Food Chemistry 185 (2015) 371–376

Contents lists available at ScienceDirect

Food Chemistry

journal homepage: www.elsevier.com/locate/foodchem

Nutrient composition and starch characteristics of *Quercus glandulifera Bl.* seeds from China

Songnan Li, Yibin Zhou *, Mei Liu, Yang Zhang, Shengnan Cao

School of Tea and Food Technology, Anhui Agricultural University, 130 Chang Jiang West Road, Hefei 230036, China

ARTICLE INFO

Article history:
Received 6 November 2014
Received in revised form 24 March 2015
Accepted 27 March 2015
Available online 7 April 2015

Keywords:
Acorn
Quercus glandulifera Bl. seeds
Nutrient composition
Starch characteristics

ABSTRACT

The chemical composition and starch characteristics of acorn (*Quercus glandulifera Bl.*) were studied. The moisture content of acorn seeds was 7.55%. The crude fat, crude protein, dietary fiber, total ash, and nitrogen-free extract contents of acorn seed were 4.20%, 10.16%, 2.95%, 0.03%, and 82.66%, respectively, on a dry weight basis. Linoleic, oleic, and palmitic were the most predominant fatty acids. UFA:SFA and SFA:MUFA:PUFA ratios were 2.6:1 and 1.25:1.34:1, respectively. The essential amino acid content from acorn seeds was low based on FAO reference values. Acorn seeds were a good source of Fe, Zn, and Mn. The contents of vitamins A and E were 1.40 mg RE/100 g and 10.78 mg/100 g, respectively. Starch extracted from acorn seeds had round, triangle, and elliptical morphology with granule size of 3.3–126.2 μm. The ratio between amylose and amylopectin contents was 25.39:72.94. Acorn starch had a typical A-type crystal pattern with 23.53% relative crystallinity. The gelatinization temperature was 66.53 °C and the transition enthalpy was 4.33 J/g.

1. Introduction

Acorn-producing plants belong to the genus *Quercus*, which includes more than 300 species. Most of the *Quercus* species consist of tall trees or shrubs. *Quercus glandulifera Bl.* is an acorn-producing shrub.

Q. glandulifera Bl. grows in the hills of Qinhuai, China, i.e., in the provinces of Anhui, Jiangxi, Hunan, and Guangdong. The plant is a deciduous shrub different to *Cyclobalanopsis blakei* (*Skan*) *Schott* but with seeds similar to those of oak. In certain regions of China, the yield of *Quercus* seeds is high and comparable to that of cereal grains (Xie & Xie, 2002). Bainbridge (1986), who evaluated the nutritional composition of 18 acorn species but not of *Q. glandulifera Bl.*, reported that acorns contain 8.7–44.6% water, 2.3–8.6% protein, 1.1–31.3% fat, and 32.7–89.7% carbohydrate. Acorns are rich in several nutrients and are used in a variety of traditional dishes (Bainbridge, 1986) including tofu and cold noodles. The phenolic compound and antioxidant activity of *Quercus robur* and *Quercus cerris* methanol extracts were investigated (Rakić et al., 2007). Additionally, Rakić, Povrenović, Tešević, Simić, and Maletić (2006) evaluated the effects of thermal treatment on the physical and nutritive characteristic of *Q. robur*. Charef, Yousfi, Saidi, and Stocker (2008) and Petrovic, Sobajic, Rakic, Tomic, and Kukic (2004) reported that *Quercus* seeds are good sources of unsaturated fatty acids. However, the chemical composition of acorns varies with species and origin (Galván et al., 2012). *Quercus* seeds are harvested mainly for human consumption and livestock feed. This study evaluated the nutritional composition and starch characteristics of *Q. glandulifera Bl.* seeds.

2. Materials and methods

2.1. Sample collection and preparation

Acorn seeds were harvested from 50 *Quercus* shrubs. The seeds were hand-peeled, oven-dried at 40 ± 5 °C for 24 h, and dry-milled. The resulting acorn flour was passed through a 0.3-mm mesh sieve and stored in sealed containers for analysis.

2.2. Starch preparation

Acorn flour was dispersed in 0.3% sodium hydroxide (1:5, w/w), mixed, and allowed to stand for 2 h. The dispersion was passed through a 0.18-mm mesh sieve. The starch milk was allowed to settle, and the supernatant was subsequently decanted and discarded. The precipitate (containing the starch) was rinsed several times with distilled water, air-dried, and stored in sealed containers (Nwokocha & Williams, 2011).

* Corresponding author. Tel./fax: +86 551 65786342.
E-mail address: zhouyibin@ahau.edu.cn (Y. Zhou).

http://dx.doi.org/10.1016/j.foodchem.2015.03.147
0308-8146/

2.3. Proximate composition analyses

Acorn moisture and ash content were determined according to AOAC Methods (2000). Crude protein content was determined by the Kjeldahl instrument (VELP UDK159, Milan, Italy) using a nitrogen–protein conversion factor of 6.25 (AOAC, 2000). Crude fat was obtained following petroleum ether and hexane extractions (Charef et al., 2008; Petrovic et al., 2004). Dietary fiber content of the defatted samples was determined by hydrolyzing starch molecules with acid, denaturing protein molecules with base, and filtering these compounds (James, 1995). Total carbohydrate content, as nitrogen-free extract (NFE), was calculated using the following equation (Pérez-Pacheco et al., 2014; Rakić, Janković, Marčetić, Živković, & Kuzevski, 2014):

$$\%\text{NFE} = 100 - \%\ (\text{crude protein} + \text{crude fat} + \text{ash} + \text{crude fiber})$$

2.4. Nutrient analyses

2.4.1. Fatty acids

Acorn oils were converted to methyl esters using a boron trifluoride methanol complex (14% w/v) at 100 °C for 1 h. The reaction was stopped with the addition of 0.5 ml distilled water. The extracted fatty acid methyl esters (FAMES) were dissolved in pure heptane for gas chromatography–mass spectrometry (GC–MS) analyses (Besbes, Blecker, Deroanne, Drira, & Attia, 2004).

GC–MS analyses were performed in an Agilent 6890–5975c mass selective detector (Agilent, Folsom, California, USA). The desorption time was 5 min, the injection port was maintained at 250 °C, and the column consisted of an HP-5 ms (30 m × 0.25 mm i.d., 0.25 μm thick; J&W Scientific, Agilent). The temperature was held at 140 °C for 5 min, increased to 250 °C at 4 °C/min, and finally increased to 280 °C at 3 °C/min. The interface temperature was 200 °C (Dong et al., 2013).

2.4.2. Free amino acids

The extraction and purification of free amino acids were performed according to the method reported by Moore and Stein (1951) with slight modifications. Acorn flour (0.3 g) was weighed into a 50-ml volumetric flask and adjusted to 50 ml with 6 M HCl, containing 1 ml of 1 g/L reagent-grade phenol and 5000 nmol of norleucine (internal standard). Subsequently, the acid was removed in a rotary evaporator at 50 °C. The resulting hydrolysate was transferred to a 50-ml volumetric flask and the volume was adjusted to 50 ml with distilled water. Subsequently, 2 ml of this solution was centrifuged in Allegra 64R Centrifuge (Beckman coulter, California, USA) at 2,295 g for 2 min. The pellet was dissolved in 5 ml sodium citrate buffer (pH 2.2), passed through a 0.22-μm syringe filter, and stored at −80 °C. Aliquots were subsequently analyzed by ion-exchange chromatography (HITACHI L-8900 automatic amino acid analyzer, Tokyo, Japan), using the standard protein hydrolysate program with sodium citrate buffer and ninhydrin detection. The amino acids were detected at 440 and 570 nm. Amino acid identification and quantification were performed by comparisons to standard calibration curves using Ezchrom TM Chromatography Data System, version 6.7.

2.4.3. Vitamins

Vitamins were determined by HPLC (High Performance Liquid Chromatography) using the method reported by Chung, Shin, Hwang, and Choi (2013). Acorn flour (5 g) was saponified at room temperature with 10 ml of KOH (1 kg/L), 10 ml distilled water, 30 ml ethanol, and 0.5 g ascorbic acid. The reaction mixture was mixed under liquid nitrogen for 10 h, centrifuged at 825*g* for 15 min, and extracted with ethyl ether (3× 200 ml). The organic phase was rinsed twice with phosphate buffer (pH 7.4, 2× 100 ml), concentrated under vacuum, and diluted to 5 ml with the eluent phase. A 25-μl aliquot was injected into the chromatographic system. The chromatographic system consisted of an autosampler (Waters 2707, Milford, Massachusetts, USA) equipped with a binary HPLC pump (Waters 1525), a column heater, and a UV/visible detector (Waters 2489). Each chromatogram was analyzed with Breeze 2 (Waters 2008). Chromatography was performed at 1 ml/min on a Discovery C_{18} ODS reverse phase column (250 mm × 4.6 mm i.d., 5 μm film thickness; Hypersil, Dalian, China).

Tocopherol analysis was performed in isocratic mode using 65:26:9 (v/v/v) acetonitrile/dichloromethane/methanol as the solvent. Carotenoid analysis was performed in gradient mode using 45:10:9 (v/v/v) acetonitrile/dichloromethane/methanol (solvent A) and 65:26:9 (v/v/v) acetonitrile/dichloromethane/methanol (solvent B). The 25-min program was the following, 0–5 min, 100% solvent A; 10–11 min, increase from 0% to 100% solvent B; 11–19 min, 100% solvent B; 19–20 min, increase from 0% to 100% solvent A; and 20–25 min, 100% solvent A. Carotenoid and tocopherol contents were determined by diode array detection at 445 and 298 nm, respectively.

2.4.4. Minerals

Samples were ashed in the presence of nitric acid/perchloric acid (9:1, v/v) on a hot plate at 200 °C (James, 1995). Mineral content was determined by inductively coupled plasma-optical emission spectrometry (ICP-OES); K was analyzed by atomic absorbance spectroscopy (ZEEnit 700P, Jena, Germany). Standard curves of Cu (324.754 nm), Zn (202.548 nm), Fe (259.94 nm), Mn (257.610 nm), Ca (422.673 nm), Ni (231.604 nm), Pb (220.353 nm), Se (196.090 nm), Al (309.271 nm), As (189.042 nm), Cd (226.502 nm), and Mg (280.270 nm) were generated with different concentrations of each element (0–10 mg/L). The standard curve of K (766.5 nm) was generated with 0–40 mg K/L. The correlation coefficients were 0.999.

2.5. Starch analyses

2.5.1. Microstructure and granule size

Starch granule surface and shape were examined under a scanning electron microscope (SEMXL-20, Philips, Amsterdam, Netherlands). The starch sample was mounted onto circular aluminum stubs with double sticky tape, coated with 20 nm gold, and photographed in a Philips Hitachi S-4800 (Hitachi, Tokyo, Japan) at an accelerating potential of 30 kV. Granule size analysis was performed with a laser light scattering-based particle size analyzer (Mastersizer 2000, Malvern, Solihull, UK).

2.5.2. X-ray diffraction

The starch samples were oven-dried at 50 °C overnight and pulverized to a particle size < 63 μm. X-ray diffraction analysis was performed in an X-ray diffractometer (X'Pert PRO, Panalytical, Netherlands) operated at 40 kV and 200 mA. Diffractograms were obtained from 3° 2θ to 60° 2θ with a scanning speed of 8°/min and scanning step of 0.02°. Relative crystallinity was calculated based on the method reported by Hayakawa, Tanaka, Nakamura, Endo, and Hoshino (1997):

$$\text{Relative crystallinity}\ (\%) = \text{Ac}/(\text{Ac} + \text{Aa}) \times 100$$

where Ac is the crystalline area on the X-ray diffractogram and Aa is the amorphous area on the X-ray diffractogram.

2.5.3. Amylose content

Starch samples were first defatted with hot *n*-propanol–water (3:1 v/v) for 7 h and subsequently dissolved (20 mg) in 90%

dimethylsulfoxide (8 ml) in 10-ml screw-cap reaction vials. The vials were vigorously mixed for 2 min and heated at 85 °C in a water bath (with intermittent shaking) for 15 min. The vials were cooled to room temperature, and the contents were diluted to 25 ml with distilled water. One milliliter of the diluted solution was mixed with 40 ml of water and 5 ml of I_2/KI (0.0025 M I_2 and 0.0065 M KI) and adjusted to a final volume of 50 ml. The solution was allowed to stand for 15 min at room temperature before measuring absorbance at 600 nm. Amylose content was determined from a standard curve, generated with amylose and amylopectin solutions (Ratnayake, Hoover, Shahidi, Perera, & Jane, 2001).

2.5.4. Thermal properties

Thermal properties (e.g., gelatinization temperature and transition enthalpy) were determined in a DSC (differential scanning calorimeter, DSC 8000 Perkin Elmer, Waltham, MA, USA), according to the method described by Paredes-Lopez and Hernández-Löpez (1991). Five milligrams of starch was transferred to an aluminum container; the moisture level was adjusted to 70% by adding deionized water. The aluminum container was hermetically sealed and allowed to equilibrate for 2 h at room temperature. Following the 2-h equilibration, the container was placed in the DSC and heated from 50 to 120 °C at 5 °C/min, using an empty aluminum container as a reference. Gelatinization temperature was determined by automatically computing the onset temperature (To), peak temperature (Tp), conclusion temperature (Tc), and gelatinization enthalpy (ΔH) from the resulting thermogram.

2.6. Statistical analyses

All tests were performed in triplicate. Data were analyzed by ANOVA and Duncan's multiple-range test using SPSS software (SPSS Inc., USA). Statistical significance was set to $P < 0.05$.

3. Results and discussion

3.1. Proximate composition

3.1.1. Acorn seeds

The proximate composition of acorn seeds is shown in Table 1. Moisture content was 7.55%. Rakić et al. (2006) reported that the moisture content of acorns must be reduced to <10–15% for long term storage. The crude fat, crude protein, dietary fiber, total ash, and NFE contents of acorn were 4.2%, 10.16%, 2.95%, 0.03%, and 82.66%, respectively, on a dry weight basis. These results were in accordance with those reported by Bainbridge (1986). According to Pérez-Pacheco et al. (2014), total carbohydrate represents NFE. The NFE content (82.66%) was the highest, which revealed that acorns represent an excellent source of starch. The fat content (4.2%) was within that reported by Bainbridge (1986), i.e., 1.1–31.3%, comparable to that of *Quercus lobata* (4.25%; Wagnon & Hart, 1945), and lower than that of *Quercus ilex* (9.0%) and *Quercus suber* (9.0%; Charef et al., 2008). Protein content (10.16%) was higher than the protein range obtained from 18 *Quercus* species (2.3–8.6%; Bainbridge, 1986) and from 20 Turkey *Quercus taxa* (2.75–8.44%; Özcan, 2006). The acorn used in this study is suitable to the production of tofu and flour due to its relatively high protein (10.16%) and starch (82.66%) content, respectively.

Table 1
Chemical composition of acorn seeds and acorn starch (%).

Components	Acorn seed	Acorn starch
Moisture	7.55 ± 0.06	7.02 ± 0.01
Crude fat[a]	4.20 ± 0.02	0.63 ± 0.01
Crude protein[a]	10.16 ± 0.03	1.02 ± 0.01
Dietary fiber[a]	2.95 ± 0.09	ND
Total ash[a]	0.03 ± 0.01	ND
Amylose[a]	–	25.39 ± 0.75
Amylopectin[a]	–	72.94 ± 0.72
NFE[a]	82.66 ± 0.21	98.34 ± 0.03

–: not analyzed; ND: not detected. Means of three determination ± SD.
[a] Percentage of dry matter.

3.1.2. Acorn starch

The chemical composition of acorn seeds and acorn starch is shown in Table 1.The extracted starch contained 7.02% moisture, 0.63% crude fat of dry matter, 1.02% crude protein of dry matter, and a low content of dietary fiber and total ash. Starch purity was 98.34%, which was higher than that of certain *Pachyrhizus ahipa* varieties (56–59%; Forsyth et al., 2002). The acorn starch consisted of 25.39% amylose and 72.94% amylopectin (Table 1), which were similar to Malanga starch (24% and 76%, respectively; Torruco-Uco & Betancur-Ancona, 2007).

3.2. Nutrient composition

3.2.1. Fatty acids

The fatty acid composition of oil extracted from acorn seeds is shown in Table 2. A total of 12 fatty acids were identified; however, linoleic, oleic, and palmitic acid were the most predominant fatty acids, with concentrations higher than those present in *Q. ilex* and *Q. suber* seed oil (Charef et al., 2008). Linoleic and oleic accounted for 36.11% and 32.98% of the total fatty acids, respectively. Linoleic and oleic are the most predominant fatty acids in Spanish *Quercus* ssp. acorn oil (León-Camacho, Viera-Alcaide, & Vicario, 2004). The UFA content in acorn oil was similar to that reported in olive oil (Firestone, 2005). Monounsaturated fatty acids (MUFAs) have higher oxidative stability compared to polyunsaturated fatty acids (PUFAs; Aguilera et al., 2005). The UFA:SFA and SFA:MUFA:PUFA ratios were 2.6:1 and 1.25:1.34:1, respectively. These results suggest that acorn oil has potential applications in the food industry.

3.2.2. Free amino acids

The free amino acid contents of *Q. glandulifera Bl.* seeds are shown in Table 3. The results were in good agreement with those

Table 2
Fatty acid composition of oils extracted from acorn seeds (%).

Fatty acid[a]	Of total FA content[b]
Oleic (18:1)	32.98 ± 0.02
Gadoleic (20:1)	0.74 ± 0.01
MUFA[c]	33.72
Linoleic (18:2)	36.11 ± 0.1
PUFA[d]	36.11
Dodecanoic (12:0)	0.26 ± 0.002
Palmitic (16:0)	21.07 ± 0.2
Margaric (17:0)	0.17 ± 0.002
Stearic (18:0)	3.83 ± 0.02
Arachidic (20:0)	0.47 ± 0.001
Heneicosanoic (21:0)	0.12 ± 0.003
Behenic (22:0)	0.68 ± 0.006
Lignoceric (24:0)	0.22 ± 0.003
Hexacosanoic (26:0)	0.07 ± 0.001
SFA[e]	26.89
UFA[f]:SFA	2.6:1
SFA:MUFA:PUFA	1.25:1.34:1

[a] C number of carbon atoms in the fatty acid.
[b] Means of three determination ± SD.
[c] Monounsaturated fatty acid.
[d] Polyunsaturated fatty acid.
[e] Saturated fatty acid.
[f] Unsaturated fatty acid.

Table 3
Free amino acid content of acorn seeds (mg/100 g of sample).

Amino acid		FAO[a]
Alanine	2.2 ± 0.1	
Glycine	2.0 ± 0.1	
Valine	2.6 ± 0.1	3.5
Leucine	3.3 ± 0.1	6.6
Isoleucine	1.7 ± 0.1	
Proline	2.8 ± 0.1	
Cysteine	2.0 ± 0.0	
Methionine	0.3 ± 0.0	2.5[b]
Phenylalanine	2.8 ± 0.0	
Serine	2.2 ± 0.0	
Threonine	1.7 ± 0.0	3.4
Tyrosine	2.1 ± 0.0	6.3[c]
Aspartic acid[d]	6.9 ± 0.2	
Glutamic acid[e]	8.0 ± 0.2	
Lysine	2.6 ± 0.1	5.8
Isoleucine	ND	2.8
Tryptophan	ND	1.1
Arginine	3.3 ± 0.1	
Histidine	1.2 ± 0.0	1.9

ND: not detected. Means of three determination ± SD.
[a] FAO/WHO/UNU. Energy and protein requirement (FAO, 1985).
[b] Phenylalanine + tyrosine.
[c] Methionine + cysteine.
[d] Aspartic acid + asparagine.
[e] Glutamic acid + glutamine.

reported by Özcan (2006). Due to the very low crude protein content, the total quantity of free amino acids was very low. The most predominant amino acids were aspartic (6.9 mg/100 g) and glutamic acid (8.0 mg/100 g) similar to those reported in Turkish *Q. lobata* (Özcan, 2006). Leucine (3.3 mg/100 g), valine (2.6 mg/100 g), lysine (2.6 mg/100 g), and threonine (1.7 mg/100 g), which are essential amino acids, are about a half of FAO recommendations. On the other hand, the content of the other essential amino acids were very low or not detected by ion-exchange chromatography. Therefore, the level of all essential amino acids in acorn seeds was not adequate based on FAO recommendations.

3.2.3. Vitamins and minerals

Vitamin A and E contents in *Q. glandulifera Bl.* seeds were 1.40 ± 0.25 mg RE/100 g and 10.78 mg/100 g, respectively (Table 4). The vitamin A content was higher than that reported in *Quercus phellos* (King & Titus, 1943). Additionally, the vitamin A content of acorn seeds was 1.40 ± 0.25 mg RE/100 g, higher than that recommended by FAO/WHO (270 μg RE/d and 300 μg RE/d for adult males and females, respectively). The vitamin E content was comparable to that present in mung bean (10.95 mg/100 g; Lee, Mitchell, & Shibamoto, 2000). The vitamin E content (10.78 ± 0.08 mg/100 g) was adequate for adults (10 mg/d and 7 mg/d for males and females, respectively) based on FAO/WHO recommendations. Therefore, acorns are good sources of vitamins A and E.

Table 4
Vitamin and mineral content of acorn seeds.

Mineral (mg/100 g of sample)		Adult DIRs (male, female)[a]
K	2088.92 ± 49.81	(4.7,4.7) g/day
Ca	58.2 ± 4.9	(1.0,1.0) g/day
Mg	102.9 ± 1.5	(420.320) mg/day
Fe	11.9 ± 0.6	(8,18) mg/day
Mn	8.4 ± 0.1	(2.3,1.8) mg/day
Zn	5.1 ± 0.8	(7.0, 4.9) mg/day
Cu	1.0 ± 0.0	
Al	ND	
As	ND	
Cd	ND	
Se	ND	
Ni	0.3 ± 0.1	
Pb	0.3 ± 0.1	
Vitamin		Adult DIRs (male, female)[b]
Vitamin A (mg RE/100 g)	1.40 ± 0.25	(270, 300) μg RE/day
Vitamin E (mg/100 g)	10.78 ± 0.08	(10, 7) mg/day

ND: not detected; means of three determination ± SD.
[a] Values are based on people at 19–70 years old from USDA (2013).
[b] FAO/WHO. Vitamin and mineral requirements in human nutrition, 2005.

The contents of K, Mg, and Ca were the highest amongst all minerals (Table 4). K was the most abundant mineral in the seeds, followed by Mg and Ca. The other minerals, in descending order by content, were Fe, Mn, Zn, Cu, Ni, and Pb. Al, As, Cd, and Se were not detected. Ni and Pb might have resulted from soil contamination. According to the adult dietary reference intake of K, Ca, Mg, Fe, Mn, and Zn (USDA, 2013), the content of Fe (11.9 mg/100 g), Zn (5.1 mg/100 g) and Mn (8.4 mg/100 g) were appreciable for adult males and females (Fe: 8 mg/d and 18 mg/d; Zn: 7.0 mg/d and 4.9 mg/d; Mn: 2.3 mg/d and 1.8 mg/d, respectively). Therefore, acorns are good sources of Fe, Zn, and Mn.

3.3. Acorn starch characteristics

3.3.1. Granule morphology and particle size

The acorn starch granule morphology is shown in Fig. 1A. The surface of acorn starch granules was smooth with no evidence of cracks. The granules had a variety of shapes (e.g., small round, medium triangle, and large elliptical forms) with a broad distribution size (3.3–126.2 μm), similar to that reported in potato

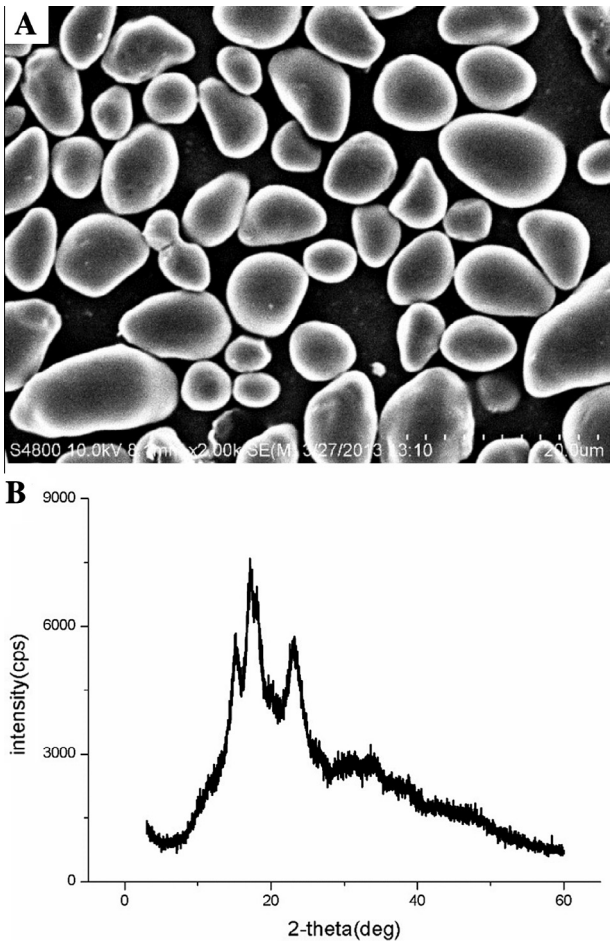

Fig. 1. Scanning electron microscopy (SEM) and X-ray diffraction pattern of acorn starch. (A): SEM (×2000); (B): X-ray diffraction pattern.

Table 5
Gelatinization properties of acorn starch.

	To (°C)	Tp (°C)	Tc (°C)	ΔH (J/g)
Acorn starch	60.78 ± 0.35	66.53 ± 0.23	73.75 ± 0.8	4.31 ± 0.8

To: onset temperature; Tp: peak temperature; Tc: conclusion temperature; ΔH: enthalpy of gelatinization. Means of three determination ± SD.

starch granules (1–110 μm; Singh, Singh, Kaur, Sodhi, & Gill, 2003). The mean particle size diameter was 13.9 μm.

The variation in starch granule shape and size is attributed to the origin (Svegmark & Hermansson, 1993). Starch granule sizes play important roles in starch pasting parameters (Noda et al., 2004). Moreover, the average granule size of the starch molecules is significantly correlated with physicochemical properties, such as swelling power, gelatinization, and retrogradation (Singh et al., 2003).

3.3.2. X-ray diffraction

The X-ray diffraction of acorn starch is shown in Fig. 1B. The starch had an A-type X-ray diffraction pattern, which is characteristic of most cereal starches (Singh et al., 2003). Acorn starch had strong reflections at 15° and 23° (2θ) and unresolved at 17° and 18° (2θ). The relative crystallinity, which was based on diffraction intensity, was 23.53%. The relative crystallinity percentage of *Q. glandulifera Bl.* starch was similar to that reported for *Q. palustris Muenchh.* (22.3%; Stevenson, Jane, & Inglett, 2006) and other A-type starches (Cooke & Gidley, 1992). The values of starch relative crystallinity vary from 15% to 45% (Liu, 2005) depending on the starch source and the method of calculating relative crystallinity.

3.3.3. Thermal analysis

Acorn starch had defined single endotherms. The gelatinization onset, peak, and conclusion temperatures were 60.78 °C, 66.53 °C, and 73.75 °C, respectively; gelatinization enthalpy was 4.31 J/g (Table 5). It had been reported the acorn starch has limited gelatinization at 61–68 °C; *Quercus crispula* and *Quercus mongolica* have the lowest and highest gelatinization, respectively (Kim, 1976). With similar moisture content, the gelatinization enthalpy of acorn starch was lower than that of normal corn (12.3 J/g), rice (13.2 J/g), and wheat (10.7 J/g; Singh et al., 2003), indicating that the initial gelatinization step requires less energy (ΔH = 4.31 J/g). Whilst Tp is a measure of crystallinity quality (possibly including double helix length), ΔH provides an overall measure of crystallinity (quality and quantity), and is regarded as an indicator of the loss of molecular order due to the disruption of hydrogen bonds within the granule (Cooke & Gidley, 1992). The gelatinization temperature of *Q. glandulifera Bl.* starch was lower than that of *Q. palustris Muenchh.* (73.7 °C). Furthermore, the gelatinization enthalpy of *Q. glandulifera Bl.* starch was lower than that of *Q. palustris Muenchh.* (20.8 J/g), which may be related to the fine structure of amylose and amylopectin molecules and to the crystallization of starch granules (Van Hung & Morita, 2007). Kaur, Singh, Ezekiel, and Guraya (2007) reported that Tp might be dependent on the long chains of amylopectin molecules, which require higher temperature and more energy.

4. Conclusion

The composition and nutritional quality of acorn seeds grown in China was investigated. The results revealed that acorn (*Q. glandulifera Bl.*) seeds contain high contents of starch. The fatty acids in acorn seeds were mostly UFAs; the UFA:SFA and SFA:MUFA:PUFA ratios were 2.6:1 and 1.25:1.34:1, respectively, comparable to those present in olive oil. *Q. glandulifera Bl.* seeds were good sources of vitamins A and E, Fe, Mn, and Zn according to USDA (2013) and FAO/WHO (2005), recommendations. Additionally, starch extracted from *Q. glandulifera Bl.* seeds had a variety of shapes and sizes (3.3–126.2 μm). The ratio between amylose and amylopectin was 23.61:74.72. The crystal type of acorn starch had an A-type pattern with 23.53% relative crystallinity. The gelatinization temperature was 66.53 °C and the transition enthalpy was 4.33 J/g, indicating the acorn starch is adequate for pasting applications.

Acorn seeds contain appreciable levels of nutrients, making them suitable as food supplements. More research should focus on the physicochemical properties, functional characteristics, and processing methods of acorns.

Acknowledgments

We gratefully acknowledge the staff of the University of Science and Technology of China for their support and comments during the preparation of this manuscript. This work was supported by grants from the National Science Foundation of China (No. 31271960) and the Science and Technology Department of Anhui Province of China (No. 1401032009).

References

Aguilera, M. P., Beltrán, G., Ortega, D., Fernández, A., Jiménez, A., & Uceda, M. (2005). Characterisation of virgin olive oil of Italian olive cultivars:Frantoio'andLeccino', grown in Andalusia. *Food Chemistry, 89*(3), 387–391.

AOAC (2000). *Official methods of analysis* (17th ed.). Washington: Association of Official Analytical Chemists.

Bainbridge, D. A. (1986). Use of acorns for food in California: past, present, future. In *Symposium on multiple-use management of California's hardwoods* (pp. 12–14).

Besbes, S., Blecker, C., Deroanne, C., Drira, N. E., & Attia, H. (2004). Date seeds: Chemical composition and characteristic profiles of the lipid fraction. *Food Chemistry, 84*(4), 577–584.

Charef, M., Yousfi, M., Saidi, M., & Stocker, P. (2008). Determination of the fatty acid composition of acorn (*Quercus*), *Pistacia lentiscus* seeds growing in Algeria. *Journal of the American Oil Chemists' Society, 85*(10), 921–924.

Chung, K. H., Shin, K. O., Hwang, H. J., & Choi, K. S. (2013). Chemical composition of nuts and seeds sold in Korea. *Nutrition Research and Practice, 7*(2), 82–88.

Cooke, D., & Gidley, M. J. (1992). Loss of crystalline and molecular order during starch gelatinisation: Origin of the enthalpic transition. *Carbohydrate Research, 227*, 103–112.

Dong, L., Piao, Y., Zhang, X., Zhao, C., Hou, Y., & Shi, Z. (2013). Analysis of volatile compounds from a malting process using headspace solid-phase microextraction and GC–MS. *Food Research International, 51*(2), 783–789.

FAO (1985). *Energy and protein requirements: Report of a joint FAO/WHO/UNU expert consultation (No. 724)*. World Health Organization.

FAO & World Health Organization (2005). *Vitamin and mineral requirements in human nutrition*.

Firestone, D. (2005). Olive oil. *Bailey's industrial oil and fat products*. Wiley Online Library. http://dx.doi.org/10.1002/047167849X.bio029.

Forsyth, J. L., Ring, S. G., Noel, T. R., Parker, R., Cairns, P., Findlay, K., et al. (2002). Characterization of starch from tubers of yam bean (*Pachyrhizus ahipa*). *Journal of Agricultural and Food Chemistry, 50*(2), 361–367.

Galván, J. V., Novo, J. J. J., Cabrera, A. G., Ariza, D., García-Olmo, J., & Cerrillo, R. M. N. (2012). Population variability based on the morphometry and chemical composition of the acorn in Holm oak (*Quercus ilex subsp.*). *European Journal of Forest Research, 131*(4), 893–904.

Hayakawa, K., Tanaka, K., Nakamura, T., Endo, S., & Hoshino, T. (1997). Quality characteristics of waxy hexaploid wheat (*Triticum aestivum L.*): Properties of starch gelatinization and retrogradation. *Cereal Chemistry, 74*(5), 576–580.

James, G. S. (1995). *Analytical chemistry of foods*. London: Blackie Academic and Professional, pp. 117–120.

Kaur, A., Singh, N., Ezekiel, R., & Guraya, H. S. (2007). Physicochemical, thermal and pasting properties of starches separated from different potato cultivars grown at different locations. *Food Chemistry, 101*(2), 643–651.

Kim, J. O. (1976). Chemical evaluation of acorn starch from three species of *Quercus*. *Korean Journal of Food Science and Technology, 8*(4), 230–235.

King, T. R., & Titus, H. W. (1943). Acorns of the Willow oak, *Quercus phellos*, a source of vitamin A activity. *Poultry Science, 22*(1), 56–60.

Lee, K. G., Mitchell, A., & Shibamoto, T. (2000). Antioxidative activities of aroma extracts isolated from natural plants. *Biofactors, 13*(1), 173–178.

León-Camacho, M., Viera-Alcaide, I., & Vicario, I. M. (2004). Acorn (*Quercus* spp.) fruit lipids: Saponifiable and unsaponifiable fractions: A detailed study. *Journal of the American Oil Chemists' Society, 81*(5), 447–453.

Liu, Q. (2005). Understanding starches and their roles in foods. In S. W. Cui (Ed.), *Food carbohydrates: Chemistry, physical properties, and applications* (pp. 327–329). CRC Press, Taylor and Francis Group, LLC.

Moore, S., & Stein, W. H. (1951). Amino acid determination, methods and techniques. *Journal of Biological Chemistry, 192*, 663–670.

Noda, T., Tsuda, S., Mori, M., Takigawa, S., Matsuura Endo, C., Hashimoto, N., et al. (2004). Properties of starches from potato varieties grown in Hokkaido [Japan]. *Journal of Applied Glycoscience (Japan)*.

Nwokocha, L. M., & Williams, P. A. (2011). Structure and properties of *Treculia africana*, (Decne) seed starch. *Carbohydrate Polymers, 84*(1), 395–401.

Özcan, T. (2006). Total protein and amino acid compositions in the acorns of Turkish *Quercus L. taxa*. *Genetic Resources and Crop Evolution, 53*(2), 419–429.

Paredes-Lopez, O., & Hernández-Löpez, D. (1991). Application of differential scanning calorimetry to amaranth starch gelatinization—Influence of water, solutes and annealing. *Starch-Stärke, 43*(2), 57–61.

Pérez-Pacheco, E., Moo-Huchin, V. M., Estrada-León, R. J., Ortiz-Fernández, A., May-Hernández, L. H., Ríos-Soberanis, C. R., et al. (2014). Isolation and characterization of starch obtained from *Brosimum alicastrum* Swarts Seeds. *Carbohydrate Polymers, 101*, 920–927.

Petrovic, S., Sobajic, S., Rakic, S., Tomic, A., & Kukic, J. (2004). Investigation of kernel oils of *Quercus robur* and *Quercus cerris*. *Chemistry of Natural Compounds, 40*(5), 420–422.

Rakić, S., Janković, S., Marčetić, M., Živković, D., & Kuzevski, J. (2014). The impact of storage on the primary and secondary metabolites, antioxidant activity and digestibility of oat grains (*Avena sativa*). *Journal of Functional Foods, 7*, 373–380.

Rakić, S., Petrović, S., Kukić, J., Jadranin, M., Tešević, V., Povrenović, D., et al. (2007). Influence of thermal treatment on phenolic compounds and antioxidant properties of oak acorns from Serbia. *Food Chemistry, 104*(2), 830–834.

Rakić, S., Povrenović, D., Tešević, V., Simić, M., & Maletić, R. (2006). Oak acorn, polyphenols and antioxidant activity in functional food. *Journal of Food Engineering, 74*(3), 416–423.

Ratnayake, W. S., Hoover, R., Shahidi, F., Perera, C., & Jane, J. (2001). Composition, molecular structure, and physicochemical properties of starches from four field pea (*Pisum sativum L.*) cultivars. *Food Chemistry, 74*(2), 189–202.

Singh, N., Singh, J., Kaur, L., Sodhi, N. S., & Gill, B. S. (2003). Morphological, thermal and rheological properties of starches from different botanical sources. *Food Chemistry, 81*(2), 219–231.

Stevenson, D. G., Jane, J. L., & Inglett, G. E. (2006). Physicochemical properties of pin oak (*Quercus palustris Muenchh.*) acorn starch. *Starch-Stärke, 58*(11), 553–560.

Svegmark, K., & Hermansson, A. M. (1993). Microstructure and rheological properties of composites of potato starch granules and amylose: A comparison of observed and predicted structures. *Food Structure, 12*, 181–193.

Torruco-Uco, J., & Betancur-Ancona, D. (2007). Physicochemical and functional properties of makal (*Xanthosoma yucatanensis*) starch. *Food Chemistry, 101*(4), 1319–1326.

USDA (2013). *Dietary reference intakes: Recommended intakes for individuals, dietary guidance*. Food and Nutrition Information Center.

Van Hung, P., & Morita, N. (2007). Chemical compositions, fine structure and physicochemical properties of kudzu (*Pueraria lobata*) starches from different regions. *Food Chemistry, 105*(2), 749–755.

Wagnon, K. A., & Hart, G. H. (1945). Durango root (datisca–glomerata) poisoning of range stock. *Journal of the American Veterinary Medical Association, 107*(820), 3–5.

Xie, B. X., & Xie, T. (2002). Exploitation study of acorn resources in China. *Journal of Central South Forestry University, 22*(3), 37–41.