Study on the Fatty Acids, Aromatic Compounds and Shelf Life of *Paeonia ludlowii* Kernel Oil

Chao-Qi Zhang¹, Yuan-Jiang Xu¹,², Ya-Zhou Lu¹, Lian-Qiang Li¹, Xiao-Zhong Lan¹* and Zheng-Chang Zhong¹*

¹ TAHHC-SWU Medicinal Plant Joint R&D Centre, Tibetan Collaborative Innovation Centre of Agricultural and Animal Husbandry Resources, Food Science College, Xizang Agricultural and Animal Husbandry University, Nyingchi of Tibet 860000, CHINA
² Research Institute of Tibet Plateau Ecology, Tibet Agriculture & Animal Husbandry University, Nyingchi of Tibet 860000, CHINA

Abstract: To determine the food potential of *Paeonia ludlowii* D.Y.Hong (*P. ludlowii*) kernel oil, in this study, we analysed the fatty acid composition and volatile components of this oil, compared the antioxidant effects of two natural antioxidants on it, and then predicted its shelf life at room temperature (25°C). The results showed that *P. ludlowii* kernel oil mainly contained 20 fatty acids, of which linoleic acid, oleic acid and other unsaturated fatty acid contents together made up 86.99%. The aromatic composition of the crude *P. ludlowii* kernel oil was analysed, and 34 aromatic compounds were obtained, including 5 lipids (2.30%), 9 alcohols (12.64%), 6 aldehydes (14.67%), 2 alkanes (1.30%), 5 acids (2.70%), 1 ketone (0.41), 2 alkenes (39.12%) and 4 other substances (26.85%). The effects of the antioxidants were ranked as follows: 0.04% tea polyphenols + crude oil > 0.04% bamboo flavonoids + crude oil > crude oil. In addition, the shelf lives at room temperature (25°C) of each kernel oil-antioxidant mixture were 200.73 d, 134.90 d and 131.61 d, respectively. Overall, these results reveal that *P. ludlowii* kernel oil is a potential candidate for a new high-grade edible oil, and its development has broad application prospects.

Key words: *Paeonia ludlowii* kernel oil, unsaturated fatty acids, aromatic substance, shelf life, natural antioxidants

1 Introduction

In 1936, the Englishman Ludlow discovered *Paeonia ludlowii* during his investigation in Tibet. In 1953, he published an article in the British "Botanical Magazine" naming *Paeonia ludlowii*. It is a deciduous shrub of the genus *Paeonia* in the family Ranunculaceae, a subspecies of *Paeonia delavayi*, and it is endemic to Tibet. It is distributed only in a narrow range of approximately 100 km in length in Brahmaputra Canyon at an altitude of 2900~3200 m; it is one of the eight peony species in China. However, the distribution range of *P. ludlowii* is narrow, its population is small, and it is considered endangered, as it is included in the "Chinese Red List of Species". China issued the "Announcement of the Ministry of Health on Approving *Acer truncatum* kernel oil and Peony seed oil as New Food Resources" on March 22, 2011, approving Peony seed oil as a new food resource; thus, peony seed oil has officially become an edible oil from a woody plant in China. According to the literature, *P. ludlowii* can be used as a new material for the development of oil peony varieties.

Local Tibetans began to treat gynaecological ailments, skin diseases, and cardiovascular and cerebrovascular diseases with the root bark of *P. ludlowii* hundreds of years ago. In recent years, compounds from *P. ludlowii* have shown strong anti-tumour, anti-inflammatory, and other activities. Therefore, more efforts should be devoted to the propagation of *P. ludlowii* in the future to change its endangered status and allow *P. ludlowii* to fulfill its important medicinal and edible potential as soon as possible.

To the author's knowledge, a detailed study of the chemical composition and aromatic substances of *P. ludlowii* kernel oil and a prediction of its shelf life has not been reported in the literature. Therefore, this work set out to determine the fatty acid composition and aromatic composition of this oil by gas chromatography. Then, the OXITEST (an oil oxidation analyser adopted by AOCS, CD 12c-16) method was used to determine the oxidation stability of *P. ludlowii* kernel oil with different natural antioxidants. Then, the shelf life of the oil at room temperature (25°C) was inferred, and the effects of different natural antioxidants in *P. ludlowii* kernel oil were studied. The results...
provided here may provide a reliable theoretical basis for quality evaluation of this oil, the influence of different shelf life durations on its content of unsaturated fatty acids and the changes in its aromatic components, and the effects and mechanisms by which temperature change causes the changes in its two antioxidant components.

2 Experimental Details

2.1 General

Gas chromatography-mass spectrometry instrument: Thermo TRACE GC Ultra - DSQ II; ultrapure water instrument: Beijing Puri General Instrument Co., Ltd., Ltd.; analytical balance, Mettler Toledo Instrument Co., Ltd., al204-ic, sensitivity 0.0001 g; LYNX4000 high speed centrifuge, Thermo Fisher Technology Co., Ltd.; R-1001vn rotating evaporator, Zhengzhou Great Wall Technology Industry and Trade Co., Ltd.; Xlw-1500y crusher, Yongkang Xin Longwei Industry and Trade Co., Ltd.; VELP OXITEST oil oxidation analyser, VELP Scientifica SRL, Italy.

2.2 Chemicals

Unless otherwise stated, the reagents used in this method were analytically pure, and the water was ultrapure. Hexane (pure by chromatography), acetyl chloride (98%), n-heptane (pure by chromatography), methanol (pure by chromatography), anhydrous sodium sulfate, and sodium carbonate were purchased from Shanghai McLean Biochemical Technology Co., Ltd. Bamboo leaf flavonoids (40% purity) and tea polyphenols (98% purity) were purchased from Shanghai Yuanye Biotechnology Co., Ltd.

2.3 Plant material

*P. ludlowii* kernels were collected in Mirui township, Nyingchi city, Tibet, in October 2018 and identified as *P. ludlowii* kernels by Professor LAN Xiaozhong, School of Food Science, Tibet Agriculture and Animal Husbandry University. *P. ludlowii* kernels were obtained by removing the black outer kernel coats of *P. ludlowii* kernels and then pressed after drying.

2.4 Fatty acid composition analysis

2.4.1 GC-MS conditions

Chromatographic column: HP-WAX; column length: 30 m; internal diameter: 0.25 mm; film thickness: 0.25 μm. Inlet temperature: 270°C. Programmed temperature rise: the initial column temperature was 40°C; it was maintained for 1 min, raised to 210°C at 7°C/min, maintained for 5 min, and then raised to 240°C at 1.5°C/min. Carrier gas: high purity helium (purity > 99.9999%), flow rate: 1.0 mL/min. Injection method: split.

Injection quantity: 1 μL. Mass spectrometry reference conditions: ionization mode: electron bombardment ionization source (EI); ionization energy: 70 eV; transmission line temperature: 280°C; ion source temperature: 230°C; solvent delay: 5 min; scanning mode: selected ion scanning (SIM).

2.4.2 Sample methyl esterification

Samples were weighed to 0.5 g and placed into 50 mL centrifuge tubes; then, 5 mL n-hexane and 15 mL of 10% acetyl chloride - methanol solution were added, the bottle mouth was sealed, and the samples were incubated for 2 h at 80°C in a water bath response with shaking once every 20 min. Then, the samples were removed and cooled at room temperature, and 10 mL 6% sodium carbonate and 5 mL n-hexane were added. After 30 min oscillation, the supernatant was removed and passed through a 0.22 μm filter membrane. When the concentration was too high, it was diluted it 100 times and then tested. Blank test: blank samples were subjected to the same protocol as the samples except that no samples were included.

2.5 Analysis of volatile flavour substances in *P. ludlowii* kernel oil samples

2.5.1 Extraction of volatile flavour compounds from *P. ludlowii* kernel oil

Five grams of *P. ludlowii* kernel oil was weighed and placed in the bottom of a headspace bottle. The extraction needle was aged to ensure the removal of any volatile components that might have been adsorbed, and the aged extraction needle was inserted into the headspace bottle by pushing the quartz fibre head through the handle and exposing it to the upper part of the gas in the headspace bottle. One millilitre of the upper gas was taken from the sample. The headspace bottle was placed in a water bath at a constant temperature of 55°C for extraction for 30 min and stirred at 200 rpm/min. Then, the quartz fibre head was pushed back into the needle while pulling it out, the sample was inserted into the GC-MS sampler, and the instrument was set to collect data.

GC-MS analysis conditions.

Chromatographic conditions: chromatographic column methylpolysiloxane capillary column (50 m × 0.32 mm × 0.5 μm). The inlet temperature was 230°C, the carrier gas (He) flow rate was 1.0 mL/min, and the shunt ratio was 10:1. The heating procedure of the column temperature box was as follows: the initial temperature was 40°C, the temperature was maintained for 3 min, and the temperature was raised to 230°C at 5 degrees/min and then maintained for 1 min. The solvent delay time was 3 min.

Mass spectrometry conditions: detection method: mass scanning method, 35 m/z-600 m/z. Ionization mode: EI source, electron energy 70 ev. The ionization voltage was −70 V, and the temperature of the ion source was 230°C. Headspace injection conditions for oil sample: 1 mL upper layer of gas from oil sample. The heating temperature was 55°C, the heating time was 30 min, and the stirring rate...
was 200 rpm/min.

2.6 Prediction of shelf life of *P. ludlowii* kernel oil

The induction periods 110°C, 90°C, and 70°C were measured by a VELP-Oxygen Oxidation Analyser (OXITEST) for *P. ludlowii* kernel oil. The measurement conditions were as follows: the sample size was 5 g; the oxygen pressure was 6 bar; and the specific steps were as follows: weigh 5 g of sample, spread it evenly on the surface of the reaction tank, and heat to the set temperature to start the measurement. The OXITEST provides relatively stable results for a short period of time in an environment where the food is sealed at room temperature and oxygen is not over-pressurized. When the temperature is increased and the atmosphere is pressurized, the food’s own inhibitory effect on fat oxidation will be weakened. This instrument records changes in oxygen pressure due to food oxidation and can therefore reveal the oxidative stability of food oil. After the oxidation experiment, the OXISoft™ software automatically calculates the IP value of each sample run using the IP results obtained at different temperatures. When the results correspond to a linear equation, the dedicated OXISoft™ program estimates the shelf life of the product. With reference to GB 2760-2014 "National Food Safety Standard Food Additive Use Standards", two natural antioxidants, tea polyphenols and bamboo leaf flavones, were both applied at 0.04 %. To ensure that the antioxidants were fully dissolved, ultrasonic treatment was used as needed.

2.7 Statistical analysis

Excel 2010 and Origin 8.1 were used to produce graphs. The OXISoft™ program, which automatically calculates the IP value of each sample run, was used to estimate shelf life.

3 Results and Discussion

3.1 Fatty acid composition analysis of *P. ludlowii* kernel oil

Total ion chromatograms of fatty acid methyl esters and ion flow diagrams of *P. ludlowii* kernel oil samples were obtained by GC-MS detection and analysis (Supporting Information, Fig. 1). Twenty fatty acid methyl esters were detected in the *P. ludlowii* kernel oil samples (Table 1). Among them, six unsaturated fatty acids accounted for 86.99 % of the total fatty acids, three monounsaturated fatty acids accounted for 41.60 %, three polyunsaturated fatty acids accounted for 45.39 %, and saturated fatty acids accounted for 13.01 % of the total fatty acids. According to the peak area normalization method, palmitic acid (8.95 %), oleic acid (41.56 %), linoleic acid (15.08 %), and α-linolenic acid (29.56 %) were the main fatty acid components of *P. ludlowii* kernel oil. α-linolenic acid is sometimes called "plant brain gold" for its functions of lowering blood lipids and cholesterol and promoting fat metabolism and liver cell regeneration. Common peony seed oil generally has an α-linolenic acid content of over 32 %, while its content in *P. ludlowii* kernel oil was lower (29.56 %). Similar to hazelnut oil, the compound making up the highest percentage of
C.-Q. Zhang, Y.-J. Xu, Y.-Z. Lu et al.

The fatty acids was oleic acid, but the oleic acid content of *P. ludlowii* kernel oil was only approximately half that of hazelnut oil. The results of the fatty acid analysis of *P. ludlowii* kernel oil were similar to those of Zeng, showing large differences in the composition and content of fatty acids between *P. ludlowii* kernel oil and peony kernel oil and among the main fatty acids of *P. ludlowii* kernel oil, as follows: oleic acid > α-linolenic acid > linoleic acid > palmitic acid > stearic acid. However, in most common peony kernel oil, the α-linolenic acid content is the highest, followed by linolenic acid > linoleic acid > oleic acid > palmitic acid > stearic acid. There are also rare odd-carbon fatty acids in *P. ludlowii* kernel oil, including undecanoic acid, pentadecanoic acid, heptadecanoic acid, heocene decanoic acid, and tricosoic acid. Notably, odd-carbon fatty acids have strong physiological activity, so it can be speculated that the physiological activity of *P. ludlowii* kernel oil may be related to the odd-carbon fatty acids it contains. It has also been reported worldwide that odd-carbon fatty acids have anticancer effects. Overall, these results show that *P. ludlowii* kernel oil is a new oil with a high content of unsaturated fatty acids, and it has broad research and application value in food, health care products, medicine and other fields.

### 3.2 Analysis of volatile aromatic components of *P. ludlowii* kernel oil

#### 3.2.1 Analysis of the types and contents of aroma substances of *P. ludlowii* kernel oil

Headspace solid-phase microextraction-gas chromatography-mass spectrometry (HS-SPME-GC-MS) was used to analyse the volatile aromatic components in the samples, and total ion chromatograms were obtained (Fig. 2). The flavour of vegetable oil is mainly affected by plant variety, maturity, planting area and storage conditions, and *P. ludlowii* kernel oil should have its own characteristic aromatic components. A total of 34 volatile components of *P. ludlowii* kernel oil were identified by GC-MS (Table 2), in-

| Serial number | Retention time (min) | Carbon/Unsaturated number | Compound name          | Relative content/% | Scanning-ion |
|---------------|----------------------|---------------------------|------------------------|--------------------|--------------|
| 1             | 14.36                | C10:0                      | Decanoic acid          | 0.02               | 74           |
| 2             | 16.09                | C11:0                      | Undecanoic acid        | 0.04               | 74           |
| 3             | 17.74                | C12:0                      | Lauric acid            | 0.07               | 74           |
| 4             | 19.31                | C13:0                      | Thirteen (alkane) acid | ND.                | 74           |
| 5             | 20.81                | C14:0                      | Myristic acid          | 0.15               | 74           |
| 6             | 22.25                | C15:0                      | Pentadecanoic acid     | 0.13               | 74           |
| 7             | 23.65                | C16:0                      | Palmitic acid          | 8.95               | 74           |
| 8             | 23.99                | C16:1                      | Palm oleic acid        | 0.17               | 51           |
| 9             | 24.96                | C17:0                      | Pearl acid             | 0.37               | 74           |
| 10            | 26.36                | C18:0                      | Stearic acid           | 1.85               | 74           |
| 11            | 26.73                | C18:1n9                    | Oleic acid             | 41.56              | 55           |
| 12            | 27.48                | C18:2n6                    | Linoleic acid          | 15.08              | 67           |
| 13            | 28.75                | C18:3n3                    | α-Linolenic acid       | 29.56              | 79           |
| 14            | 30.23                | C20:0                      | Icosanoic acid         | 0.44               | 74           |
| 15            | 30.74                | C20:1                      | Eicosenic acid         | 0.32               | 55           |
| 16            | 32.01                | C20:2n6                    | Eicosadienic acid      | 0.24               | 67           |
| 17            | 32.88                | C21:0                      | 21 alkanoic acid       | 0.24               | 74           |
| 18            | 35.83                | C22:0                      | 22 acid                | 0.28               | 74           |
| 19            | 39.07                | C23:0                      | 23 carboxylic acid     | 0.26               | 74           |
| 20            | 42.54                | C24:0                      | 24 alkanoic acid       | 0.28               | 74           |

Total saturated fatty acid                           13.01
Total unsaturated fatty acids                        86.99
Monounsaturated fatty acid                           41.60
Polysaturated fatty acids                            45.39

Note: "ND." means not detected. The contents were calculated by methyl esters of fatty acids.
Study on the Fatty Acids, Aromatic Compounds and Shelf Life of Paeonia ludlowii Kernel Oil

Aldehydes and other compounds accounted for a large proportion of the total, followed by aldehydes and alcohols. At present, there is no literature on the aromatic components of P. ludlowii kernel oil. Most studies of this type have focused on flax kernel oil, tea kernel oil, olive oil and so on. Yu\(^{21}\) studied 27 volatile components of cold-pressed flax kernel oil and identified fewer species than appeared in citral this experiment. It was found that styrene and \(m\)-xylene accounted for a large proportion of the aromatic components of P. ludlowii kernel oil, in contrast to flax kernel oil, and these compounds endowed peony seed oil with its unique, smooth fragrance. At the same time, it can be clearly seen that there were some differences in the main volatile compounds of P. ludlowii kernel oil (Fig. 3). The contents of various volatile substances were ranked as follows: alkenes > other compounds > aldehydes > alcohols > acids > esters > alkanes > ketones. The other compounds mainly included 4 species, naphthalene, N-dimethyl acetamide, n-butyl chloride, and 1,3-xylene, the contents of which were as follows: 0.29 μg/mL, 1.83 μg/mL, 1.56 μg/mL, 23.17 μg/mL, respectively. The aromatic components accounted for 26.85% of the total, indicating that these substances made important contributions to the aromatic qualities of P. ludlowii kernel oil.

3.2.2 Analysis of different classes of key aromatic substances in P. ludlowii kernel oil

Aldehyde compounds generally produce fragrant flavours and are mainly found in oily and nutty foods. Most aldehydes play positive roles in oil flavour\(^{22,23}\). The main aldehydes are benzaldehyde (6.80%), citral (3.87%), (E)-2-decenal (1.46%), 1-octyl aldehyde (1.17%), 2-undecenal (1.09%), and so on. It can be seen that benzaldehyde is an aromatic compound and is the Strecker degradation product of phenylalanine, which has an almond-like taste\(^{24,25}\). In general, the aldehydes found in vegetable oils ranging from C5 to C9 tend to taste fatty, fruity or grassy; thus, it can be seen that aldehydes are an important aromatic component of P. ludlowii kernel oil. The main alcohols included nonyl alcohol (4.60%), benzyl alcohol (3.47%), 1-hexanol (1.17%) and \(n\)-decanol (1.02%). Alcohols usually carry the aromatic smells of plants, and here, the contents of nonyl alcohol and benzyl alcohol were higher than those of the other alcohols. Nonyl alcohol has a fruity, waxy aroma, while benzyl alcohol has a weak fruity aroma. The acid compounds mainly included acetic acid (1.40%), mono-hydroxybutyric acid (0.42%), ethyl benzoic acid (0.32%), \(n\)-hexanoic acid (0.34%) and carboxylic acid (0.22%). Acetic acid was the most important volatile acid in P. ludlowii kernel oil and has aromatic characteristics similar to those of vinegar. Among the alkenes and other compounds, styrene and \(m\)-xylene were the main compounds, with contents as high as 38.49% and 23.17%, respectively, accounting for a relatively high proportion of all the detected components. The flavours of hydrocarbon compounds are usually fragrant and sweet, and those of alkenes with branched chains are more obvious\(^{26}\). Thus, hydrocarbons have a strong effect on the flavour of P. ludlowii kernel oil. Only geranyl acetone (0.41%) was detected among ketones, and its content was low. The overall content of alkanes was also low at only 1.3%.

A total of 5 lipids were detected, primarily methyl benzoate (0.83%). A previous study showed that the lipid components had fruity and flowery fragrances and could cover the unpleasant smells caused by free fatty acids and improve the aroma characteristics of the oil\(^{27}\). Overall, the volatile aromatic substances in pressed P. ludlowii kernel oil included mainly aldehydes and alcohols, but the presence of other aliphatic compounds in P. ludlowii kernel oil provided additional different flavours.

3.3 Effects of antioxidant addition on the shelf life of P. ludlowii kernel oil

A good linear fitting relationship between InP and T was found; with increasing temperature, the oxidation induction time was gradually shortened by approximately 50% per 10°C temperature increment (Fig. 4). These results indicate that the oxidation stability of P. ludlowii kernel oil is very sensitive to changes in temperature when exposed to a stable oxygen level. The control P. ludlowii kernel oil had the shortest oxidation induction time (1.15 h) at 110°C,
and at normal room temperature (25°C), its shelf life was 131.61 d. However, adding two different natural antioxidants prolonged the oxidation induction time of *P. ludlowii* kernel oil to varying degrees, indicating that these natural antioxidants had a certain inhibitory effect on the oxidation of *P. ludlowii* kernel oil. The oxidation induction time of *P. ludlowii* kernel oil at 110°C after adding flavonoids from bamboo leaves was 2.0 h, and the shelf life was 134.90 d at normal room temperature (25°C); after adding tea polyphenols, the oxidation induction time of *P. ludlowii* kernel oil at 110°C was the longest, reaching 7.41 h, and the shelf life at 25°C was 200.73 d. The antioxidant

### Table 2

The total ion chromatogram was retrieved and analyzed by mass spectrometry to obtain volatile flavor substances and their relative contents.

| Molecular formula | CAS Number | Compound name            | Retention time | Relative content % |
|-------------------|------------|--------------------------|----------------|--------------------|
| C8H10             | 108-38-3   | 1,3-Xylene               | 5.15           | 23.17              |
| C4H9Cl            | 109-69-3   | N-butylchloride          | 5.22           | 1.56               |
| C8H8              | 100-42-5   | Cinnamene                | 6.82           | 38.49              |
| C8H16O            | 124-13-0   | 1-Octanal                | 7.33           | 1.17               |
| C6H14O            | 111-27-3   | 1-Hexyl alcohol          | 8.19           | 1.17               |
| C9H18O            | 124-19-6   | Germanium aldehyde      | 8.75           | 3.87               |
| C4H9NO            | 127-19-5   | N-Dimethyl acetamide     | 9.06           | 1.83               |
| C8H16             | 16746-86-4 | 2,3-Dimethyl-1-Hexene    | 9.25           | 0.63               |
| C2H4O2            | 64-19-7    | Methyl ant acid          | 9.43           | 0.41               |
| C2H4O2            | 107-31-3   | Acetic acid              | 9.43           | 1.40               |
| C7H16O            | 111-70-6   | 1-Heptanol               | 9.57           | 0.55               |
| C8H18O            | 104-76-7   | 2-Ethyl-1-Hexyl alcohol  | 10.01          | 0.26               |
| C16H34            | 544-76-3   | Hexadecane               | 10.11          | 0.40               |
| C7H6O             | 100-52-7   | Benzaldehyde             | 10.43          | 6.80               |
| C9H18O            | 31502-14-4 | Trans-2-Nonene-1-Alcohol | 10.62          | 0.91               |
| C10H20O           | 2404-44-6  | 1,2-Epoxy decane         | 10.62          | 0.90               |
| C8H8O2            | 93-58-3    | Methyl benzoate          | 11.67          | 0.83               |
| C6H14O3           | 111-90-0   | Ethyl carbitol           | 11.67          | 0.33               |
| C4H8O3            | 591-81-1   | γ-Hydroxybutyric acid    | 11.75          | 0.42               |
| C10H18O           | 3913-81-3  | (E)-2-Decenaldehyde      | 11.93          | 1.46               |
| C9H20O            | 143-08-8   | Nonyl alcohol            | 12.1           | 4.60               |
| C9H10O2           | 93-89-0    | Ethyl phenyl acid        | 12.2           | 0.32               |
| C6H10O2           | 695-06-7   | γ-Caprolactone           | 12.64          | 0.22               |
| C10H8             | 91-20-3    | Parallel benzene         | 13.07          | 0.29               |
| C11H20O           | 2463-77-6  | 2-Undecenal              | 13.18          | 1.09               |
| C10H22O           | 112-30-1   | N-decyl alcohol          | 13.27          | 1.02               |
| C10H16O           | 25152-84-5 | Trans-2,4-Decadienal     | 13.83          | 0.28               |
| C6H12O2           | 142-62-1   | N-hexanoic acid          | 14.12          | 0.34               |
| C13H22O           | 3796-70-1  | Vanilla acetone          | 14.29          | 0.41               |
| C7H8O             | 100-51-6   | Benzyliccohol            | 14.51          | 3.47               |
| C12H26O           | 112-53-8   | Twelve alcohol           | 15.46          | 0.33               |
| C6H6O             | 108-95-2   | Methyl hexadecanoate     | 15.79          | 0.22               |
| C17H34O2          | 112-39-0   | Methyl hexadecanoate     | 17.87          | 0.27               |
| C19H36O2          | 112-62-9   | (Z)Methyl oleate         | 19.88          | 0.57               |

and the shelf life at 25°C was 200.73 d. The antioxidant
effects can be ranked as follows: tea polyphenols + crude kernel oil > bamboo leaf flavonoids + crude kernel oil > crude kernel oil. There was a linear relationship between the ln(IP) of P. ludlowii kernel oil and temperature (Fig. 4), as follows: crude oil, \( \ln(IP) = -0.092787 \times T + 10.377585 \), \( R^2 = 0.986241 \); flavonoids from bamboo leaves, \( \ln(IP) = -0.088276 \times T + 10.289952 \), \( R^2 = 0.994963 \); tea polyphenols, \( \ln(IP) = -0.075688 \times T + 10.372250 \), \( R^2 = 0.997867 \). These results are consistent with the research by Xiao and Hasenhuettl. The OXITEST method can be used to extrapolate the storage periods of edible oils at room temperature; therefore, it was deduced from this equation that the shelf lives of the crude kernel oil and the oils with bamboo flavonoids and tea polyphenols added were predicted to be 332.86 d, 326.28 d and 427.89 d at 15°C, respectively. The shelf lives of these P. ludlowii kernel oil formulations were extrapolated as follows: tea polyphenols + crude oil > crude oil > bamboo leaf flavonoids + crude oil. Intriguingly, these results are not consistent with the shelf life results at normal room temperature (25°C), and it is clear that after 110°C, the crude oil ln(IP) exceeded that of the oil containing bamboo flavonoids (Fig. 4). This phenomenon may be related to the chemical structures of the antioxidants or the antioxidant content of the oil itself, so the established equation can be applied to only a certain temperature range and cannot accurately extrapolate the shelf life of P. ludlowii kernel oil outside the measured temperature range.

4 Conclusions
The current study shows that P. ludlowii kernels are a valuable source of plant kernel oil. This oil has a high level of polyunsaturated fatty acids (86.99%), and there are a small amount of odd-carbon fatty acids (1.04%), which are important in health and medicine. In addition, there are 34 kinds of aromatic components in the oil. The results also showed that the oxidation stability of the oil at 25°C without adding antioxidants is good (131.61 d), which is very important for food safety. Overall, P. ludlowii kernel oil is a potential candidate for a new type of high-grade vegetable-derived edible oil.

Author Contributions
C.Z. and X.L. conceived and designed the work; Y.X., C.Z. and Y.L. collected samples; C.Z. and Z.Z. performed the experiments; C.Z. wrote the manuscript; Y.X. and C.Z. analysed the data; C.Z., Y.L. and X.L. revised the manuscript; X.L. and Z.Z. provided funding support. All authors gave final approval of the paper.

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