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Research Article

Quality Evaluation of Thirteen Geographical Populations of *Lycium chinense* Using Quantitative Analysis of Nutrients and Bioactive Components

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Lycium chinense Mill. is an important medicinal and edible perennial plant that has been developed as a popular vegetable and healthcare tea in southern China in recent years. In this study, we evaluated the nutritional quality of 13 different geographical *L. chinense* populations through a common-garden experiment. There were significant differences ($P < 0.05$) in active components and nutrient elements among the populations. Principal component and clustering analyses showed that populations in the central China showed better integrated quality than the other populations; populations in southern China also showed good prospects for further development, having special characteristics such as high contents of amino acids, total flavonoids, and chlorogenic acid. Moreover, all the populations had much higher contents than most vegetables of flavonoids and of the mineral elements Fe, Se, Mn, and K. These results provide important information required for the development of *L. chinense* germplasm resources and to ensure the sustainable utilization of *L. chinense*.

1. Introduction

Lycium L. (Solanaceae) is a genus of important medicinal and edible perennial shrubs, comprising seven species and two varieties in China; *Lycium chinense* Mill. and *Lycium barbarum* L. have been a widely cultivated and are globally traded commodities [1, 2]. *L. chinense* is widely distributed in central, southern, and northwest China; its leaves are referred to as "TianJingCao" in "Ben Cao Gang Mu," the Compendium of Materia Medica [3]. Containing abundant nutritional and functional components, its leaves and young shoots contain compounds that have antioxidant and antiaging actions, strengthen muscles and bones, improve eyesight, reduce blood sugar and blood pressure, enhance memory, and regulate nerve functioning [1, 2, 4, 5]. Additionally, it has recently been developed as a popular vegetable and healthcare tea in southern China [6, 7].

As a widely distributed species, high-quality information about its various natural populations is a prerequisite to identify source populations for the sustainable breeding, cultivation, and use of *L. chinense*. Currently, most studies have been conducted on *L. barbarum* [8, 9]; yield, function, and taste were found to be key quality variables in the comprehensive evaluation system [10, 11]. However, there have been relatively few studies of quality variation among different geographical resources for *L. chinense*. With respect to the main evaluation indicators (taste, yield, medicinal, and nutritional quality), shoot tip, tender stem, and leaves of *L. chinense* have been appraised as a first-grade vegetable [12, 13]. Several valuable cultivars of *L. chinense* have been obtained by regional screening of wild resources [13, 14].

The leaves of *L. chinense* contain plentiful amounts of polysaccharides, flavonoids, rutin, chlorogenic acid, alkaloids, terpenoids, steroids, proteins, trace elements, mineral elements, and vitamins [7,15–17]. Rutin and chlorogenic

acid were the dominant polyphenols in *L. chinense* [6, 7]. The contents of proteins, trace elements, mineral elements, and vitamins of *L. chinense* were reported to be much high than those of many vegetables [14, 18]. Meanwhile, studies have shown that there are significant differences in the levels of active constituents, such as phenolic compounds, polysaccharides, and metallic elements, between different geographical resources [8, 19, 20]. Information about the quality of various natural populations is a prerequisite for formulating a germplasm collection strategy and identifying the source population for breeding and cultivation purposes. This will help to ensure the sustainable use of *L. chinense*.

Common-garden cultivation describes the practice of cultivating individuals from different populations and different habitats in the same garden. This ensures the same culture conditions and helps to eliminate phenotypic variation induced by environmental factors [21]. Common-garden experiments can be used to analyse phenotypic variation among different populations; they are thus ideal for examining how genetic and environmental factors affect resource quality. Common-garden experiments have become an important method in resource evaluation [22].

Our objective was to investigate variation in the levels of the main active compounds and nutrient elements among different *L. chinense* populations, using a common-garden experiment. We aimed to provide information about the nutritional quality of *L. chinense*, which will assist in functional food development using this plant. Our study will enhance our ongoing efforts in the domestication and cultivation of traditional Chinese medicinal and functional plants.

2. Materials and Methods

2.1. Materials and Reagents. Individuals from 13 natural populations of *L. chinense* were randomly collected from its main natural range across eight provinces in China, including Yuncheng City in Shanxi province (YC), Huining County in Gansu province (HN), Xinji City in Hebei province (XJ), Jiujiang City in Jiangxi province (JJ), Luotian County (LT), Jianli County (JL), Shishou City (SS), Xinshan County (XS), Shiyan City (SY), and Jingzhou City (JZ) in Hubei province, Guilin City in Guangxi Autonomous Region (GL), Guangzhou City in Guangdong province (GZ), and Kunming City in Yunnan province (KM) (Figure 1). From each population, 10–15 individuals were translocated into the Wuhan Botanical Garden of the Chinese Academy of Sciences in 2015, where the annual temperature, annual relative humidity, and annual yearly precipitation were 17.1°C, 80.7%, and 1455.7 mm, respectively, in 2015–2017. Common-garden cultivation was used, including the same soil formula (20% sand, 30% humus, and 50% garden soil) and light intensity (200–650 μmol m^{-2}s^{-1}), measured at 10'o clock in June.

Standards of rutin and anhydrous glucose were purchased from the National Institutes for Food and Drug Control (Beijing, China). Standards of chlorogenic acid were purchased from Shanghai Yuanye Biotechnology Co., Ltd. (Shanghai, China). Standards of amino acids and vitamin C were purchased from Alta Scientific Ltd (Tianjin, China). Other reagents of analytical grade were used, including phenol, ethanol, methanol, acetonitrile, and concentrated sulphuric acid (Sinopharm Chemical Reagent Co., Ltd., Shanghai, China).

2.2. Elemental Determination

2.2.1. Index Measurement of Raw Medicinal Materials. Fifty individuals of each population were randomly sampled on April 2, 2017 (because *L. chinense* mainly reproduces asexually by belowground rhizomes in nature, the number of individuals per population increased in a large amount after two years). From each individual, we randomly collected five lignified healthy tender stem with leaves. The samples were cleaned and divided into two groups. One was packaged immediately in a sample box with an ice bag and sent for analysis of crude protein, crude fibre, vitamin C, amino acids, mineral elements, and reducing sugar content on fresh weight basis (fw). The other was dried in the shade for 24 hours, oven-dried at 45°C, ground, and kept dry and sealed, for the analysis of polysaccharides, flavonoids, rutin, and chlorogenic acid content on dry weight basis (dw). Each experiment was repeated three times ($n = 3$).

2.2.2. Determination of Polysaccharide and Reducing Sugar Contents. An improved phenol-sulphuric acid method was used for analysing polysaccharide contents [23]. Plant tissue samples of 1.0 g were added to 25 mL of water and shaken; the crude extract was extracted at 100°C using a water bath for two separate 1 h periods, before being filtered through a filter paper. Then, the merged filtrate was concentrated into 10 mL, and 5 mL concentrate was added to 25 mL 95% ethanol solution. The extract was then centrifuged at 3500 rpm for 10 min; the sediment was dissolved in water to 50 mL, and a sample of this polysaccharide solution was then taken for analysis. Then, 1 mL polysaccharide solution was measured into a plug test tube, and 1 mL of 5% phenol solution and 6 mL of concentrated sulphuric acid (1.84 g/L) were added in sequence; the solution was shaken and left to stand for 40 min at 25°C. The regression equation of glucose (Glu) $y = 0.5166X - 0.0029$, $r = 0.9999$, was drawn by plotting six concentrations (20–100 μg/ml) against their absorbances and was calculated with RSD lower than 2.57% and accuracy 99.21%–102.36%. The absorbance of the solution was used to quantify polysaccharides based on the regression equation of glucose. All the standards and samples were tested using the V-1800PC spectrophotometer (Shanghai Mapada Instruments Co., Ltd., Shanghai, China). The determination wavelength was 484 nm. The results were expressed as mg·Glu/g (dw).

The reducing sugar content was determined according to the method of GB 5009.7-2016 (the first method) [24]. Plant tissue samples of 3.0 g each were added to 50 mL of water, 5 mL of zinc acetate solution (219 g/L), and 5 mL of potassium ferrocyanide solution (106 g/L) in sequence, and fixed to 250 mL; the solution was left to stand for 30 min before being filtered through filter paper. The filtrate was

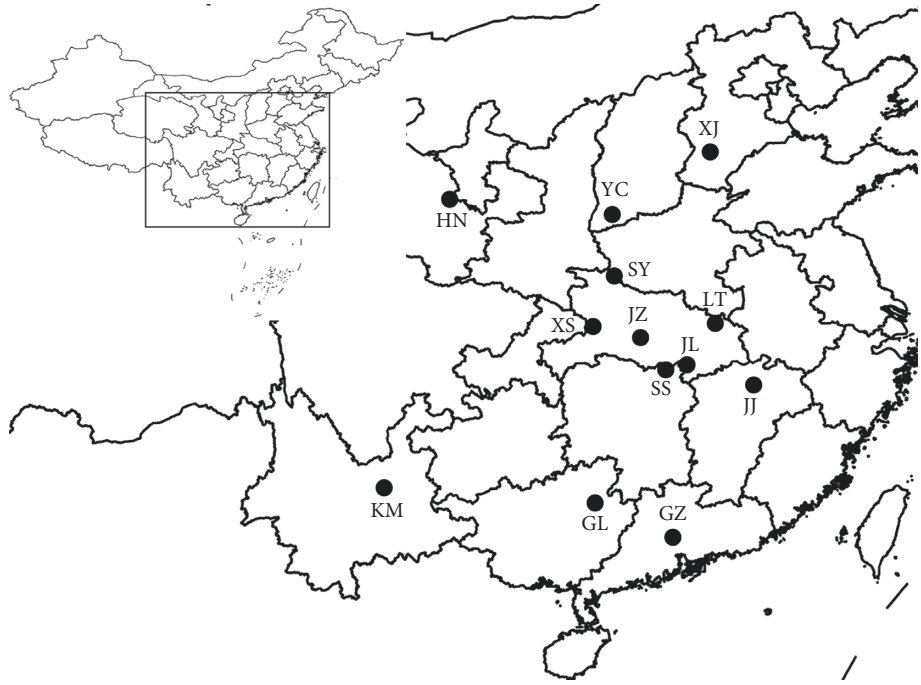

Figure 1: The geographic distribution of the selected 13 populations of *Lycium chinense* in China.

then obtained and standardized using basic copper tartrate solution. The content of reducing sugar was calculated according to the following formula:

$$X = \frac{m_1}{m \times F \times (V/250) \times 1000} \times 100, \quad (1)$$

where X is the content of reducing sugar (g/100 g), m_1 is the volume of basic copper tartrate which is equivalent to the mass of glucose (or other reducing sugar) (mg), m is the quality of plant tissue samples (g), F is the coefficient ($F = 1$ or 0.8), and V is the volume of filtrate consumed during the test (mL).

2.2.3. Determination of Total Flavonoids, Rutin, and Chlorogenic Acid. An improved UV spectrophotometry method described in the Chinese Pharmacopoeia [25] was used for total flavonoids analysis. Plant tissue samples of 1.0 g were added to 30 mL 75% ethanol solution and extracted for 2 × 1 h periods before being filtered through a filter paper. Then, a constant volume of 50 mL hydroalcoholic solution was obtained by merging the filtrate. Then, 3 mL of hydroalcoholic solution was added into a 25 mL plug test tube and 6 mL of 75% ethanol solution and 1 mL of 5% sodium nitrite solution were added; this solution was left to stand for 6 min at 25°C; then, 1 mL of 10% aluminium nitrate solution was added, and the solution was left to stand for 6 min; finally, 10 mL of 4% sodium hydroxide solution was added, and a 25 mL constant volume was attained by adding 75% ethanol solution; this was then left to stand for 15 min at 25°C before detection. Furthermore, six concentrations of 30, 40, 50, 60, 70, and 80 mg/mL were prepared with standard rutin (RE), and the regression equation of the standard curve $y = 0.4566X - 0.0096$, $r = 0.9999$, was calculated with RSD lower than 1.12% and accuracy 99.21%–102.36%. The determination wavelength was 510 nm. All the standards and samples were tested using the V-1800PC spectrophotometer (Shanghai Mapada Instruments Co., Ltd., Shanghai, China). The results were expressed as mg·RE/g sample (dw).

An improved HPLC method described in the Chinese Pharmacopoeia [25] was used for rutin content analysis. Plant tissue samples of 100 mg each were added to 20 mL of 75% ethanol solution and then extracted with the aid of ultrasonic waves at 30°C for two separate 30 min periods. The resulting filtrate was gradient eluted using an eluent comprising methanol and 0.5% phosphoric acid water, according to this elution programme: 0–5 min using 30%–40% eluent, 5–10 min using 40%–50% eluent, and 10–20 min using 50%–60% eluent. During the elution process, the flow rate remained at 1.0 mL/min, column temperature at 30°C, detection wavelength at 358 nm, data acquisition rate at 1 reading/s, and injection volume at 10 μL. All the standards and samples were tested using the WATERS-2695 HPLC (Waters Ltd., Elstree, Herts, UK).

An improved HPLC method was used for chlorogenic acid content detection [25]. Samples of 100 mg were added to 15 mL of 50% ethanol solution and then extracted with the aid of ultrasonic waves for 30 min. The resulting filtrate was gradient eluted using an eluent comprising methyl cyanide and 0.4% phosphoric acid and water (10 : 90, v/v). During the 30 min elution process, the flow rate remained at 1.0 mL/

min, column temperature at 30°C, detection wavelength at 327 nm, data acquisition rate at 1 reading/s, and injection volume at 10 μL. All the standards and samples were tested using the WATERS-2695 HPLC (Waters Ltd., Elstree, Herts, UK).

2.2.4. Determination of Crude Protein, Crude Fibre, Amino Acids, and Vitamin C. Crude protein contents were determined using the method GB5009.5-2010 [26]. Plant tissue samples of 1.0 g were added to 0.4 g cupric sulphate, 6 g potassium sulphate, and 20 mL sulphuric acid (1.84 g/L); these were weighed or measured accurately and were added in sequence; the mixture was placed in a digestive furnace, where it was digested continuously for 1 h once the temperature reached 420°C; the digestion solution was then cooled, and 50 mL water was added; the contents were analysed using an automatic Kjeldahl nitrogen meter (UDK-159, VELP Scientific Co., Ltd., Brianza, Italy).

Crude fibre contents were determined using the method of GB/T5009.10-2003 [27]. Plant tissue samples of about 20.0 g were added to 200 mL of boiling sulphuric acid (1.25%) in a 500 mL conical flask in sequence, kept boiling for 30 min, and filtered through linen. The residual was fully washed to remove all acid and boiled in 200 mL of 1.25% potassium hydroxide solution following the same procedures. Then, the residual was washed using water, ethanol, and ether and extracted, dried at 105°C to constant weight, and weighed (m_1). Finally, all residuals were burnt in the muffle furnace at 550°C for 5.5 h and weighed (m_2) after cooling in the exsiccator. The crude fibre content (X) was calculated as follows:

$$X = \frac{m_1 - m_2}{20} \times 100. \quad (2)$$

Amino acid contents were determined using the method of GB/T5009.124-2003 [28]. Plant tissue samples of 200 mg were weighed accurately and placed in a hydrolysis tube; then 15 mL of hydrochloric acid (6 mol/L) and 3-4 drops of phenol solution were added. The hydrolysis tube was repeatedly frozen and then evacuated and flushed into nitrogen, and the contents were then hydrolysed for 22 h at 110°C. Then, the hydrolysate was filtered and kept at a 50 mL constant volume; samples of 1 mL of this filtrate were obtained and repeatedly dried, and then 1 mL of pH 2.2 buffer was added to obtain the testing solution. All standards and samples were tested using the automatic amino acid analyser (ICS 5000+, Thermo Fisher Scientific, Waltham, MA, USA).

Vitamin C contents were determined using the method of GB 5009.86-2016 [29]. Plant tissue samples of 2 g were weighed accurately and fixed to 50 mL using 20 g/L metaphosphoric acid solution and then extracted with the aid of ultrasonic waves for 5 min. After that, the extract was centrifuged at 4000 rpm for 5 min and the supernatant fluid was filtered through a 0.45 μm filtration membrane to obtain the testing solution. All the standards and samples were tested using the WATERS-2695 HPLC (Waters Ltd., Elstree, Herts, UK).

2.2.5. Determination of Mineral Element Content. *L. chinense* samples need to be digested before mineral element determination. Plant tissue samples of 2 g were weighed accurately and placed in a hydrolysis tube, and then 20–30 mL of mixed acid solution of nitric acid (69.2%) and perchloric acid (70%) (4 : 1 v/v) was added. The mixture was placed in a digestive furnace, until colourless transparency liquid was obtained. The digestion solution was added water and fully heated to remove all acids. Finally, the digestion solution was then cooled, and 10 mL of water was added to obtain the testing solution. Mineral elements of all the thirteen populations were determined according to the following methods: Na and K (GB/T5009.91-2003, flame emission spectrometry) [30]; Ca (GB/T5009.92-2003, atomic absorption spectrometry) [31]; Fe, Mg, and Mn (GB/T5009.90-2003, atomic absorption spectrophotometry) [32]; Zn (GB/T5009.14-2003, atomic absorption spectrometry) [33]; Cu (GB/T5009.13-2003, atomic absorption spectrometry) [34]; P (GB/T5009.87-2003, spectrophotometric method) [35]; Se (GB5009.93-2010, hydride atomic fluorescence spectrometry) [36]; and Pb (GB5009.12-2010, graphite furnace atomic absorption spectrometry) [37].

2.3. Data Analysis

2.3.1. ANOVA. ANOVA using SPSS 21 was applied to compare component concentrations among the thirteen populations.

2.3.2. Principal Component Analysis. Principal component analysis using 34 active components and the nutrient element contents was performed using the SPSS 21 [38]. Based on initial eigenvalues (λ) and component matrices (a), eigenvectors were calculated and principal component expression functions (Z) were constructed.

Eigenvectors (u) were calculated as follows:

$$u_{ij} = \frac{a_{ij}}{\sqrt{\lambda_i}}, \quad (3)$$

where i refers to principal components 1, 2, 3, ..., k and j refers to the elements.

Principal component expression functions and the scores of principal components (Z) were calculated as follows:

$$Z_i = \sum_{j=1}^{p} u_{ij} X_j, \quad (4)$$

where X_j refers to the active component and nutrient element content.

Raw values were standardized to the same order of magnitude. To do this, the active component and nutritional element contents were divided by their maximal values in the same column and were calculated as follows:

$$X_j = \frac{X}{X_{\max}}. \quad (5)$$

Comprehensive scores (F) that represent the overall nutritional quality were calculated using the scores of the nine principal components (Z) as follows:

$$F = \sum_{i=1}^{p} q_i Z_i, \quad (6)$$

where q is the contribution rate as percentage.

2.3.3. Hierarchical Clustering Analysis. Hierarchical clustering analysis was carried out using SPSS 21, using all the components to group the selected populations.

3. Results and Discussion

3.1. Main Active Components

3.1.1. Polysaccharide Content. Abundant polysaccharides were detected in all populations with contents ranging from 43.15 mg·Glu/g (dw) to 53.29 mg·Glu/g (dw), which was consistent with that of vegetable wolfberry leaves which is derived from *L. barbarum* [12, 39]. Moreover, polysaccharide content varied significantly between populations ($P < 0.05$) (Figure 2). GZ and SS had the highest content of 53.29 mg·Glu/g (dw), while XS had the lowest content of 43.15 mg·Glu/g (dw).

3.1.2. Total Flavonoid Content. All *L. chinense* populations were rich in total flavonoids, with an average content of 54.76 mg·RE/g samples (dw), indicating a much greater health value than most vegetables [40]; this result was consistent with that for Ningxia wolfberry dish which is derived from *L. barbarum* [41]. Meanwhile, significant differences in total flavonoid contents were observed among different populations ($P < 0.05$) (Figure 2). For instance, KM had the highest content of 68.14 mg·RE/g samples (dw), followed ordinally by SS, LT, and JJ, with contents of 65.26 mg·RE/g samples (dw), 60.96 mg·RE/g samples (dw), and 58.18 mg·RE/g samples (dw), respectively, while YC had the lowest content at 45.28 mg·RE/g samples (dw).

3.1.3. Rutin Content. Similarly to the total flavonoid content, all the populations were rich in rutin, with an average content of 13.55 mg/g (dw). This content was higher than that of *L. barbarum*, and it revealed the potential for functional food development using *L. chinense* (Figure 2) [41–43]. Moreover, significant differences in rutin content ($P < 0.05$) were observed among the populations ($P < 0.05$) and the patterns matched those in total flavonoids, with KM, SS, XJ, and LT having higher contents of 18.28 mg/g (dw), 17.60 mg/g (dw), 16.17 mg/g (dw), and 16.11 mg/g (dw), respectively, and YC having the lowest content of 8.51 mg/g (dw).

3.1.4. Chlorogenic Acid Content. Significant differences in chlorogenic acid contents were found among the populations ($P < 0.05$) (Figure 2). KM had the highest content of 7.37 mg/g (dw), followed ordinally by SS, GL, and JJ with contents of 7.27 mg/g (dw), 6.64 mg/g (dw), and 6.55 mg/g (dw), respectively; these contents are higher than that of *L. barbarum* [42, 43].

Polysaccharides are the most important biologically active compounds in *L. chinense*; they have extensive biological functions [43, 44]. As a key component of *L. chinense*, polysaccharides are important for maintaining healthy eyes [45, 46], preventing protecting cardiac function [47, 48] and preventing heart failure and diabetes [49, 50]. In our study, the polysaccharide content of *L. chinense* was consistent with that of *L. barbarum*, indicating that *L. chinense* also have potential value as a functional food [39, 43]. Due to their antioxidative, anti-inflammatory, antimutagenic, and anticarcinogenic effects, flavonoids have potential health benefits and a strong preventive effect on various diseases [51–55]. The fact that the total flavonoids level in *L. chinense* was higher than those of most vegetables, therefore indicating the greater health value of *L. chinense* [40, 56, 57]. Rutin and chlorogenic acid were the dominant flavonoids in *L. chinense*; they are important for the prevention of allergic inflammatory diseases and have anti-inflammatory and antiangiogenic effects, as well as protective effects on the retinal ganglion; this suggests their great value in eye health and in prevention of cardiovascular and cerebrovascular diseases [55, 58, 59]. In our study, higher contents of rutin and chlorogenic acid were found in *L. chinense* than have been reported for *L. barbarum*; this is consistent with previous studies [43]. All these findings showed the great potential value of *L. chinense* for development as a functional food.

3.2. Main Nutrient Elements

3.2.1. Crude Protein Content. In our study, crude protein content was on average of 5.57 g/100 g (fw), higher than that in many vegetables [60]. Significant differences in crude protein content were found among certain populations ($P < 0.05$) (Figure 3). XS had the highest crude protein content at 6.60 g/100 g (fw), JZ and SS had the second and third highest crude protein contents at 6.05 g/100 g (fw) and 5.91 g/100 g (fw), respectively, and YC had the lowest crude protein content at 5.01 g/100 g (fw).

3.2.2. Crude Fibre Content. Crude fibre contents varied among the populations (Figure 3). SY and XS had the highest (1.50 g/100 g (fw)) and lowest (0.60 g/100 g (fw)) crude fibre contents, respectively, while the contents of other populations varied from 0.90 g/100 g (fw) to 1.00 g/100 g (fw), with no significant difference. These results show lower crude fibre contents than previously reported; a more systematic evaluation of crude fibre contents among different geographical resources is needed [61].

3.2.3. Reducing Sugar Content. There were significant differences in the reducing sugar contents among the populations ($P < 0.05$) (Figure 3). JZ had the highest content of 1.30 g/100 g (fw), followed by HN and SS, with contents of 1.04 g/100 g (fw) and 1.00 g/100 g (fw), respectively. SY and

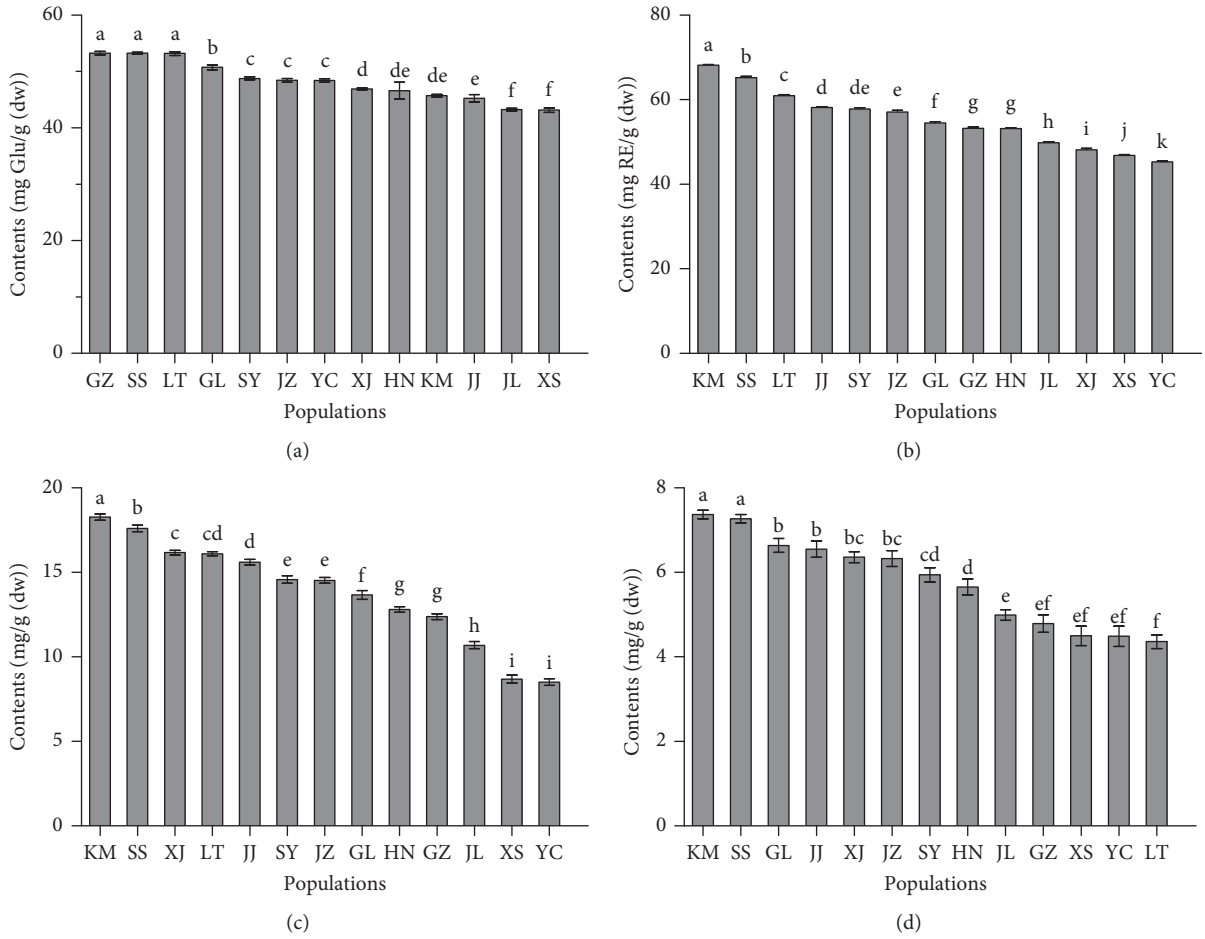

Figure 2: Main active component contents of 13 *Lycium chinense* populations in China. Bars: standard errors, $n = 3$. dw, dry weight; Glu, glucose; RE, rutin. Lowercase letters identify groups of populations that differ significantly ($P < 0.05$) (see Figure 1 for population locations). (a) Polysaccharide, (b) total flavonoid, (c) rutin, and (d) chlorogenic acid.

GZ had the lowest reducing sugar contents of 0.66 g/100 g (fw), respectively. There was no obvious association between polysaccharide content and reducing sugar content in different populations. Further study is needed to explore variation in glucose metabolism mechanisms among the different populations.

3.2.4. Vitamin C Content. There were significant differences in vitamin C (Vc) content among the populations ($P < 0.05$) (Figure 3). JL, JJ, and XJ had higher Vc contents than some fruits and most vegetables, at 16.00 mg/100 g (fw), 15.00 mg/100 g (fw), and 11.00 mg/100 g (fw), respectively [62]. The Vc content of HN, GL, LT, YC, and SS ranged from 6.90 mg/100 g (fw) to 9.00 mg/100 g (fw). However, no Vc was detected in the other populations. It is possible that the Vc content is very low or Vc was degraded during the experiment. More research needs to be conducted regarding the synthesis and accumulation of vitamin C in different *L. chinense* resources.

3.2.5. Amino Acid Content. All populations had detectable levels of the other 16 common amino acids except for tryptophan (Trp), cysteine (Cys), asparagine (Asn), and glutamine (Gln); the seven essential amino acids (threonine (Thr), valine (Val), methionine (Met), isoleucine (Ile), leucine (Leu), phenylalanine (Phe), and lysine (Lys)) and two essential amino acids that are particularly important for child health (histidine (His) and arginine (Arg)) were detected in all populations, and the contents of total amino acids varied between 36.90 g/kg (fw) and 44.90 g/kg (fw) (Table 1). These levels are lower than those reported in other studies [63]. This indicated that there was a large variation in amino acid constituents and contents between the different geographical resources. XS, SS, and JJ showed relatively higher content of total amino acids, at 44.90 g/kg (fw), 42.10 g/kg (fw), and 41.20 g/kg (fw), respectively, while the total amino acid contents of SY, GL, and KM were lower, at only 36.90 g/kg (fw), 37.60 g/kg (fw), and 37.90 g/kg (fw), respectively. There was not a significant correlation between total amino acid content and crud protein content which might be due to the higher proportion of nonprotein nitrogen (non-amino acid component) in crude protein. Further study is needed to explore the specific reasons. There were significant differences ($P < 0.05$) between the populations in essential amino acid content, which ranged from

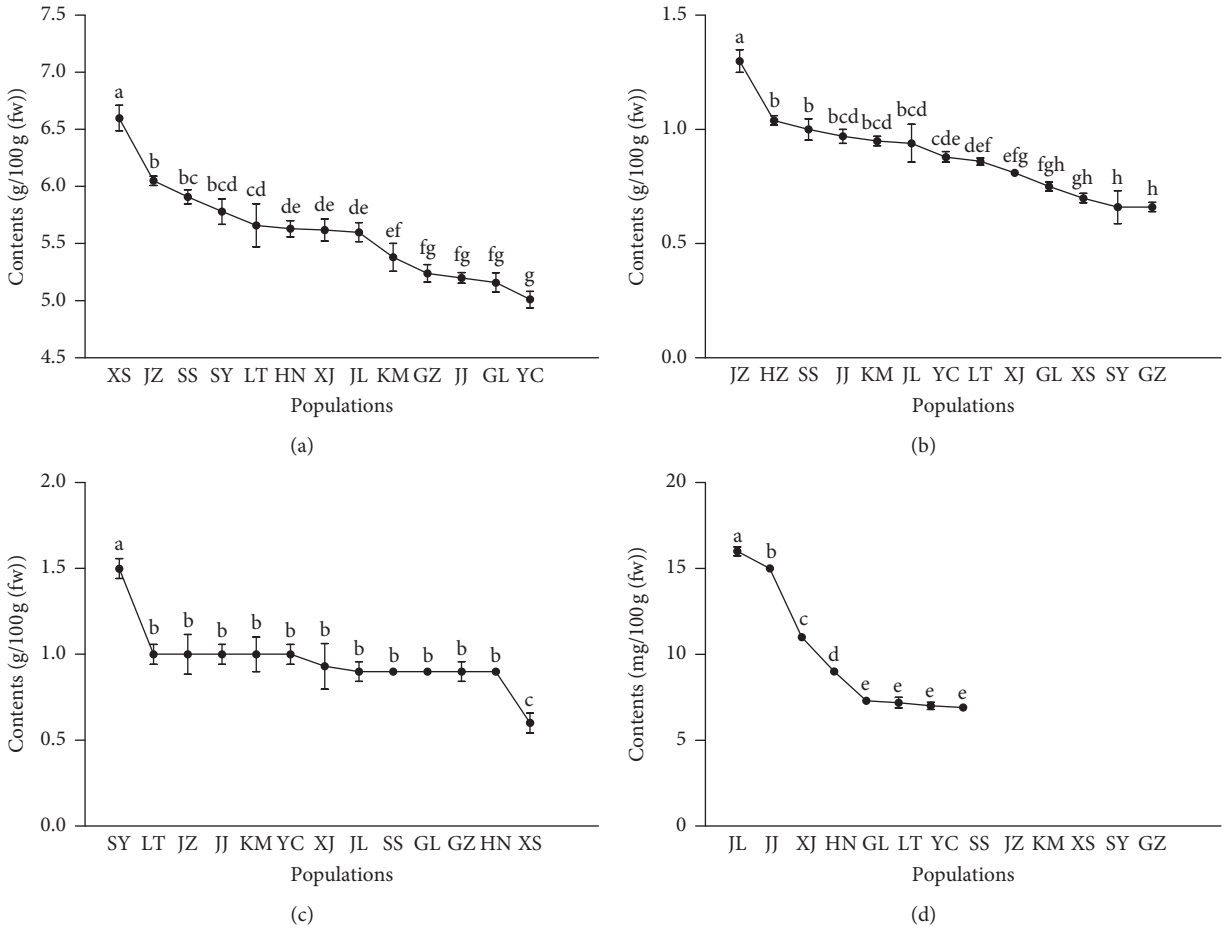

Figure 3: Main nutrient element contents of 13 *Lycium chinense* populations in China. Bars: standard errors, $n = 3$. fw, fresh weight. Lowercase letters identify groups of populations that differ significantly ($P < 0.05$). Missing data (in vitamins panel): no content detected (see Figure 1 for population locations). (a) Crude protein, (b) reducing sugar, (c) crude fibre, and (d) vitamin.

15.80 g/kg (fw) to 19.90 g/kg (fw), with a mean content of 17.56 ± 0.20 g/kg (fw); XS, SS, and JJ had higher essential amino acid content, at 19.90 g/kg (fw), 18.60 g/kg (fw), and 18.30 g/kg (fw), respectively, while the essential amino acid content in SY, HN, and KM was only 16.50 g/kg (fw), 16.40 g/kg (fw), and 15.80 g/kg (fw), respectively; the content of the essential amino acids that are particularly important for child health ranged from 3.20 g/kg (fw) (YC) to 4.00 g/kg (fw) (XS).

The closer the proportion of essential amino acids in protein is to levels found in the human body, the better the quality of the protein is for human health [64, 65]. Ideally, the best foods have an INQ (index of nutritional quality) of at least 1, indicating good quality, or INQ > 1, indicating high quality [64, 65]. We found that the amino acid mass fractions of all the populations exceeded the FAO/WHO (Food and Agriculture Organization of the United Nations/World Health Organization) standard of 40% [64]. The amino acids Phe and Lys in all populations were in relative excess, with ratio coefficients >1 (RC = 1.19–1.44). The ratio coefficients of amino acids Thr, Leu, and Ile were consistent with nutritional requirements with RC values of 0.97–1.10 (Table 1). However, Val contents differed among the populations; XS, SY, GL, and HN fulfilled the Val amino acid requirements (RC = 0.99–1.09), but Val was relatively deficient in the other populations. Met + Cys was the first restrictive amino acid for all the populations with the lowest ratio coefficient (RC range: 0.14–0.39). Among the populations, GL had the highest mass fraction at 48.14%, followed by LT with 45.80%, indicating the higher protein nutrition value of these two populations relative to the other populations.

Medicinal amino acids include mainly aspartic acid (Asp), glutamic acid (Glu), glycine (Gly), Met, Leu, tyrosine (Tyr), Phe, Lys, and Arg [66, 67]. Our study showed that there were significant differences among the populations ($P < 0.05$) and that XS, SS, JJ, JL, and KM had higher contents of medicinal amino acids, at 26.00 g/kg (fw), 24.20 g/kg (fw), 23.50 g/kg (fw), 23.30 g/kg (fw), and 23.00 g/kg (fw), respectively (Table 2), while lower contents of medicinal amino acids were detected in SY (21.40 g/kg (fw)), GZ (21.70 g/kg (fw)), and GL (21.80 g/kg (fw)) populations. The fact that levels of medicinal amino acids in XS and SS were higher than in many fruits indicates that this species has beneficial healthcare functions and that further research is needed for the exploration of resources [6, 66, 67].

Table 1: Variation in amino acid contents of thirteen geographical populations of *Lycium chinense*.

	Amino acid contents (g/kg (fw))												
Amino acids	GL	GZ	HN	JJ	JL	JZ	KM	LT	SS	SY	XJ	XS	YC
Thr	1.90 ± 0.12c	2.00 ± 0.00bc	2.00 ± 0.10bc	2.20 ± 0.06ab	2.10 ± 0.06abc	2.10 ± 0.06abc	1.90 ± 0.10c	2.00 ± 0.06bc	2.20 ± 0.10ab	1.90 ± 0.00c	2.10 ± 0.06abc	2.30 ± 0.10a	1.90 ± 0.06c
Val	2.60 ± 0.06ab	2.30 ± 0.06cd	2.20 ± 0.10cde	2.30 ± 0.06cd	2.30 ± 0.00cd	2.30 ± 0.06cd	2.00 ± 0.00e	2.40 ± 0.10bc	2.30 ± 0.06cd	2.20 ± 0.06cde	2.10 ± 0.00de	2.70 ± 0.12a	2.20 ± 0.12cde
Ile	1.90 ± 0.06bcd	1.60 ± 0.10c	1.90 ± 0.00bcd	1.70 ± 0.06d	2.10 ± 0.06ab	2.10 ± 0.10ab	1.80 ± 0.10cd	2.00 ± 0.10abc	2.20 ± 0.06a	1.90 ± 0.06bcd	1.93 ± 0.07bc	2.10 ± 0.00ab	2.00 ± 0.12abc
Phe	1.90 ± 0.00ab	1.60 ± 0.10c	1.60 ± 0.10c	1.70 ± 0.12bc	1.70 ± 0.00bc	1.70 ± 0.12bc	1.80 ± 0.06bc	1.80 ± 0.00bc	1.70 ± 0.10bc	1.70 ± 0.10bc	1.70 ± 0.12bc	2.10 ± 0.06a	1.80 ± 0.00bc
Leu	3.30 ± 0.00fg	3.40 ± 0.06efg	3.30 ± 0.06fg	3.90 ± 0.12ab	3.70 ± 0.10bcd	3.60 ± 0.10cde	3.20 ± 0.12g	3.50 ± 0.10def	3.80 ± 0.00abc	3.30 ± 0.06fg	3.60 ± 0.10cde	4.00 ± 0.06a	3.40 ± 0.10efg
Lys	3.50 ± 0.12cde	3.30 ± 0.06e	3.30 ± 0.10e	3.70 ± 0.10bc	3.60 ± 0.06bcd	3.60 ± 0.06bcd	3.50 ± 0.00cde	3.50 ± 0.00cde	3.80 ± 0.10b	3.50 ± 0.00cde	3.60 ± 0.06bcd	4.20 ± 0.06a	3.60 ± 0.00bcd
Met	0.70 ± 0.06a	0.50 ± 0.00b	0.50 ± 0.06b	0.50 ± 0.06b	0.50 ± 0.00b	0.30 ± 0.00d	0.30 ± 0.00d	0.70 ± 0.00a	0.50 ± 0.00b	0.30 ± 0.00d	0.40 ± 0.06c	0.40 ± 0.06c	0.30 ± 0.00d
Arg	2.10 ± 0.00f	2.30 ± 0.06de	2.40 ± 0.10cd	2.50 ± 0.00bc	2.50 ± 0.00b	2.30 ± 0.06de	2.30 ± 0.10de	2.30 ± 0.10de	2.50 ± 0.06bc	2.20 ± 0.00ef	2.30 ± 0.00de	2.70 ± 0.06a	2.20 ± 0.00ef
Tyr	2.30 ± 0.06a	1.90 ± 0.06d	1.70 ± 0.00e	1.90 ± 0.00d	1.90 ± 0.06d	1.70 ± 0.06e	1.60 ± 0.06e	2.10 ± 0.10b	2.10 ± 0.10b	1.70 ± 0.00e	2.20 ± 0.00ab	2.10 ± 0.10bc	2.00 ± 0.10cd
Asp	3.60 ± 0.06h	3.90 ± 0.23fg	4.20 ± 0.10cde	4.20 ± 0.12cde	4.20 ± 0.06cde	4.30 ± 0.15bcd	4.40 ± 0.06bc	3.80 ± 0.06gh	4.50 ± 0.10ab	3.80 ± 0.00gh	4.10 ± 0.06def	4.70 ± 0.06a	4.00 ± 0.10efg
Glu	4.40 ± 0.10e	4.80 ± 0.06d	5.10 ± 0.12bcd	5.10 ± 0.15bcd	5.20 ± 0.10bc	5.20 ± 0.10bc	6.10 ± 0.21a	4.80 ± 0.12d	5.30 ± 0.10b	4.90 ± 0.12cd	5.00 ± 0.12bcd	5.80 ± 0.15a	4.90 ± 0.06cd
Gly	2.00 ± 0.12d	2.10 ± 0.06cd	2.00 ± 0.06d	2.40 ± 0.06ab	2.20 ± 0.06bcd	2.20 ± 0.10bcd	2.00 ± 0.00d	2.20 ± 0.15bcd	2.30 ± 0.10abc	2.00 ± 0.06d	2.10 ± 0.06cd	2.50 ± 0.15a	2.10 ± 0.10cd
Ala	2.50 ± 0.06c	3.00 ± 0.06ab	2.90 ± 0.12b	3.10 ± 0.06ab	3.10 ± 0.00ab	2.90 ± 0.06b	2.20 ± 0.12d	2.60 ± 0.10c	3.10 ± 0.06ab	2.40 ± 0.00cd	2.60 ± 0.10c	3.20 ± 0.10a	3.00 ± 0.10ab
Ser	1.80± 0.00cd	1.80 ± 0.12cd	1.90 ± 0.06bcd	2.00 ± 0.06bc	2.00 ± 0.06bc	2.00 ± 0.10bc	1.90 ± 0.10bcd	1.90 ± 0.06bcd	2.10 ± 0.10ab	2.00 ± 0.00bc	2.10 ± 0.10ab	2.30 ± 0.06a	2.00 ± 0.10bc
Pro	1.90 ± 0.10e	2.20 ± 0.15cd	2.20 ± 0.12cd	2.40 ± 0.12bc	2.50 ± 0.15ab	2.70 ± 0.10a	2.20 ± 0.10cd	2.40 ± 0.00bc	2.40 ± 0.10bc	2.10 ± 0.06de	2.30 ± 0.06bcd	2.50 ± 0.10b	2.40 ± 0.00bc
His	1.20 ± 0.00ab	1.10 ± 0.12ab	1.30 ± 0.06a	1.20 ± 0.06ab	1.20 ± 0.10ab	1.00 ± 0.06b	1.00 ± 0.06b	1.30 ± 0.06a	1.30 ± 0.10a	1.00 ± 0.00b	1.00 ± 0.10b	1.30 ± 0.10a	1.00 ± 0.10b
TAA	37.60 ± 0.17hi	38.10 ± 0.83fghi	38.40 ± 0.55fgh	41.20 ± 0.31bc	40.80 ± 0.50cd	39.70 ± 0.32de	37.90 ± 0.66ghi	39.30 ± 0.35ef	42.10 ± 0.23b	36.90 ± 0.35i	39.13 ± 0.33efg	44.90 ± 0.40a	38.80 ± 0.25efgh
EAA	18.10 ± 0.10bc	16.90 ± 0.31gh	16.40 ± 0.31hi	18.30 ± 0.15bc	17.90 ± 0.40bcd	17.10 ± 0.21fgh	15.80 ± 0.45i	18.00 ± 0.15bc	18.60 ± 0.15b	16.50 ± 0.20ghi	17.63 ± 0.12cdf	19.90 ± 0.15a	17.20 ± 0.29dfg

Note: the values are mean ± standard error ($n = 3$). fw, fresh weight; Thr, threonine; Val, valine; Ile, isoleucine; Phe, phenylalanine; Leu, leucine; Lys, lysine; Met, methionine; Arg, arginine; Tyr, tyrosine; Asp, aspartic acid; Glu, glutamic acid; Gly, glycine; Ala, alanine; Ser, serine; Pro, proline; His, histidine; TAA, total amino acids; EAA, essential amino acids. Lowercase letters identify groups of populations that differ significantly ($P < 0.05$).

Table 2: Amino acid composition and contents of different *Lycium chinense* populations.

Populations	Amino acid contents (g/kg (fw))				
	Medicinal amino acids	Umami taste amino acids	Sweet amino acids	Aromatic amino acid	Total taste amino acids
XS	26.00 ± 0.17a	13.47 ± 1.53a	10.50 ± 0.26a	17.80 ± 0.30a	38.80 ± 0.61a
SS	24.20 ± 0.06b	12.63 ± 1.50a	9.90 ± 0.12b	16.20 ± 0.15b	35.90 ± 0.06b
JJ	23.50 ± 0.25bc	12.17 ± 1.27a	9.90 ± 0.10b	16.00 ± 0.06bc	35.20 ± 0.26bc
JL	23.30 ± 0.44cd	12.23 ± 1.41a	9.80 ± 0.26b	15.70 ± 0.35bcd	34.90 ± 0.40bc
KM	23.00 ± 0.40cde	12.10 ± 1.89a	8.30 ± 0.12e	14.20 ± 0.35g	33.00 ± 0.47e
XJ	22.90 ± 0.15cde	11.47 ± 1.57a	9.10 ± 0.10c	15.50 ± 0.12cd	33.70 ± 0.20de
JZ	22.80 ± 0.25cde	12.13 ± 1.54a	9.80 ± 0.06b	15.30 ± 0.21de	34.60 ± 0.31cd
LT	22.50 ± 0.12def	10.90 ± 1.40a	9.10 ± 0.21c	15.60 ± 0.10bcd	33.30 ± 0.20e
YC	22.20 ± 0.06efg	11.63 ± 1.50a	9.50 ± 0.17bc	15.20 ± 0.12def	33.60 ± 0.21de
HN	22.20 ± 0.36efg	11.83 ± 1.23a	9.00 ± 0.21cd	14.60 ± 0.17fg	32.90 ± 0.50ef
GL	21.80 ± 0.15fg	10.27 ± 1.21a	8.20 ± 0.23e	15.70 ± 0.12bcd	31.90 ± 0.15f
GZ	21.70 ± 0.46fg	11.57 ± 1.49a	9.10 ± 0.31c	14.80 ± 0.26efg	32.60 ± 0.72ef
SY	21.40 ± 0.25g	10.83 ± 1.41a	8.50 ± 0.10de	14.60 ± 0.15fg	31.80 ± 0.30f

Note: the values are mean ± standard error, $n = 3$. fw, fresh weight; medicinal amino acids: Asp, Glu, Gly, Met, Leu, Tyr, Phe, Lys, and Arg; umami taste amino acids: Asp, Glu, Gly, and Ala; sweet amino acids: Gly, Ala, Ser, and Pro; aromatic amino acids: Val, Leu, Phe, Lys, Arg, and Tyr. Lowercase letters identify groups of populations that differ significantly ($P < 0.05$).

Taste amino acids generally comprise the umami taste amino acids (Asp, Glu, Gly, and alanine (Ala)), sweet amino acids (Gly, Ala, serine (Ser), and proline (Pro)), and aromatic amino acids (Val, Leu, Phe, Lys, Arg, and Tyr) [68]. Higher contents of total taste amino acids were found in XS (38.80 g/kg (fw)), SS (35.90 g/kg (fw)), and JJ (35.20 g/kg (fw)); XS had the highest contents of umami taste amino acids, sweet amino acids, and aromatic amino acids, at 13.47 g/kg (fw), 10.50 g/kg (fw), and 17.80 g/kg (fw), respectively. SY and GL had lower contents of total taste amino acids, at 31.90 g/kg (fw) and 31.80 g/kg (fw), respectively (Table 2). There were certain taste differences among different geographical populations, and XS, SS, and JJ may have better taste than the other 10 populations due to higher contents of total taste amino acids.

3.2.6. Mineral Element Content. Eleven mineral elements' contents were detected (Table 3). Several elements including iron (Fe), selenium (Se), manganese (Mn), and potassium (K), with average contents of 80.94 mg/kg (fw), 0.03 mg/kg (fw), 11.75 mg/kg (fw), and 6299.83 mg/kg (fw), respectively, were present at much higher levels than in most vegetables [61, 68]. The highest content of total mineral elements was 9715.22 mg/kg (fw) (JZ), while the lowest content was 8460.41 mg/kg (fw) (GZ). The content of K was significantly higher than that of the other mineral elements; the highest content of K was detected in JZ, and this may bias our results. The low level of ratio of Zn to Cu in food has been found to lower the ratio of Zn to Cu (15.04) in patients with hypertension, coronary heart disease, and cancer [68]. The lower proportion of Zn to Cu, averaged 1.84, was found in *L. chinense*, suggesting *L. chinense* is more valuable as a functional food. Se is important for maintaining the overall health, especially of the thyroid and immune system, and for maintaining homeostasis. The Se contents in *L. chinense* were significantly higher than the standard of Se-rich vegetables [68–70]. In terms of the main heavy metals, Cu and Pb contents were far lower than upper limits stated in the Chinese Pharmacopoeia (2015) and the Green Trade Standard of Medicinal plants (2005). These results provide an important basis for the functional food development of *L. chinense* in preventing anaemia, cardiovascular disease, and cancer, and for detoxification, antioxidation, and lowering blood pressure [68].

Significant differences in mineral element contents were found among the populations ($P < 0.05$). LT, JJ, and SS had contents of the mineral elements indicating high quality; higher contents of sodium (Na), Ca, Fe, Zn, magnesium (Mg), Mn, and phosphorus (P) were all detected in LT, and high levels of Ca, Mg, K, Mn, and P were found in JJ; SS had higher contents of Zn, K, Mn, Cu, and Se. Combined with the geographic distribution, we found that the resources in the central China provided high-quality mineral nutrition; the differences were possibly caused by differences in mineral metabolism or the root absorption ability between the *L. chinense* resources [68]. The mineral metabolism and accumulation mechanisms of the different *L. chinense* resources require further investigation.

3.3. PCA. Data for the 34 analytes, including the main active components and main nutrient elements, were used to conduct a PCA; nine principal components were extracted. The principal components (PC 1 to PC 9) described 31.88%, 18.34%, 12.67%, 9.32%, 6.55%, 5.09%, 4.47%, 3.71%, and 3.14% of the variance in the original observations, respectively; they accounted for 95.14% of the total variance. PC 1 explained variation caused by crude protein, eight amino acids (Leu, Thr, Gly, Lys, Arg, Ser, Ala, and Asp) and two mineral elements (Mg and Mn); PC 2 explained variation caused by four amino acids (Met, Tyr, Glu, and Val) and two mineral elements (Na and Zn); PC 3 explained variation caused by rutin, chlorogenic acid, and flavonoids; PC 4 explained variation caused by reducing sugars, two mineral elements (K and Fe), and Pro; PC 5 explained variation caused by polysaccharides and two mineral elements (Pb and Cu); PC 6 to PC 9 explained variation caused

Table 3: Variation in mineral element contents among thirteen geographical populations of *Lycium chinense*.

Populations	Mineral element contents (mg/kg (fw))										
	Na	Ca	Fe	Zn	Mg	K	Mn	Cu	P	Se	Pb
GL	46.10 ± 0.55a	1021.70 ± 3.48d	63.20 ± 0.15i	9.20 ± 0.06a	552.03 ± 0.47h	6117.00 ± 1.95j	6.30 ± 0.10i	2.40 ± 0.10e	850.00 ± 5.77e	0.03 ± 0.00ef	0.14 ± 0.00f
GZ	27.40 ± 0.45c	955.80 ± 2.30g	77.50 ± 0.31f	4.90 ± 0.10f	566.00 ± 1.84g	6048.40 ± 1.34k	7.70 ± 0.10h	2.50 ± 0.00de	770.00 ± 10.00gh	0.04 ± 0.00d	0.17 ± 0.01e
HN	18.90 ± 0.30i	962.10 ± 6.50g	76.50 ± 0.83f	3.80 ± 0.06g	493.70 ± 1.72j	6235.10 ± 2.18g	6.50 ± 0.17i	2.90 ± 0.06c	890.00 ± 0.00d	0.04 ± 0.00c	0.22 ± 0.01b
JJ	25.90 ± 0.35d	1040.40 ± 1.54c	71.60 ± 0.36h	5.70 ± 0.06e	719.60 ± 1.12b	6537.20 ± 1.49b	17.90 ±0.15b	2.50 ± 0.06de	820.00 ± 10.00f	0.03 ± 0.00h	0.14 ± 0.00f
JL	22.10 ± 0.10g	821.60 ± 1.57k	75.30 ± 0.15g	7.10 ± 0.06c	519.60 ± 0.46i	6116.10 ± 2.08j	11.90 ± 0.15e	2.50 ± 0.06de	1133.3 ± 28.48a	0.03 ± 0.00f	0.14 ± 0.01f
JZ	15.70 ± 0.21j	974.80 ± 1.63f	97.00 ± 0.67a	2.90 ± 0.06i	611.20 ± 1.12e	7238.10 ± 1.51a	13.20 ± 0.06d	2.10 ± 0.06g	760.00 ± 0.00h	0.03 ± 0.00h	0.19 ± 0.01cd
KM	24.70 ± 0.20e	1127.90 ± 2.87a	93.40 ± 1.14b	0.45 ± 0.01j	437.70 ± 0.38l	6279.30 ± 2.45f	9.20 ± 0.15g	2.60 ± 0.06d	800.00 ± 5.77f	0.04 ± 0.00b	0.20 ± 0.01c
LT	32.30 ± 0.26b	1062.30 ± 2.06b	88.30 ± 0.70c	7.40 ± 0.15b	670.20 ± 0.52c	6480.90 ± 2.26d	17.50 ± 0.20b	2.20 ± 0.00fg	930.00 ± 0.00bc	0.03 ± 0.00e	0.22 ± 0.01b
SS	21.20 ± 0.25gh	857.70 ± 1.17j	83.50 ± 1.16d	7.20 ± 0.06c	626.60 ± 1.45d	6509.90 ± 2.40c	21.20 ± 0.15a	8.00 ± 0.10a	890.00 ± 11.55d	0.05 ± 0.00a	0.36 ± 0.01a
SY	25.70 ± 0.46d	1036.10 ± 2.53c	78.20 ± 0.40ef	0.00 ± 0.00k	486.30 ± 0.72k	6227.50 ± 1.36h	3.10 ± 0.06j	1.70 ± 0.00h	810.00 ± 5.77f	0.02 ± 0.00i	0.19 ± 0.01cd
XJ	23.30 ± 0.31f	942.30 ± 1.93h	83.00 ± 0.50d	6.20 ± 0.06d	610.50 ± 0.46e	6196.60 ± 3.84i	13.50 ± 0.12d	3.10 ± 0.06b	950.00 ± 5.77b	0.03 ± 0.00g	0.13 ± 0.01f
XS	20.80 ± 0.26h	1036.80 ± 2.63c	84.90 ± 1.32d	3.10 ± 0.00h	816.90 ± 3.67a	5922.30 ± 1.50m	13.50 ± 0.21d	3.20 ± 0.06b	770.00 ± 5.77gh	0.04 ± 0.00bc	0.18 ± 0.01de
YC	23.60 ± 0.20f	899.70 ± 1.59i	79.80 ± 0.50e	7.10 ± 0.06c	596.80 ± 0.83f	5989.40 ± 1.19l	11.30 ± 0.15f	2.37 ± 0.03ef	910.00 ± 5.77cd	0.03 ± 0.00ef	0.18 ± 0.00de

Note: the values are mean ± standard error, $n = 3$. fw, fresh weight; Na, sodium; Ca, calcium; Fe, iron; Zn, zinc; Mg, magnesium; K, potassium; Mn, manganese; Cu, copper; P, phosphorus; Se, selenium; Pb, lead. Lowercase letters identify groups of populations that differ significantly ($P < 0.05$).

Table 4: Principal component scores and comprehensive scores of thirteen *Lycium chinense* populations.

Scores	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8	PC 9	F
GL	2.58	1.02	1.21	0.99	1.57	−0.27	2.39	0.71	1.70	1.53
GZ	2.70	0.46	1.07	1.17	1.81	−0.38	2.07	0.76	1.48	1.46
HN	2.76	0.22	1.21	1.38	1.93	−0.17	2.14	0.82	1.62	1.59
JJ	3.05	0.48	1.33	1.44	1.71	−0.30	2.19	0.76	1.43	1.63
JL	2.98	0.45	1.00	1.35	1.68	0.23	2.26	0.79	1.46	1.58
JZ	2.95	−0.00	1.32	1.77	1.86	−0.31	2.35	0.60	1.14	1.54
KM	2.61	−0.12	1.66	1.47	1.87	−0.60	2.36	0.73	1.25	1.42
LT	2.89	0.78	1.27	1.47	1.92	−0.27	2.42	0.71	1.71	1.66
SS	3.31	0.46	1.68	1.66	2.85	0.10	2.32	1.14	1.57	1.89
SY	2.45	0.02	1.29	1.18	1.58	−0.58	2.33	0.10	1.22	1.28
XJ	2.88	0.41	1.28	1.33	1.71	−0.08	2.33	0.68	1.15	1.55
XS	3.44	0.25	0.91	1.27	1.89	−0.39	2.62	1.02	1.51	1.68
YC	2.82	0.40	0.92	1.28	1.69	−0.01	2.27	0.66	1.12	1.48

by two mineral elements (P and Ca), two amino acids (Phe and Ile), crude fibre, and Se and His.

PCA indicated some associations between the geographic distribution and the quality of different *L. chinense* populations; populations in the central China, including SS, XS, LT, JJ, and JL, showed better nutritional value with higher comprehensive scores (F) of 1.89, 1.68, 1.66, 1.63, and 1.58, respectively (Table 4). Meanwhile, XS, SS, JJ, JL, and JZ in the central China scored higher on PC1, with higher protein content, and higher content of most amino acids, relative to the other populations; this is consistent with the results obtained for total amino acids and essential amino acids. Moreover, SS, KM, JJ, JZ, SY, and XJ had higher levels of active components including rutin, chlorogenic acid, and flavonoids with higher scores on PC 3. Eleven mineral elements were explained by six principal components (PC 1, PC 2, PC 4, PC 5, PC 6, and PC 8), and populations of SS, JJ, KM, and HN had higher levels of these mineral elements.

Germplasm quality has a genetic basis and is affected by environmental factors [21]. In this study, different germplasm resources were grown in the same climate and soil environment by using common-garden cultivation; this eliminates the influence of different environmental factors on each index and makes it possible to detect genetic differences between the resources. *L. chinense* is widely distributed in the central and southern China, and there is a high level of genetic diversity between and within *L. chinense* populations [71]. Abundant genetic variation, especially of the metabolic mechanisms variation about nutrients and the bioactive compounds, is the basis for the significant differences that we observed in the main active components and nutrient contents among the populations. More researches are needed regarding the metabolic mechanisms that determine the levels of the main active components and therefore the nutritional quality of the various *L. chinense* resources.

3.4. Clustering Analysis. SPSS hierarchical clustering analysis was carried out for all the components including main active components (total flavonoids, polysaccharide, chlorogenic acid, and rutin), main nutrient elements (crude protein, crude fibre, total amino acids, and total essential amino acids), and total mineral elements (Figure 4). Using hierarchical cluster analysis, we found that the populations clustered into three groups with different quality phenotypes. XS represented a separate group that was rich in total amino acids, total essential amino acids, and crude protein, indicating that it has the potential for development as a high-protein and nutritious resource. The second group consisted of KM, SS, JZ, XJ, and JJ, having high levels of functional activity and high contents of total flavonoids, chlorogenic acid, rutin, and mineral elements; this is consistent with the results of the PCA. The third group, including GZ, LT, GL, SY, YC, JL, and HN, had higher polysaccharide contents than the other populations and was rich in rutin, flavonoids, and mineral elements. Polysaccharide, flavonoids, and mineral elements including Cu, Fe, Ca, Mg, and Na are the most important factors related to the medicinal and health functions of *L. chinense* [20, 43]. Our clustering results indicate that there were three main sets of characteristics determining quality and function in these geographical resources. Our findings have important implications for the development of these resources and the exploitation of their functional characteristics. XS showed special characteristics, having high amino acid contents. Clustering identified other groups with beneficial characteristics, specifically KM and SS, which had high contents of total flavonoids and chlorogenic acid, and GZ and LT, which had higher polysaccharide contents than the other populations, and were rich in rutin.

4. Conclusion

We have evaluated the nutritional quality of different geographical *L. chinense* populations. This species has promise as a functional vegetable, in addition to its traditional medicinal usages. Significant differences in active component and nutrient element contents were detected among the different geographical populations. Principal component analysis revealed some associations between the geographic distribution and nutritional quality of *L. chinense* populations. The resources in the central China, including SS, XS, LT, JJ, and JL, showed better integrated quality than resources in the northern and southern regions. Meanwhile, clustering analysis showed that the populations could be

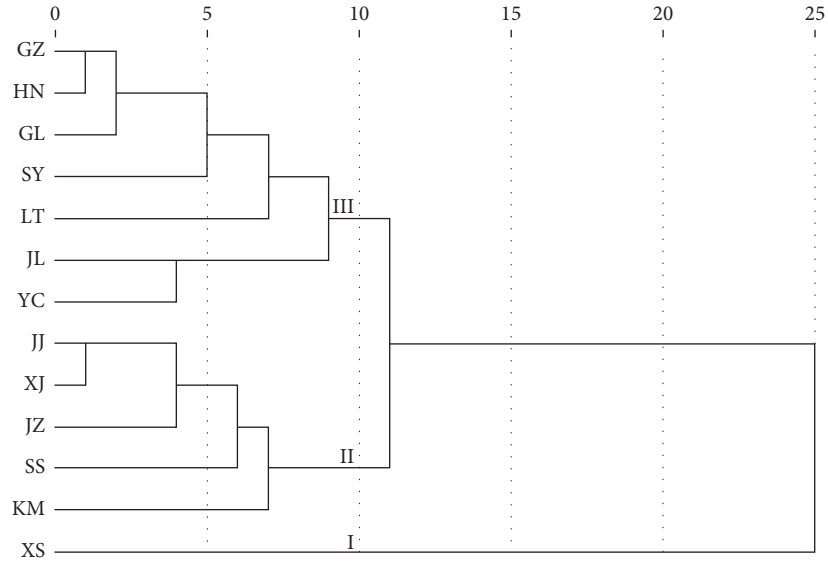

Figure 4: Hierarchical clustering analysis, based on nutrients and bioactive components, of the 13 *Lycium chinense* populations in China (see Figure 1 for population locations).

clustered into three quality-based phenotypes, of which several representative populations were screened for further development; these include XS, which had the special characteristic of having high amino acid contents; KM and SS, which had high total flavonoids and chlorogenic acid contents; and GZ and LT, which had higher polysaccharide and rutin contents than the other populations. Moreover, all the geographical populations showed much higher contents than most vegetables, in terms of total flavonoids, rutin, the mineral elements Fe, Se, Mn, and K, and in the mass fraction of amino acids. These results presented indicate that *L. chinense* has great potential for use in health food development.

Data Availability

The authors confirm that the data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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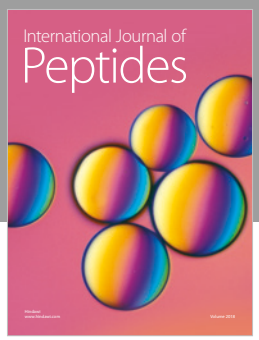

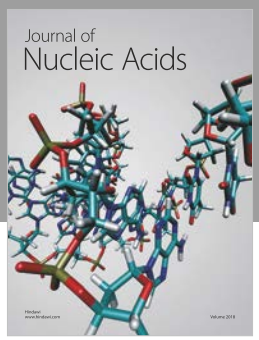

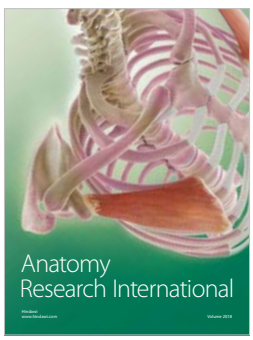

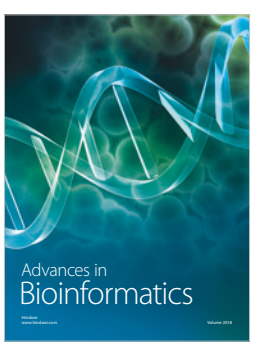

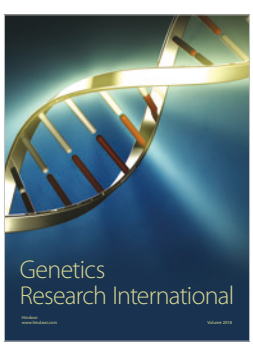

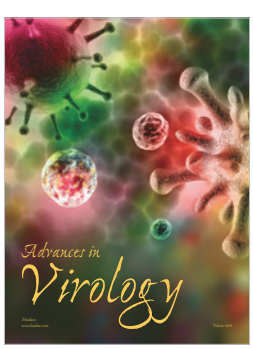

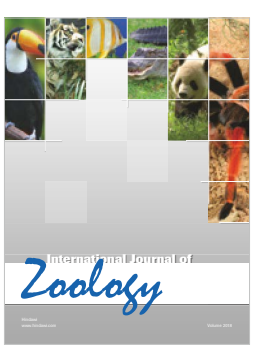

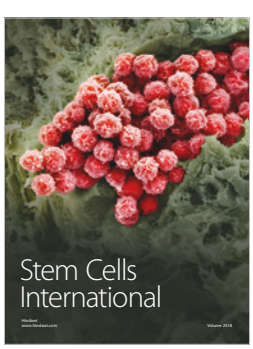

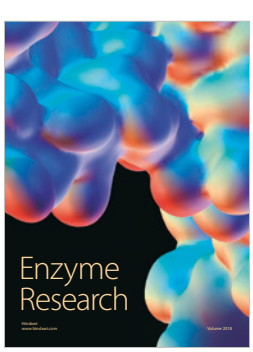

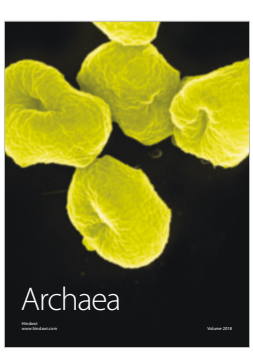


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