}
Z-4	22.95±0.81^{a}	18.44±0.98^{g}	17.80±0.47^{bc}	170.28±2.69^{def}	38.60±1.08^{d}	—	—	268.07±0.50^{cd}
Z-5	21.93±0.28^{a}	16.88±0.86^{gh}	19.30±0.26^{a}	162.70±2.00^{ef}	33.88±0.40^{g}	—	—	274.69±0.64^{cd}
B-1	12.43±0.15^{g}	13.31±0.80i^{jk}	10.07±0.41^{h}	165.56±2.76^{ef}	33.74±0.23^{g}	—	—	235.11±0.71^{def}
B-2	12.18±0.21^{g}	14.21±0.17^{hij}	10.46±0.55^{gh}	172.60±0.66^{def}	31.66±0.02^{hi}	—	—	241.11±0.88^{de}
S-3	17.59±0.30^{c}	31.74±1.56^{cd}	13.94±1.07^{ef}	176.40±0.46^{de}	—	2.99±0.44^{de}	—	242.66±1.62^{de}
S-5	12.17±0.14^{g}	32.37±0.39^{c}	14.44±0.28^{de}	174.47±3.32^{de}	—	2.26±0.46^{de}	—	225.71±1.21^{ef}
S-6	11.83±0.19^{h}	32.84±1.02^{c}	11.75±0.46^{g}	198.70±4.17^{bc}	—	3.17±0.09^{de}	—	258.29±0.84^{cde}
S-2	14.43±0.35^{e}	36.60±1.05^{b}	10.95±1.01^{gh}	199.40±1.91^{bc}	—	5.97±0.28^{c}	—	267.35±1.05^{cd}
WS-2	11.90±0.23^{h}	36.28±0.97^{b}	15.75±1.72^{cd}	232.30±4.69^{a}	41.26±0.65^{bc}	7.92±0.14^{ab}	5.96±0.46^{c}	351.37±0.54^{a}
WS-3	11.95±0.09^{gh}	42.90±5.30^{a}	18.42±1.08^{ab}	224.67±34.56^{a}	32.59±0.10^{h}	2.43±1.6^{de}	4.46±3.50^{a}	337.42±1.75^{ab}
WS-4	12.43±0.07^{g}	31.89±1.47^{de}	15.46±0.37^{cde}	221.30±2.61^{a}	33.31±0.29^{g}	9.32±0.37^{a}	4.05±0.58^{e}	327.76±1.83^{ab}
WS-5	13.04±0.18^{f}	13.86±1.20^{k}	15.24±2.27^{cde}	239.23±3.43^{a}	32.38±0.11^{h}	9.87±0.31^{a}	4.33±0.32^{e}	347.95±1.43^{a}
WA-1	20.39±0.22^{b}	28.19±1.33^{e}	15.75±0.98^{cd}	237.03±2.25^{a}	34.57±0.10^{f}	9.15±0.21^{a}	7.91±0.64^{d}	352.99±1.67^{a}
WA-2	20.22±0.58^{b}	32.19±1.13^{c}	15.74±0.17^{cd}	240.67±1.07^{a}	39.52±0.29^{c}	3.75±0.41^{d}	8.50±0.39^{b}	360.59±1.54^{a}
Average	14.88±4.05	23.90±5.39	15.56±2.92	191.14±28.51	36.37±4.56	5.68±0.51	5.87±0.57	280.33±43.96
CV/%	27.22	22.55	18.77	14.92	12.54	14.45	16.19	15.68

Column data marked with different superscripts indicate significant differences among accessions at $P < 0.05$.

Table 4 Total tocopherols and tocopherols composition of 22 *Chionanthus retusus* accessions.

Accessions	tocopherols μg/g				
	α-tocopherol	β-tocopherol	γ-tocopherol	δ-tocopherol	Total tocopherols
T-2	$32.82±0.45^{def}$	$5.75±0.11^{efg}$	$555.60±10.45^{bcd}$	$11.65±0.63^{bcd}$	$605.82±2.37^{bcd}$
T-4	$37.53±0.22^{c}$	$7.33±0.32^{d}$	$586.55±14.76^{a}$	$14.12±0.87^{a}$	$645.53±5.84^{a}$
T-5	33.86±0.83	$6.85±0.17^{de}$	$572.71±4.56^{ab}$	$11.94±0.42^{bc}$	$625.36±4.28^{abc}$
T-8	$44.21±1.56^{a}$	$9.16±0.23^{ab}$	$583.85±8.39^{a}$	$14.88±0.61^{a}$	$652.10±8.56^{a}$
T-9	$36.38±1.05^{cde}$	$7.00±0.61^{de}$	$560.84±5.28^{abc}$	$12.24±0.70^{ab}$	$616.46±6.10^{abc}$
T-10	$40.19±0.74^{b}$	$7.83±0.30^{cd}$	$593.94±13.92^{a}$	$12.26±0.61^{ab}$	$654.22±1.94^{a}$
T-11	$39.64±0.92^{bc}$	$9.11±0.45^{ab}$	$524.26±15.21^{cd}$	$12.61±0.94^{ab}$	$585.62±5.45^{bcd}$
Z-1	$19.13±0.60^{h}$	$4.82±0.32^{fg}$	$452.21±11.17^{fg}$	$4.78±0.11^{i}$	$480.94±2.11^{efg}$
Z-4	$21.20±0.67^{h}$	$6.93±0.55^{de}$	$465.27±6.82^{efg}$	$4.96±0.20^{i}$	$498.36±4.06^{def}$
Z-5	$15.12±0.59^{i}$	$6.48±0.21^{a}$	$472.14±9.76^{efg}$	$5.25±0.16^{i}$	$501.99±3.17^{def}$
B-1	$44.15±0.62^{a}$	$8.43±0.33^{bc}$	$508.31±7.24^{cde}$	$8.03±0.44^{g}$	$568.92±4.85^{cde}$
B-2	$42.64±0.71^{ab}$	$9.56±0.52^{a}$	$523.63±8.18^{cd}$	$10.02±0.53^{def}$	$585.85±1.81^{bcd}$
S-3	$32.37±0.61^{ef}$	$6.54±0.15^{def}$	$439.49±11.34^{fgh}$	$6.54±0.47^{h}$	$484.94±1.79^{efg}$
S-5	$34.83±0.38^{de}$	$7.56±0.41^{cd}$	$438.73±6.23^{fgh}$	$8.51±0.58^{g}$	$489.63±5.72^{efg}$
S-6	$30.13±0.45^{g}$	$7.37±0.50^{cd}$	$484.36±8.42^{def}$	$7.67±0.36^{gh}$	$529.53±6.44^{def}$
S-2	$33.58±0.79^{de}$	$8.84±0.39^{bc}$	$498.91±6.71^{def}$	$9.25±0.30^{efg}$	$550.58±5.13^{cde}$
WS-2	$35.07±0.32^{de}$	$8.03±0.24^{bcd}$	$556.86±7.06^{abc}$	$8.58±0.54^{g}$	$608.54±1.90^{bcd}$
WS-3	$40.65±0.64^{b}$	$9.01±0.16^{ab}$	$558.64±9.05^{abc}$	$9.52±0.60^{efg}$	$617.82±4.05^{abc}$
WS-4	$33.59±0.70^{de}$	$7.26±0.30^{cde}$	$579.12±6.41^{a}$	$8.50±0.33^{g}$	$628.47±3.88^{abc}$
WS-5	$36.94±1.54^{cde}$	$6.77±0.45^{de}$	$586.23±5.55^{a}$	$11.64±0.41^{bcd}$	$641.58±3.27^{a}$
WA-1	$30.60±1.07^{g}$	$5.84±0.31^{efg}$	$501.43±4.84^{cd}$	$10.32±0.74^{de}$	$548.19±5.32^{cde}$
WA-2	$36.22±0.44^{cde}$	$6.72±0.57^{de}$	$548.67±7.39^{bcd}$	$10.83±0.68^{cde}$	$602.44±4.44^{bcd}$
Average	34.1±7.56	7.50±1.28	526.90±51.36	9.60±3.05	578.31±58.66
CV/%	22,17	17.07	9.47	31,77	10.14

Column data marked with different superscripts indicate significant differences among accessions at $P < 0.05$.

Table 5 Spearman’s correlation coefficients fruit morphology, oil, total phytosterol and tocopherol content, and saturated, monounsaturated and polyunsaturated fatty acid content of *Chionanthus retusus* accessions

Characteristics	Correlation coefficient												
	Fresh weight	FTD	FSI	Grain weight	GVD	GTD	VD/ST	Kernel weight	Kernel rate	Oil content	SFA	MUFA	PUFA
Fresh weight	1.000												
FTD	0.589**	1.000											
FSI	0.902**	0.448*	1.0000										
Grain weight	-0.259	0.566**	-0.478*	1.000									
GVD	0.907**	0.663**	0.787**	-0.086	1.000								
GTD	0.414	0.953**	0.229	0.722**	0.524*	1.000							
VD/ST	0.810**	0.556**	0.844**	-0.223	0.860**	0.412	1.000						
Kernel weight	0.794**	0.219	0.201	0.032	0.314	0.181	0.105	1.000					
Kernel rate	0.790**	0.385	0.758**	-0.34	0.855**	0.215	0.763**	0.049	1.000				
Oil content	-0.209	-0.487*	-0.030	-0.459*	-0.266	-0.501*	-0.119	0.762**	0.235	1.000			
SFA	-0.003	-0.228	0.072	-0.300	-0.179	-0.345	-0.068	0.154	0.099	0.407	1.000		
MUFA	-0.164	0.017	-0.115	0.131	-0.106	0.038	0.012	0.330	-0.024	0.136	0.289	1.000	
PUFA	-0.076	-0.085	-0.093	0.005	-0.229	-0.090	-0.103	-0.029	-0.177	0.043	-0.561**	-0.693**	1.000
phytosterol	-0.024	-0.158	-0.043	-0.110	-0.096	-0.198	-0.051	0.022	0.038	-0.653**	0.038	-0.548**	-0.811**
Total tocopherols	0.097	0.032	0.063	-0.056	0.053	-0.048	0.016	-0.069	0.109	0.002	0.271	-0.119	0.093

FTD, Fruit transverse diameter; FSI, Fruit shape index ; GVD, Grain vertical diameter; GTD, Grain transverse diameter; VD/ST, Vertical diameter/shell thickness; SFA, saturated fatty acid; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid. * $P < 0.05$; ** $P < 0.01$.

Figures

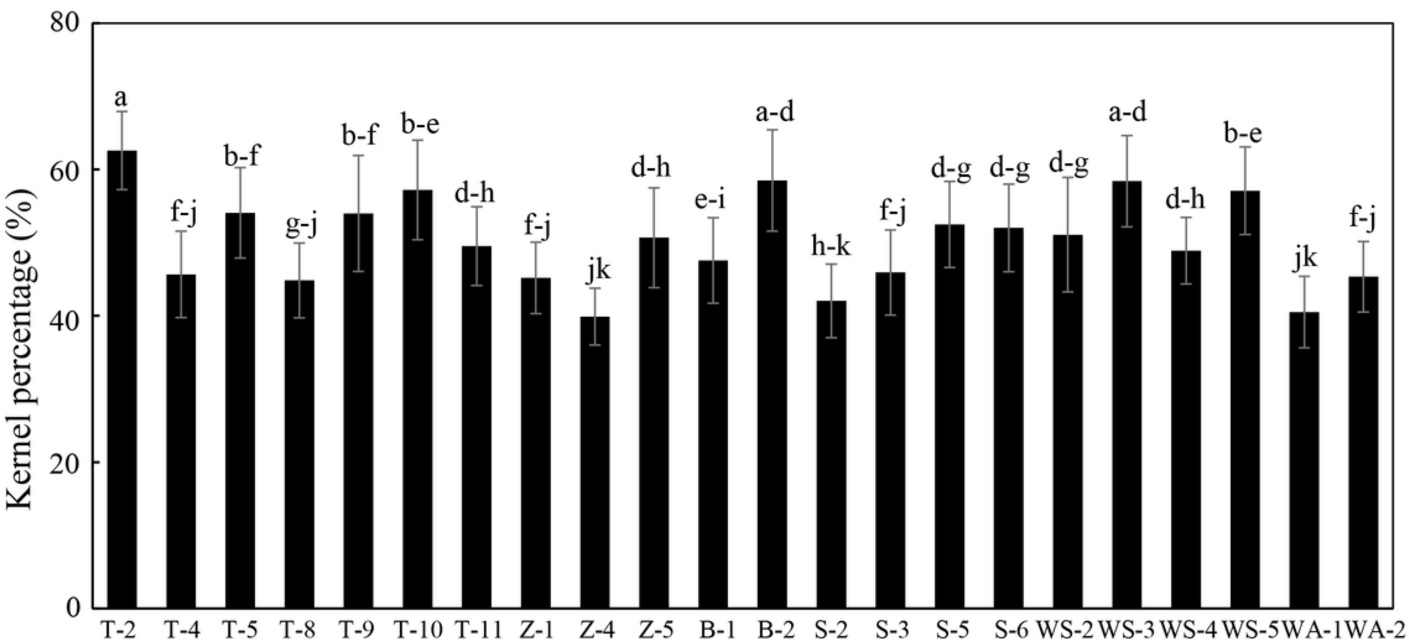

Figure 1

Kernel percentage (ratio of kernel dry biomass to grain dry biomass) in 22 *Chionanthus retusus* accessions. Means with the same lowercase letter are not significantly different at the 0.05 level.

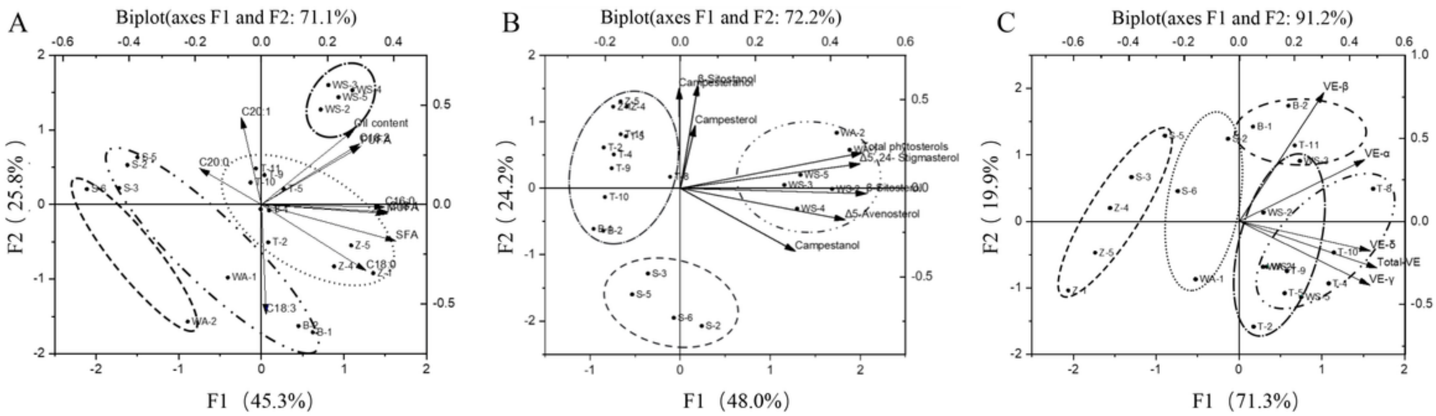

Figure 2

Principal component analyses based on fatty acids composition (A), phytosterols composition (B) and tocopherols composition (C).

Supplementary Files

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- TableA1GeographicsourceofC.retusussuperiortrees.docx