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Nutritional composition and antioxidant activity of twenty mung bean cultivars in China

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ABSTRACT

Interest in mung bean (*Vigna radiata* L.) as a functional food is growing; however, studies on the nutritional composition of major mung bean cultivars planted in China are limited. Twenty Chinese mung bean cultivars were collected and their nutritional compositions including starch, fat, protein, and phytochemicals were analyzed. The cultivars were found to have a high amount of resistant starch, accounting for 16.1%–22.3% of total starch, and balanced amino acid constitutions. Palmitic acid and linoleic acid were the two dominant fatty acids, accounting for respectively 32.4% and 36.1% of all of the assayed fatty acids. Four bound phenolic acids (syringic, caffeic, *p*-coumaric, and ferulic acids) and two free phenolic acids (caffeic and ferulic acids) were identified by HPLC. The antioxidant activity of 70% ethanol extracts from the 20 mung bean cultivars was evaluated. Their DPPH and $ABTS^+$ free-radical-scavenging capacity ranged from 28.13 ± 2.24 to 35.68 ± 0.71 μmol g^{-1} and from 3.82 ± 0.25 to 13.44 ± 1.76 μmol g^{-1}, respectively. Significant positive correlations of $ABTS^+$ free-radical-scavenging capacity with total phenolic acids and total flavonoid contents were observed. These results suggest that Chinese mung bean cultivars are rich in balanced nutrients and that their phytochemicals should be considered as potential sources of natural antioxidants.

1. Introduction

Mung bean (*Vigna radiata* L.) is a food source of vitamins, minerals, and essential amino acids and has a high nutrient value comparable to that of soybean (*Glycine max* L. Merr.) and kidney bean (*Phaseolus vulgaris* L.) [1]. Mung bean is traditionally known as a functional food, and its functional components have been identified over decades with the development of analytical techniques. In recent years, the physiological functionality of mung bean has received attention, particularly with respect to the content of anti-angiotensin I-converting enzyme and to antitumor, antioxidant, anti-diabetic, and anti-melanocyte effects [2–6]. Mung bean starch is also considered to be the most suitable raw material for starch noodle-making, as it contains resistant starch that can escape digestion in the small intestine. Starches that are fermented in the gut are generally recognized as components that can improve the gut environment [7,8]. In starch granules, amylose and amylopectin are densely packed in a semicrystalline state with inter- and intramolecular bonds.

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Amylose is insoluble in cold water and is resistant to chemicals and enzymes [9]. Mung bean is also an excellent source of protein with an ideal essential amino acid profile [1]. It contains a variety of essential amino acids and is rich in lysine. The intake of mung bean protein may improve the plasma lipid profile by normalizing insulin sensitivity [10]. Mung bean also contains fatty acids such as linoleic acid and linolenic acid that promote the growth and health of organisms. The physical and chemical properties of triglycerides and their applications depend on the fatty acid constituents in molecules [11].

Pigmented grain contains many secondary metabolites such as phenolic acids and flavonoids. Phenolic acids represent the most common form of phenolic compounds and make up one of the major and most complex groups of phytochemicals in grain [12]. Flavonoids have many health-related functions, such as antineoplastic activity, inoxidizability, and radioresistance [3,4,6]. Both phenolic acids and flavonoids contribute to the antioxidant activity of mung bean.

Mung bean is native to the northeastern India–Burma (Myanmar) region of Asia [13], but is planted in many countries. In China, it is a major variety of food legumes and is cultivated mainly in northeast China and the *Huang*, *Huai* and *Hai* valleys [14].

To date, more than 5000 mung bean accessions have been deposited in the National Crop Genebank of China [15]. Despite the abundant germplasm resources of mung bean in China, their diversity of nutritional composition is unknown. In this study, we selected 20 major mung bean cultivars planted in China from the National Crop Genebank of China to (1) compare their nutritional compositions, (2) evaluate their antioxidant activity, and (3) investigate the correlations between phytochemical contents and antioxidant activity. The results are proposed to contribute to the assessment and application of Chinese mung bean cultivars.

2. Materials and methods

2.1. Materials

Twenty mung bean cultivars were collected from the China National Crop Germplasm Genebank. All samples were dried at 40 °C, ground in a laboratory mill, and passed through an 80-mesh screen sieve to obtain mung bean flour.

2.2. Chemicals

Standards of 3-(3,4-dihydroxyphenyl)-2-propenoic acid (caffeic acid), 4-hydroxy 3,5-dimethoxybenzoic acid (syringic acid), 4-hydroxycinnamic acid (*p*-coumaric acid), 4-hydroxy-3-methoxycinnamic acid (ferulic acid), 1,1-diphenyl-2-picrylhydrazyl radical (DPPH) 6-hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic acid (Trolox), Folin–Ciocalteu phenolic reagent, 2,2′-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt (ABTS), potassium, rutin, and aluminum chloride hexahydrate were purchased from Sigma-Aldrich (St. Louis, MO, USA). Mixed amino acid standard H was obtained from Wako Pure Chemical Industries (Osaka, Japan). All other chemicals were of analytical grade and were obtained from Beijing Chemical Reagent (Beijing, China). All analytical-grade solvents for high-performance liquid chromatography (HPLC) were purchased from Fisher Chemicals (Shanghai, China).

2.3. Nutritional composition analysis

Total starch, amylose, and resistant starch were determined using Megazyme kits (Megazyme International Ireland, Bray Business Park, Bray, Co. Wicklow, Ireland). Contents of amylose and resistant starch are expressed as percentage of total starch. Total fat content was determined by method 985.29 of AOAC [16]. Fatty acid analyses were performed according to the method of Miao et al. [17] using gas chromatography (GC) (Agilent Agilent Technologies, Palo Alto, California) equipped with a flame ionization detector. Protein content was determined by the Kjeldahl method (AOAC, 979.09, 1990) using a nitrogen-to-protein conversion factor of 5.71. Amino acid profile analyses were performed by reverse phase-high performance liquid chromatography after 22 h of hydrolysis at 110 °C with 6 mol L^{-1} HCl and further derivatization with o-phthaldialdehyde (OPA) and fluorenylmethyl chloroformate (FOMC chloride) [18].

2.4. Determination of total flavonoid content (TFC)

Mung bean flour (0.5 g) and 20 mL of 70% methanol were mixed and shaken in a water bath at 70 °C for 2 h. The solution was centrifuged at 1500 ×*g* for 10 min. One milliliter of supernatant was dried in a freeze drier. Before tests were performed, methanol was used to dissolve the dried sample. An 0.5 mL appropriate dilution of extract, 1.5 mL of 95% ethanol, 0.1 mL of 10% aluminum chloride ($AlCl_3$) hexahydrate, 0.1 mL of 1 mol L^{-1} potassium acetate (CH_3COOK), and 2.8 mL of deionized water were mixed. Before the absorbance of the reaction mixture was measured at 415 nm against a deionized water blank on a Spec Plus Spectrophotometer (Bio-Rad, USA), the mixture was incubated at room temperature for 40 min. Total flavonoid content was determined on the basis of a calibration curve of authentic rutin [19].

2.5. Determination of total phenolic content (TPC)

Mung bean flour (10 g) and 100 mL of 70% ethanol were mixed and extracted twice for 2 h at room temperature. After vacuum filtration, the supernatants were combined and concentrated under reduced pressure in a rotary evaporator at 50 °C. After freeze-drying, the sample powder was stored at −20 °C until analysis. The previously reported [20,21] Folin–Ciocalteu method was used to evaluate TPC. Briefly, 50 μL of the extract and 5 mL of distilled water were mixed in a test tube, and 500 μL of 1 mol L^{-1} Folin–Ciocalteu reagent and 500 μL of a 20% (w/v) Na_2CO_3 solution were injected into the tube. After thorough mixing, the tube was allowed to stand for 60 min at room temperature. Finally, the absorbance was measured at 765 nm (SmartSpec Plus Spectrophotometer, Bio-Rad, USA). Quantification was performed with respect to a standard curve of gallic acid. Contents are reported in mg gallic acid equivalent (GAE) per gram.

2.6. HPLC analysis of individual phenolic acids

2.6.1. Extraction of free phenolic acid

Free phenolic acids were extracted following López et al. [22] with modification. One gram of bean flour and 20 mL of 70% chilled ethanol were mixed in a tube. Tubes containing samples were shaken on a shaker for 10 min at room temperature. After centrifugation at 2500 ×*g* for 10 min, the supernatant was transferred to a new tube and the residue was extracted once more. Supernatants were combined, evaporated at 45 °C to less than 5 mL, and diluted with distilled water to 10 mL. Extracts were stored at −20 °C.

2.6.2. Extraction of bound phenolic acid

Bound phenolic acids were extracted following a previously reported method [23]. Fifteen milliliters of distilled water, 5 mL of NaOH (6 mol L^{-1}) and the residue after the extraction of free phenolic compounds were mixed in a test tube and stirred for approximately 16 h at room temperature. The solution was then adjusted to pH 2.0 and the liberated phenolic acids were extracted three times with 15 mL of a mixture of cold diethyl ether (DE) and ethyl acetate (EA, 1:1 v/v). The DE/EA layers were combined and evaporated to dryness and the residue was dissolved in 1.5 mL of methanol. Acid hydrolysis was then performed by addition of 2.5 mL of concentrated 12 mol L^{-1} HCl to the test tube and incubation in a water bath at 85 °C for 30 min after completion of the alkaline hydrolysis. The sample was cooled and adjusted to pH 2.0, with DE/EA extraction performed in the same manner as for alkaline hydrolysis.

2.6.3. HPLC analysis

An Agilent-1100 UV detector and an Agilent TC-C18 (250.0 mm × 4.6 mm, 5 μm) were used to analyze individual phenolic acids. The wavelengths of the detector were set at 280 and 320 nm. The ratio of the mobile phase was as follows: solvent A (HPLC water containing 0.05% TFA) and solvent B (acetonitrile:MeOH:TFA = 30:10:0.05). The gradient elution was programmed as follows: from 10% to 12% B over 16 min, from 12% to 38% B over 9 min, from 38% to 70% B over 7 min, from 70% to 85% B over 8 min, and from 85% to 100% B over 10 min. The flow rate was fixed at 1.0 mL min^{-1} and the injection volume was 20 μL. Each phenolic acid was quantified according to its calibration curve.

2.7. Evaluation of antioxidant activity

2.7.1. DPPH assay

A reported method was used to quantify DPPH radical-scavenging activity [20]. DPPH (100 μmol L^{-1}) was dissolved in 96% ethanol. The DPPH solution (1 mL) and 1 mL of the extract solution were mixed. After being shaken, the mixture was let stand at room temperature in the dark for 10 min. Finally, the decrease in absorbance of the resulting solution was measured at 517 nm after 10 min. The results are reported in μmol of Trolox equivalents (TE) per gram.

2.7.2. $ABTS^+$ assay

A reported method was used to identify the $ABTS^+$ radical-scavenging activity [24]. Briefly, redistilled water was used to dissolve $ABTS^+$ to a concentration of 7 μmol L^{-1}. An $ABTS^+$ radical cation was produced by reacting $ABTS^+$ stock solution with 2.45 mmol L^{-1} potassium persulfate and storage at room temperature for 16 h in the dark. The resulting solution containing the $ABTS^{\cdot+}$ solution was diluted with redistilled water to an absorbance of 0.70 (±0.02) at 734 nm and equilibrated at 30 °C. A reagent blank reading was then taken. Before the absorbance was measured exactly 6 min after initial mixing, 3.0 mL of diluted $ABTS^+$ solution (A 734 nm = 0.70 ± 0.02) was added to 30 μL of the extracts or Trolox (prepared in DMSO for use as standard). The results are expressed as μmol of Trolox equivalents per gram. All determinations were performed in triplicate.

2.8. Data analysis

All values are expressed as mean ± SD. Statistical analysis was performed using SAS (version 9.1.3), and Dunnett's multiple range tests were used to determine the significant differences between group means at $P < 0.05$. Correlations between TPC, TFC, and $ABTS^+$ were identified using Spearman's correlation (SPSS 17.0). Correlations were considered highly significant at $P < 0.01$.

3. Results and discussion

3.1. Nutritional compositions

3.1.1. Total starch, amylose and resistant starch

The total starch content of these 20 mung bean cultivars ranged from 40.6% to 48.9% of seed (Table 1). The amylose accounted for 12.5%–35.4% of total starch. These results were in agreement with that of Hoover et al. [25], who observed that the total starch content was 45.3% and the amylose content accounted for 39.8% of total starch in mung bean. Resistant starch accounted for 16.1%–22.3% of total starch, and the Inner Mongolia mung bean cultivar contained the highest resistant starch content. Resistant starch has recently attracted interest for its non-digestibility in the small intestine. It is fermented in the gut and is generally recognized as the main component in cereals that can improve gut microbiota composition [26]. Thus, the Inner Mongolia mung bean may be a major source of prebiotic food.

3.1.2. Total fat and fatty acids

Table 2 presents the fat and fatty acid content of 20 mung bean cultivars. The Jilyu 3 cultivar showed the highest fat content, 7.24 ± 0.11 mg g^{-1}, and the Jinlyu 3 cultivar the lowest, 5.63 ± 0.27 mg g^{-1}. There were clear differences in the fatty acid contents of the 20 mung bean cultivars. In agreement with these results, Zhang et al. [23] reported that the fat content of mung beans ranged from 3.2 to 7.5 mg g^{-1}. Palmitic acid and linoleic acid were the two dominant fatty acids in all beans, and their mean contents were 32.4% and 36.1%, respectively. Kim et al. [27] reported that linolenic acid has cardiovascular-protective, anti-cancer, neuroprotective, anti-osteoporotic, anti-inflammatory, and antioxidative effects. It may thus be beneficial as a nutraceutical/pharmaceutical candidate, and is safe for use as a food ingredient.

Table 1 – Contents of total starch, resistant starch, and amylose in 20 Chinese mung bean cultivars [a].

Cultivar	Total starch (%) [b]	Amylose (%) [c]	Resistant starch (%) [d]
Jilyu 3	46.0 ± 0.32	23.6 ± 3.16	20.1 ± 1.32
Jilyu 7	44.2 ± 0.64	24.5 ± 3.29	20.2 ± 0.66
Zhonglyu 5	45.5 ± 0.13	24.7 ± 2.53	21.8 ± 1.62
Zhonglyu 8	46.7 ± 1.15	17.9 ± 3.84	21.8 ± 0.72
Zhonglyu 11	43.1 ± 0.51	27.1 ± 2.06	20.3 ± 0.66
Huailyu 7	46.0 ± 0.38	21.1 ± 3.22	21.1 ± 0.60
Huailyu 8	43.8 ± 0.89	23.0 ± 4.84	21.7 ± 0.60
Bailyu 6	45.8 ± 0.76	35.4 ± 1.04	22.2 ± 0.30
Bailyu 8	45.4 ± 0.06	23.6 ± 0.95	18.9 ± 0.72
Jilyu 07	40.6 ± 0.57	23.3 ± 2.94	18.9 ± 0.84
Jilyu 9	41.6 ± 0.51	21.4 ± 3.85	16.6 ± 0.60
Bao 942	40.8 ± 1.34	26.5 ± 3.53	19.2 ± 0.54
Bao 942-34	44.3 ± 0.96	24.0 ± 4.54	17.7 ± 0.42
Nanyang mung bean	48.7 ± 0.25	16.9 ± 1.81	21.0 ± 0.90
Jinlyu 3	42.1 ± 0.57	32.3 ± 0.19	18.0 ± 0.18
Sulyu 2	48.9 ± 0.70	31.0 ± 4.31	16.1 ± 0.72
Liaolyu 8	45.6 ± 0.96	18.4 ± 1.93	20.5 ± 0.54
Zhangjiakou mung bean	40.6 ± 0.76	24.8 ± 4.04	22.0 ± 1.38
Inner Mongolia mung bean	43.5 ± 1.08	23.7 ± 4.87	22.3 ± 1.14
Lyufeng 3	43.2 ± 0.89	12.5 ± 1.36	21.0 ± 0.96
Mean ± SD	44.3 ± 2.38	12.5 ± 1.36	20.1 ± 1.82
$LSD_{0.05}$	1.06	4.53	1.20

[a] Data are expressed as mean ± standard deviation of triplicate samples.
[b] Percentage of seed.
[c] Percentage of total starch.
[d] Percentage of total starch.

3.1.3. Total protein and amino acid profile

Mung bean cultivars contained 20.00%–24.27% protein (Table 3). Bailyu 6 had the highest protein content, and Bao 942-34 had the lowest protein content. Our results were consistent with those of Dahiya et al., who determined that there is 18%–23% protein in mung bean flour [28]. The contents of 15 types of amino acids are also given in Table 3. Amino acids are important for the human body owing to their biological activities. Amino acids are the building blocks of the body. In addition to serving in building cells and repairing tissue, they form antibodies to combat bacteria and viruses, and are part of the enzyme and hormonal system [29]. In the present study, the amino acid composition was similar in these 20 mung bean cultivars and was characterized by a high amount of glutamic acid, reaching 42.12 ± 5.52 mg g^{-1} protein.

3.2. Total flavonoid content

The average TFC in these mung beans was 22.69 ± 1.08 mg g^{-1} (Table 4). The Zhonglyu 5 cultivar showed the highest TFC, 24.35 ± 0.08 mg g^{-1} and Bailyu 8 the lowest, 20.08 ± 0.15 mg g^{-1}. However, Zhang et al. (2012) reported that the highest content of TFC was 6.0 mg g^{-1} [23]. They used acetone and water to extract flavonoids, rather than methanol. The different methods of extraction and raw materials may account for the large differences between the previous and present values.

3.3. Total phenolic acid contents and individual phenolic acids

The TPC in different mung bean cultivar flours is given in Table 4. TPC as measured by the Folin–Ciocalteu method varied widely in mung beans. Phenolic compounds are regarded as

Table 2 – Contents of fat and fatty acid in 20 Chinese mung bean cultivars [a].

Cultivar	Fat (mg g^{-1})	Palmitic acid (%)	Stearic acid (%)	Oleicacid (%)	Linoleicacid (%)	Linolenicacid (%)
Jilyu 3	7.24 ± 0.11	33.1 ± 1.98	7.5 ± 0.29	4.6 ± 0.15	36.8 ± 0.85	18.0 ± 0.70
Jilyu 7	7.02 ± 0.29	33.6 ± 1.16	7.1 ± 0.20	5.0 ± 0.53	35.3 ± 2.88	19.1 ± 1.39
Zhonglyu 5	6.87 ± 0.17	30.1 ± 1.27	8.0 ± 0.03	5.0 ± 0.25	38.6 ± 0.67	18.4 ± 0.33
Zhonglyu 8	7.17 ± 0.21	31.7 ± 0.97	7.6 ± 0.55	4.9 ± 0.13	37.7 ± 0.52	18.1 ± 0.02
Zhonglyu 11	6.85 ± 0.11	32.2 ± 0.19	7.3 ± 0.10	5.1 ± 0.41	36.3 ± 0.21	19.1 ± 0.50
Huailyu 7	7.05 ± 0.17	35.4 ± 0.10	6.8 ± 0.08	4.2 ± 0.05	35.4 ± 0.24	18.2 ± 0
Huailyu 8	6.97 ± 0.19	33.9 ± 0.33	7.3 ± 0.09	4.5 ± 0.07	35.3 ± 0.01	19.0 ± 0.18
Bailyu 6	6.76 ± 0.06	31.5 ± 0.16	7.1 ± 0.06	5.1 ± 0.25	37.0 ± 0.10	19.3 ± 0.05
Bailyu 8	6.88 ± 0.05	31.3 ± 0.08	6.8 ± 0.20	4.8 ± 0.33	37.5 ± 0.96	19.6 ± 0.74
Jilyu 07	7.12 ± 0.02	33.8 ± 1.42	7.4 ± 0.31	3.6 ± 0.05	35.8 ± 1.04	19.4 ± 0.75
Jilyu 9	6.97 ± 0.14	33.1 ± 1.02	6.7 ± 0.77	4.5 ± 0.28	36.8 ± 0.10	18.9 ± 0.07
Bao 942	6.81 ± 0.32	33.8 ± 0.30	8.3 ± 0.03	4.9 ± 0.03	34.9 ± 0.05	18.1 ± 0.25
Bao 942-34	6.87 ± 0.26	33.9 ± 0.35	8.0 ± 0.08	4.5 ± 0.55	35.2 ± 0.11	18.4 ± 0.01
Nanyang mung bean	6.68 ± 0.13	35.5 ± 0.94	7.8 ± 0.17	4.5 ± 0.31	34.1 ± 0.19	18.1 ± 0.27
Jinlyu 3	5.63 ± 0.27	27.5 ± 1.26	8.1 ± 0.13	6.9 ± 0.79	36.9 ± 0.22	20.6 ± 0.12
Sulyu 2	7.21 ± 0.11	33.9 ± 0.51	7.8 ± 0.22	3.6 ± 0.22	35.5 ± 0.63	19.2 ± 0.33
Liaolyu 8	7.23 ± 0.16	31.9 ± 0.27	6.8 ± 0.43	4.9 ± 0.50	37.2 ± 0.18	19.2 ± 0.47
Zhangjiakou mung bean	6.71 ± 0.25	29.6 ± 0.08	8.2 ± 0.08	6.3 ± 0.11	35.4 ± 0.27	20.6 ± 0.37
Inner Mongolia mung bean	6.78 ± 0.15	31.5 ± 0.12	7.3 ± 0.18	5.0 ± 0.19	36.1 ± 0.70	20.1 ± 0.46
Lyufeng 3	6.96 ± 0.32	30.6 ± 1.60	7.2 ± 0.11	5.5 ± 0.63	34.1 ± 1.52	22.6 ± 0.65
Mean ± SD	6.89 ± 0.33	32.4 ± 1.94	7.5 ± 0.49	4.9 ± 0.73	36.1 ± 1.17	19.2 ± 1.09
$LSD_{0.05}$	0.27	1.29	0.39	0.51	1.23	0.72

[a] Data are expressed as mean ± standard deviation of triplicate samples.

Table 3 – Contents of protein and its components in 20 Chinese mung bean cultivars [a].

Cultivar	Protein (%)	Aspartic acid (mg g^{-1})	Glutamic acid (mg g^{-1})	Serine (mg g^{-1})	Histidine (mg g^{-1})	Glycine (mg g^{-1})	Threonine (mg g^{-1})	Arginine (mg g^{-1})
Jilyu 3	22.7 ± 0.19	32.54 ± 0.28	40.43 ± 0.33	13.81 ± 0.33	9.05 ± 0.23	7.68 ± 0.01	8.79 ± 0.09	18.44 ± 0.17
Jilyu 7	23.9 ± 0.23	29.50 ± 0.28	44.41 ± 0.26	15.79 ± 0.29	10.20 ± 0.26	8.81 ± 0.30	9.58 ± 0.15	20.09 ± 0.02
Zhonglyu 5	21.0 ± 0.02	26.78 ± 0.27	44.08 ± 0.02	17.60 ± 0.14	9.83 ± 0.15	8.79 ± 0.18	9.67 ± 0.19	19.69 ± 0.12
Zhonglyu 8	22.7 ± 0.27	29.81 ± 0.33	50.42 ± 0.31	14.80 ± 0.21	8.48 ± 0.05	7.98 ± 0.03	8.69 ± 0.24	18.97 ± 0.11
Zhonglyu 11	22.6 ± 0.23	31.09 ± 0.06	47.58 ± 0.15	19.57 ± 0.16	11.80 ± 0	9.73 ± 0.30	10.49 ± 0.26	24.71 ± 0.12
Huailyu 7	21.9 ± 0.09	32.53 ± 0.31	37.01 ± 0.19	13.47 ± 0.08	8.87 ± 0.21	8.13 ± 0.02	8.59 ± 0.29	17.33 ± 0.06
Huailyu 8	23.6 ± 0.00	31.53 ± 0.18	33.98 ± 0.26	12.93 ± 0.16	8.09 ± 0.06	7.37 ± 0.33	8.17 ± 0.18	16.47 ± 0.09
Bailyu 6	24.3 ± 0.33	27.09 ± 0.29	45.41 ± 0.24	16.89 ± 0.16	9.83 ± 0.06	7.98 ± 0.31	9.81 ± 0.10	19.99 ± 0.18
Bailyu 8	22.1 ± 0.21	30.19 ± 0.07	49.23 ± 0.17	17.43 ± 0.19	11.13 ± 0.04	9.79 ± 0.10	9.79 ± 0.24	23.72 ± 0.26
Jilyu 07	21.3 ± 0.18	25.47 ± 0.22	40.57 ± 0.09	14.49 ± 0.13	9.41 ± 0.20	8.42 ± 0.21	8.42 ± 0.04	19.81 ± 0.10
Jilyu 9	22.1 ± 0.25	28.48 ± 0.18	45.93 ± 0.03	15.72 ± 0.17	9.60 ± 0.32	8.97 ± 0.07	8.93 ± 0.15	21.11 ± 0.24
Bao 942	21.5 ± 0.09	31.17 ± 0.29	47.90 ± 0.01	17.28 ± 0.31	10.43 ± 0.30	9.47 ± 0.28	9.49 ± 0.25	22.51 ± 0.09
Bao 942-34	20.0 ± 0.16	21.62 ± 0.04	33.62 ± 0.28	12.99 ± 0.15	8.39 ± 0.05	7.77 ± 0.21	8.12 ± 0.08	16.82 ± 0.31
Nanyang mung bean	21.4 ± 0.28	24.57 ± 0.22	41.30 ± 0.05	14.77 ± 0.03	9.57 ± 0.20	8.59 ± 0.33	8.78 ± 0.06	19.41 ± 0.23
Jinlyu 3	22.5 ± 0.29	29.80 ± 0.22	47.12 ± 0.13	16.81 ± 0.09	10.50 ± 0.31	9.21 ± 0.06	8.89 ± 0.01	22.09 ± 0.26
Sulyu 2	23.4 ± 0.06	29.80 ± 0.12	48.31 ± 0.17	17.09 ± 0.11	10.31 ± 0.19	9.12 ± 0.23	9.08 ± 0.09	20.83 ± 0.27
Liaolyu 8	23.7 ± 0.28	22.29 ± 0.04	37.23 ± 0.27	14.11 ± 0.21	8.91 ± 0.30	8.20 ± 0.04	7.97 ± 0.33	17.43 ± 0.21
Zhangjiakou mung bean	22.9 ± 0.29	21.68 ± 0.23	34.30 ± 0.25	13.33 ± 0.13	8.83 ± 0.01	7.99 ± 0.22	8.17 ± 0.12	17.07 ± 0.25
Inner Mongolia mung bean	23.7 ± 0.15	21.22 ± 0.24	33.93 ± 0.23	12.92 ± 0.21	8.00 ± 0.29	7.59 ± 0.03	7.82 ± 0.28	16.83 ± 0.12
Lyufeng 3	22.9 ± 0.32	25.59 ± 0.29	39.61 ± 0.25	14.53 ± 0.05	9.10 ± 0.33	8.47 ± 0.14	8.61 ± 0.15	18.49 ± 0.01
Mean ± SD	22.5 ± 1.08	27.64 ± 3.70	42.12 ± 5.52	15.32 ± 1.87	9.52 ± 0.98	8.50 ± 0.70	8.90 ± 0.70	19.59 ± 2.31
$LSD_{0.05}$	0.31	0.32	0.29	0.26	0.30	0.29	0.27	0.26

Cultivar	Alanine (mg g^{-1})	Tyrosine (mg g^{-1})	Valine (mg g^{-1})	Isoleucine (mg g^{-1})	Phenylalanine (mg g^{-1})	Lysine (mg g^{-1})	Leucine (mg g^{-1})	Proline (mg g^{-1})
Jilyu 3	11.86 ± 0.04	8.66 ± 0.01	14.38 ± 0.15	11.28 ± 0.11	10.07 ± 0.09	17.51 ± 0.02	17.89 ± 0.06	9.06 ± 0.28
Jilyu 7	13.43 ± 0.27	8.37 ± 0.07	14.28 ± 0.02	11.98 ± 0.07	11.06 ± 0.06	21.85 ± 0.18	21.13 ± 0.11	9.57 ± 0.16
Zhonglyu 5	14.18 ± 0.27	9.43 ± 0.29	16.28 ± 0.14	10.69 ± 0.32	10.17 ± 0.29	23.60 ± 0.26	22.94 ± 0.05	8.45 ± 0.06
Zhonglyu 8	12.78 ± 0.27	8.79 ± 0.25	16.01 ± 0.26	10.68 ± 0.05	9.73 ± 0.29	18.44 ± 0.22	17.19 ± 0.32	9.64 ± 0.05
Zhonglyu 11	16.09 ± 0.18	11.11 ± 0.10	20.19 ± 0.01	13.81 ± 0.19	13.08 ± 0.22	27.12 ± 0.33	23.39 ± 0.13	10.41 ± 0.12
Huailyu 7	12.03 ± 0.25[j]	8.23 ± 0.23	14.58 ± 0.31	11.80 ± 0.07	10.89 ± 0.31	18.06 ± 0.28	19.56 ± 0.18	9.49 ± 0.17
Huailyu 8	11.02 ± 0.12	5.38 ± 0.20	12.77 ± 0.01	10.82 ± 0.22	10.42 ± 0.12	17.17 ± 0.32	17.65 ± 0.27	9.83 ± 0.07
Bailyu 6	13.67 ± 0.13	8.80 ± 0.20	17.27 ± 0.09	12.20 ± 0.17	11.83 ± 0.17	22.75 ± 0.32	22.61 ± 0.12	8.96 ± 0.10
Bailyu 8	14.62 ± 0.33	10.19 ± 0.11	19.23 ± 0.22	13.58 ± 0.24	11.49 ± 0.16	21.45 ± 0.24	21.95 ± 0.19	8.80 ± 0.29
Jilyu 07	12.59 ± 0.04	9.07 ± 0.07	16.58 ± 0.14	11.69 ± 0.20	10.92 ± 0.23	18.17 ± 0.26	20.03 ± 0.20	9.97 ± 0.28
Jilyu 9	13.28 ± 0.11	9.69 ± 0.03	18.21 ± 0.07	12.43 ± 0.26	11.93 ± 0.05	19.08 ± 0.17	20.16 ± 0.13	8.03 ± 0.32
Bao 942	14.32 ± 0.11	9.27 ± 0.26	19.37 ± 0.10	13.37 ± 0.05	12.69 ± 0	21.87 ± 0.27	21.78 ± 0.13	8.46 ± 0.23
Bao 942-34	10.99 ± 0.21	8.32 ± 0.31	13.29 ± 0.14	10.33 ± 0.30	9.50 ± 0.18	16.08 ± 0.19	17.03 ± 0.09	8.93 ± 0.15
Nanyang mung bean	12.52 ± 0.15	9.63 ± 0.24	16.69 ± 0.07	11.97 ± 0.25	11.04 ± 0.29	17.23 ± 0.25	19.12 ± 0.14	10.35 ± 0.27
Jinlyu 3	13.97 ± 0.05	9.53 ± 0.26	18.19 ± 0.17	11.39 ± 0.28	12.31 ± 0.14	20.19 ± 0.21	21.03 ± 0.30	8.10 ± 0.06
Sulyu 2	14.01 ± 0.20	9.23 ± 0.27	17.90 ± 0.00	12.88 ± 0.03	11.86 ± 0.13	21.10 ± 0.10	20.61 ± 0.22	8.07 ± 0.04
Liaolyu 8	11.77 ± 0.15	8.82 ± 0.17	14.53 ± 0.08	11.89 ± 0.07	10.09 ± 0.20	17.39 ± 0.30	18.95 ± 0.05	9.59 ± 0.23
Zhangjiakou mung bean	11.28 ± 0.08	8.90 ± 0.30	14.22 ± 0.20	11.53 ± 0.31	9.70 ± 0.24	16.31 ± 0.23	17.27 ± 0.19	8.39 ± 0.02
Inner Mongolia mung bean	10.92 ± 0.14	8.67 ± 0.07	14.00 ± 0.15	11.23 ± 0.25	9.55 ± 0.10	16.33 ± 0.33	17.33 ± 0.32	8.88 ± 0.12
Lyufeng 3	12.33 ± 0.26	8.97 ± 0.20	15.83 ± 0.04	12.63 ± 0.27	10.67 ± 0.08	18.71 ± 0.03	19.05 ± 0.01	10.01 ± 0.1
Mean ± SD	12.88 ± 1.37	8.95 ± 1.05	16.19 ± 2.11	11.91 ± 0.96	10.95 ± 1.05	19.52 ± 2.83	19.83 ± 2.00	9.15 ± 0.74
$LSD_{0.05}$	0.26	0.30	0.18	0.31	0.26	0.34	0.26	0.25

[a] Data are expressed as mean ± standard deviation of triplicate samples.

the major compounds contributing to the total antioxidant activities of grains [24]. In the present study, Julyu 9, with an average of 2.38 ± 0.34 mg g^{-1}, showed the highest TPC of all of the studied beans, and the lowest was that of Huailyu at 7 2.05 ± 0.44 mg g^{-1}. Mung bean had a high level of phenolics, in agreement with the results of Peng et al., who observed that mung bean extracts had the highest TPC among mung beans, black beans, soybeans, and cow beans [30].

In the present study, four bound phenolic acids (syringic acid, caffeic acid, *p*-coumaric acid, and ferulic acid) and two free phenolic acids (caffeic acid and ferulic acid) were found in these beans. Typical chromatographic profiles of the bound

Table 4 – Contents of total flavonoid (TFC), total phenolic (TPC), bound phenolic acid, and free phenolic acid in 20 Chinese mung bean cultivars [a].

Cultivar	TFC (mg g^{-1})	TPC (mg g^{-1})	Bound				Free	
			Syringic acid (μg g^{-1})	Caffeic acid (μg g^{-1})	P-coumaric acid (μg g^{-1})	Ferulic acid (μg g^{-1})	Caffeic acid (μg g^{-1})	Ferulic acid (μg g^{-1})
Jilyu 3	22.35 ± 0.46	2.20 ± 0.39	49.43 ± 1.10	1654.82 ± 80.09	59.05 ± 0.74	134.79 ± 2.34	214.22 ± 10.29	10.20 ± 0.05
Jilyu 7	22.13 ± 0.46	2.16 ± 0.41	48.31 ± 1.67	1656.83 ± 80.53	92.42 ± 0.67	133.80 ± 2.55	215.95 ± 10.61	9.83 ± 0.59
Zhonglyu 5	24.35 ± 0.08	2.26 ± 0.44	72.60 ± 0.34	1914.51 ± 75.18	158.21 ± 7.02	138.50 ± 3.91	218.87 ± 9.94	9.58 ± 0.77
Zhonglyu 8	23.81 ± 0.08	2.30 ± 0.38	69.88 ± 1.01	2619.79 ± 74.45	153.15 ± 6.09	135.56 ± 3.19	209.31 ± 16.14	10.97 ± 0.32
Zhonglyu 11	23.65 ± 1.83	2.27 ± 0.27	173.68 ± 6.62	1579.98 ± 80.66	340.14 ± 7.54	134.59 ± 2.13	214.64 ± 15.37	10.50 ± 0.29
Huailyu 7	21.43 ± 0.84	2.05 ± 0.44	25.86 ± 1.19	436.19 ± 19.87	40.77 ± 1.90	130.36 ± 3.86	203.52 ± 18.27	9.20 ± 0.96
Huailyu 8	22.95 ± 0.84	2.24 ± 0.36	60.05 ± 1.19	544.27 ± 20.75	113.18 ± 6.98	132.99 ± 2.91	204.90 ± 18.36	9.96 ± 0.03
Bailyu 6	21.92 ± 0.76	2.16 ± 0.33	50.11 ± 0.58	561.06 ± 24.98	76.17 ± 0.18	131.86 ± 1.09	205.54 ± 14.33	9.40 ± 0.75
Bailyu 8	20.08 ± 0.15	2.09 ± 0.44	56.83 ± 1.43	469.84 ± 22.52	102.15 ± 6.55	132.71 ± 3.73	206.02 ± 9.39	10.18 ± 0.73
Jilyu 07	21.97 ± 0.08	2.27 ± 0.39	60.17 ± 0.83	961.83 ± 17.32	97.58 ± 1.61	149.09 ± 4.91	229.07 ± 12.53	10.89 ± 0.39
Jilyu 9	23.38 ± 0.08	2.38 ± 0.34	72.25 ± 0.68	1871.47 ± 76.67	125.83 ± 7.97	135.11 ± 5.05	215.16 ± 14.03	10.44 ± 0.72
Bao 942	21.22 ± 0.38	2.20 ± 0.35	75.34 ± 0.57	1718.26 ± 79.8	109.46 ± 7.68	128.27 ± 1.96	213.17 ± 13.79	9.05 ± 0.19
Bao 942-34	22.19 ± 0.38	2.18 ± 0.35	59.01 ± 1.35	403.91 ± 79.32	88.29 ± 1.21	132.23 ± 4.70	217.37 ± 19.69	10.09 ± 0.71
Nanyang mung bean	23.92 ± 0.08	2.26 ± 0.32	40.04 ± 0.43	610.68 ± 80.58	111.31 ± 7.6	128.21 ± 3.05	209.91 ± 12.31	10.15 ± 0.71
Jinlyu 3	23.76 ± 0.15	2.23 ± 0.40	60.24 ± 0.77	3901.94 ± 75.44	197.33 ± 7.02	127.35 ± 1.50	192.52 ± 10.15	9.92 ± 0.23
Sulyu 2	21.76 ± 1.30	2.18 ± 0.45	67.04 ± 0.12	1086.30 ± 77.28	98.76 ± 1.15	126.16 ± 2.01	212.82 ± 8.19	10.09 ± 0.38
Liaolyu 8	22.35 ± 0.31	2.13 ± 0.37	73.67 ± 1.90	3397.41 ± 72.43	89.02 ± 0.03	131.36 ± 4.10	216.77 ± 11.51	10.12 ± 0.62
Zhangjiakou mung bean	23.54 ± 0.46	2.21 ± 0.50	41.12 ± 0.52	3077.02 ± 80.76	115.57 ± 6.66	133.79 ± 4.96	196.69 ± 11.65	10.40 ± 0.99
Inner Mongolia mung bean	23.38 ± 0.08	2.20 ± 0.38	163.99 ± 7.77	1673.99 ± 73.19	70.51 ± 0.90	131.79 ± 5.63	196.57 ± 11.66	10.29 ± 0.58
Lyufeng 3	23.65 ± 0.31	2.18 ± 0.35	142.89 ± 7.25	2066.12 ± 75.64	72.49 ± 0.64	132.78 ± 4.79	205.61 ± 10.27	9.07 ± 0.96
Mean ± SD	22.69 ± 1.08	2.21 ± 0.07	73.13 ± 38.93	1610.31 ± 1001.78	115.57 ± 62.25	133.07 ± 4.71	209.93 ± 8.51	10.01 ± 0.53
$LSD_{0.05}$	0.91	0.55	4.18	95.95	7.20	5.16	18.79	0.87

[a] Data are expressed as mean ± standard deviation of triplicate samples.

and free phenolic compounds extracted from mung beans by the HPLC system are shown in Figs. 1, 2. The contents of individual phenolic acids in the different bean varieties are shown in Table 4. Bound phenolics can survive upper gastrointestinal digestion and are released from the colon through microflora digestion activity. The average content of total bound phenolic acids (the sum of the four individual phenolic acids) in the mung bean samples was 1932.10 μg g^{-1}, comprising 89.8% of the total amount of phenolic acids. Caffeic acid was the dominant bound phenolic acid in all mung bean cultivars, with an average content of 1610.31 ± 1001.78 μg g^{-1}. Caffeic acid is an effective $ABTS^{+}$ and DPPH scavenger, so it may be a strong antioxidant in humans [31].

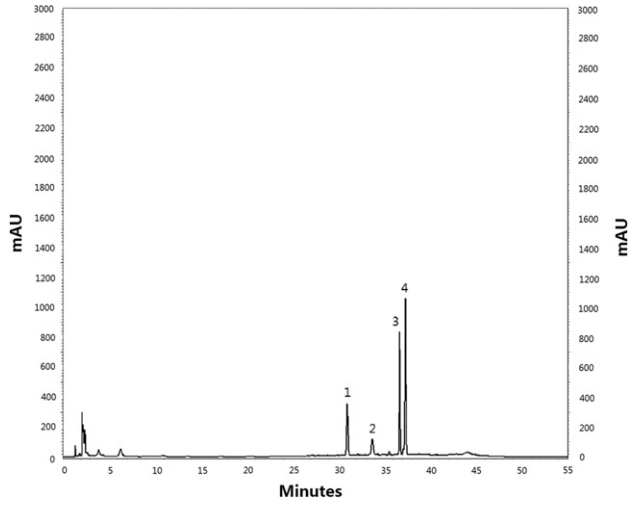

Fig. 1 – The bound phenolic acid chromatogram of mung beans. The following peaks are shown: peak 1, *p*-coumaric acid; peak 2, syringic acid; peak 3, caffeic acid; peak 4, ferulic acid.

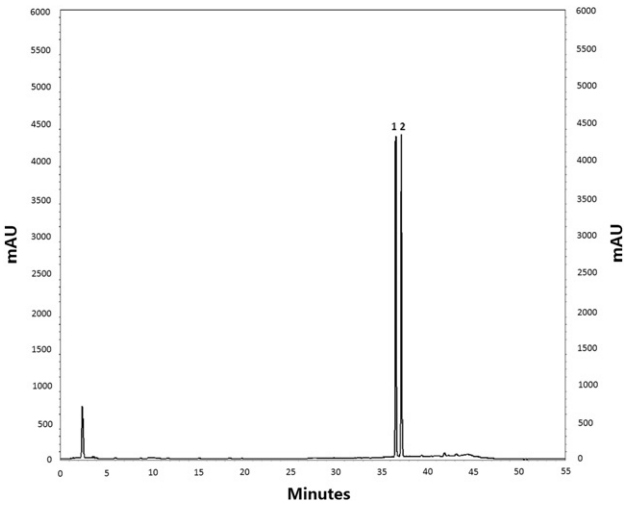

Fig. 2 – The free phenolic acid chromatogram of mung beans. The following peaks are shown: peak 1, caffeic acid; peak 2, ferulic acid.

The average total content of free phenolic acids (the sum of two individual phenolic acids) in mung bean cultivars was 219.94 μg g^{-1}, comprising 10.2% of the phenolic acids determined in mung bean samples. Caffeic acid was also the dominant free phenolic acid in all mung bean cultivars with an average content of 209.93 ± 8.51 μg g^{-1}. Significant ($P < 0.05$) differences were found among all mung beans in the contents of both bound and free phenolic acids.

Flavonoids and phenolic acids are the primary antioxidant ingredients in the tested mung beans. We determined the antioxidant activity of these mung beans.

3.4. Antioxidant activity

The antioxidant activity results are presented in Table 5. DPPH is widely used for the determination of antioxidant activity of plant extracts. In this study, the radical scavenging capacity, measured by the DPPH method, ranged from 28.13 ± 2.24 μmol g^{-1} (Julyu 9) to 35.68 ± 0.71 μmol g^{-1} (Zhonglyu 5), lower than the value (45.4 μmol g^{-1}) reported by Yao et al. [32]. The differences between the current results and those previous reported may be attributed to differences in the raw materials. Furthermore, compared with DPPH value of other cereals in our previous studies, mung bean showed higher antioxidant activity than black soybean (4.59 ± 0.27 μmol g^{-1}), black rice (8.58 ± 0.56 μmol g^{-1}) and purple corn (1.11 ± 0.09 μmol g^{-1}), but lower activity than adzuki bean (78.39 μmol g^{-1}) and rice bean (39.87 ± 1.37 μmol g^{-1}) [33–35].

Although the DPPH method is simple and rapid, it generally yields results in a relatively small linear reaction range of only 2–3-fold. Furthermore, the DPPH radical is determined by reducing agents as well as H transfer, behavior that may contribute to inaccurate interpretations of antioxidant capacity [36]. Accordingly, $ABTS^+$ radical cation assays were also used for the evaluation of free radical-scavenging properties of the 20 mung bean cultivars. The synthetic nitrogen-centered $ABTS^+$ radical is not biologically relevant, but is often used as an indicator compound in testing hydrogen-donation capacity and thus antioxidant activity [37]. As shown, the total antioxidant activities measured by the $ABTS^+$ method ranged from 3.82 ± 0.25 μmol g^{-1} (Liaolyu 8) to 13.44 ± 1.76 μmol g^{-1} (Jinlyu 3). In summary, compared with other tested mung beans, Jinlyu 3 and Huailyu 7 had higher antioxidant activity. Significant ($P < 0.05$) differences in antioxidant activity were observed in these mung beans.

Table 5 – Antioxidant activities of mung beans [a].

Cultivar	DPPH (μmol g^{-1}) [b]	$ABTS^{\cdot+}$ (μmol g^{-1}) [b]
Jilyu 3	31.03 ± 2.26	11.16 ± 1.46
Jilyu 7	33.57 ± 0.45	5.80 ± 0
Zhonglyu 5	35.68 ± 0.71	9.27 ± 1.21
Zhonglyu 8	33.48 ± 0.22	7.71 ± 3.42
Zhonglyu 11	31.66 ± 3.14	9.34 ± 7.55
Huailyu 7	30.76 ± 2.65	4.41 ± 1.96
Huailyu 8	34.85 ± 0	6.14 ± 1.20
Bailyu 6	31.94 ± 2.75	7.51 ± 2.42
Bailyu 8	29.39 ± 3.31	3.82 ± 0.25
Jilyu 07	33.62 ± 2.67	7.70 ± 1.01
Jilyu 9	28.13 ± 2.24	12.4 ± 3.22
Bao 942	31.59 ± 1.05	6.14 ± 1.20
Bao 942-34	31.88 ± 0.63	5.59 ± 1.09
Nanyang mung bean	35.34 ± 0.23	9.05 ± 2.92
Jinlyu 3	31.60 ± 1.47	13.44 ± 1.76
Sulyu 2	31.73 ± 0.42	4.20 ± 0.28
Liaolyu 8	28.95 ± 2.68	3.82 ± 0.25
Zhangjiakou mung bean	28.89 ± 0.77	6.85 ± 2.21
Inner Mongolia mung bean	28.95 ± 2.68	7.80 ± 2.02
Lyufeng 3	32.50 ± 1.51	6.39 ± 0.84
Mean ± SD	31.77 ± 2.15	7.43 ± 2.67
$LSD_{0.05}$	2.73	3.44

[a] Data are expressed as mean ± standard deviation of triplicate samples.
[b] DPPH and $ABTS^+$ scavenging activity expressed as μmol L^{-1} trolox g^{-1} for AA activities.

Table 6 – Correlation of antioxidant activity with TPC, TFC and individual phenolic acids.

	DPPH	$ABTS^+$
TFC [**]	0.291	0.700 [**]
TPC	0.222	0.609 [**]
Bound syringic acid	−0.153	0.116
Bound caffeic acid	−0.277	0.359
Bound *p*-coumaric acid	0.138	0.419
Bound ferulic acid	0.205	0.144
Free caffeic acid	0.310	−0.104
Free ferulic acid	−0.113	0.237

[**] Significant at $P < 0.01$ (2-tailed test).

3.5. Correlation of antioxidant activity with TFC, TPC, and content of individual phenolic acids

Correlation coefficients for TPC and TFC with DPPH and $ABTS^+$ assays are shown in Table 6. A high correlation between the content of total phenolic compounds and their antioxidant capacity has been previously demonstrated by Zhou et al. [36]. In our study, TFC and TPC were significantly ($P < 0.01$) correlated with the $ABTS^+$ assay, with correlation coefficients of 0.700 and 0.609, respectively.

4. Conclusions

In conclusion, there were significant differences in the nutritional composition analyses and antioxidant activities of the mung bean cultivars investigated. All of these mung beans showed high contents of resistant starch and suitable amino acid constitution. Palmitic and linoleic acids were the dominant fatty acids. Four bound and two free phenolic acids were identified by HPLC. The antioxidant activity of 70% ethanol extracts was evaluated. All of the mung beans showed strong DPPH and $ABTS^+$ free-radical-scavenging capacity. Significant positive correlations ($P < 0.01$) of antioxidant activity with TFC and TPC were observed. Compared with the other cultivars, the cultivar Zhonglyu has better nutritional composition and biological activities. These results can be used to assist in selection of bean cultivars for daily diets or in the design of

potential functional foods for use in treating diseases such as cancer and cardiovascular diseases.

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