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Evaluation of Nutritional Compositions, Bioactive Components, and Antioxidant Activity of Three Cherry Tomato Varieties

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Abstract: Cherry tomatoes are abundant in Tianyang County, Guangxi. In this study, we investigated the nutritional composition, bioactive composition and antioxidant function of three widely grown cherry tomato varieties in Tianyang County. The nutrients included sugar, fats, proteins, and minerals, and the cherry tomatoes bioactive components included fat-soluble components and water-soluble components, such as lycopene, β-carotene, esculeoside A, glutathione (GSH), and vitamin C. In addition, antioxidant activities of the three cherry tomato varieties were evaluated by their ability to scavenge 1,1-diphenyl-2-picrylhydrazyl (DPPH) and hydroxyl free radicals in vitro, preventing lipid peroxidation in the liver of mice. The results showed that all three types of cherry tomatoes were all rich in water and dietary fiber, and the Jinbi cherry tomato variety showed the highest energetic value (36.69 kcal/100 g fresh weight), suggesting cherry tomatoes as a low-calorie diet food. Constituent studies revealed that all three cherry tomato varieties were rich in GSH, esculose A, vitamin C and rutin, and the Qianxi cherry tomato variety was also rich in lycopene. In vitro scavenging of DPPH and hydroxyl radicals revealed excellent free radical scavenging activity in all three cherry tomato fat-soluble and water-soluble components, with the best results in the Qianxi variety fat-soluble component. Experimental results suggested that cherry tomatoes reduced malondialdehyde (MDA) level and increased levels of superoxide dismutase (SOD), catalase (CAT) and GSH, and prevented lipid peroxidation in the liver of mice. Our study suggests that cherry tomatoes are not only a good low-calorie nutritional supplement, but also a functional antioxidant food.

Keywords: cherry tomatoes; sugar; dietary fiber; mineral elements; bioactive components; mice; antioxidant activity

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1. Introduction

Tomato originated in the Andean region of South America and has spread throughout the world. Cultivated tomatoes are economically significant because of their high nutritional value, special flavor, and processing into tomato paste, tomato juice, and tomato beverages. Studies have reported that tomato is an excellent source of macronutrient composition and bioactive compounds and is rich in protein, fat, glucose, fructose, dietary fiber, vitamins, minerals, glutathione (GSH), carotenoids, and polyphenolic compounds [1–4]. Tomato not only provides the body with nutrients, but also plays various physiological functions, including preventing obesity, treating constipation, lowering hypertension, and reducing hyper-lipidemia [5–7].

Oxygen is essential for organisms to survive and is a highly reactive molecule that can destroy organisms by producing reactive oxygen species (ROS), which mainly include hydrogen peroxide, hydroxyl radicals, and superoxide anions. High concentrations of ROS can directly cause oxidative damage to biological macromolecules, such as deoxyribonucleic acid (DNA), proteins, and lipids. DNA damage can cause mutations and induce cancer;

protein damage can lead to inhibition of enzyme activity; and lipid damage can produce lipid peroxidation products (e.g., malondialdehyde), leading to toxic effects on cells [8–10]. Tomatoes contain numerous natural antioxidants such as β-carotene, lycopene, lutein, vitamin C, vitamin E, rutin, kaempferol, caffeic acid, and chlorogenic acid [11]. These compounds can play the role of preventing diseases by chelating metal ions, scavenging free radicals, quenching singlet-oxygen, and inhibiting oxidase activity. Many studies have shown that the predominant active substance in tomatoes is lycopene [12,13], which in ripe tomato is 0.03–0.14 mg/g. Lycopene is an important natural antioxidant, and its antioxidant activity is about 100 times that of vitamin E and more than twice that of β-carotene [12]. Continuous research on the biological functions of lycopene has reported that lycopene exerts important biological functions such as antioxidant, hypolipidemic, anticancer effects, treating nonalcoholic fatty liver, and improving the immunity of the body [7,13–15].

Cherry tomatoes are annual or perennial herbaceous plants in the genus Tomatinae of the family Solanaceae. Plants for cherry tomatoes are delicate and small in appearance, and can be grown in pots. Cherry tomatoes exhibit a short reproductive period, a long supply period, a brilliant color, and a typically sweet-sour taste, and are therefore commonly used as fruits in China. In addition, most cherry tomatoes currently cultivated are grown indefinitely and are adaptable to the environment. In addition to containing all the nutrients of a common tomato, cherry tomatoes are higher in lycopene, vitamin C, and esculeoside A [16,17]. Tianyang County in western Guangxi is subjected to a flat topography and a southern subtropical monsoon climate with an average annual temperature of 21.8–22.1 °C, and an average annual rainfall of 1053–1100 mm [18]. The unique climatic conditions have made Tianyang County a natural winter greenhouse and one of the few production bases in China, where tomatoes are largely grown in uncovered farmland during the winter. In recent years, Tianyang County has continued to grow and develop its tomato industry, including more than 13,300 hectares of cherry tomatoes, making it an essential supply site for cherry tomatoes in winter in China. Studies on the nutritional value and antioxidant properties of tomatoes from different origins have been extensively reported [3,19,20]. However, there have been no studies on cherry tomatoes from Tianyang County. Meanwhile, a thorough study is essential to better develop the tomato industry in Tianyang County. According to field research, I found that there are numerous cultivars of cherry tomatoes in Tianyang County, among which three widely grown cherry tomato varieties, Qianxi cherry tomato variety (red fruit), Jinbi cherry tomato variety (yellow fruit), and Lvfeicui cherry tomato variety (green fruit) were selected for analysis in this study.

In this study, nutrients, bioactive components, and antioxidant activity of three selected cherry tomato varieties were evaluated.

2. Materials and Methods

2.1. Materials

Qianxi cherry tomato variety [*Lycopersicon esculentum* (qianxi Group), commercial variety, Known You Seed (China) Co., Ltd. Xiamen, China], Jinbi cherry tomato variety [*Lycopersicon esculentum* (jinbi Group), commercial variety, Superior Seed Industry Co. Ltd. Xiamen, China], and Lvfeicui cherry tomato variety [*Lycopersicon esculentum* (lvfeicui Group), commercial variety, Qingfeng Yingke Seed Co. Ltd. Xingning, China] were used. The three varieties of cherry tomatoes used in the experiment were planted on 15 September 2021 at an agricultural ecological park in Tianyang County. A batch of ripe cherry tomatoes was harvested on 5 December 2021 for the experiment. The cherry tomatoes used for this experiment were consistent in climatic conditions (with an average temperature of 14–37 °C), field management, and planting sites to ensure that the differences in fruit quality were derived from the different varieties and not external factors. After harvest, the tomatoes were transported to the laboratory under refrigeration; some of them were used to describe the morphological characteristic, while the rest were immediately sealed and stored frozen at −80 °C for subsequent experiments. 1,1-diphenyl-2-picrylhydrazyl (DPPH), vitamin C, and GSH were obtained from Sigma-Aldrich Chemicals (St. Louis, MO,

USA). Lycopene, β-carotene, lutein, and rutin were purchased from Push Bio-Technology (Chengdu, China). A superoxide dismutase (SOD) assay kit, a malondialdehyde (MDA) assay kit, a catalase (CAT) assay kit, and a reduced glutathione (GSH) assay kit originated from Nanjing Jiancheng Bioengineering Institute (Nanjing, China).

2.2. Description of Morphological Characteristics and Determination of pH Value, Total Soluble Solid Content, and Total Acid Content of Cherry Tomatoes

Eight fruits of each variety of cherry tomatoes were selected and observed for fruit color and shape [3]. The weight of the cherry tomatoes was weighed using an electronic scale. Vernier calipers were employed to determine the longitudinal and transverse fruit diameter, where the ratio between them was defined as the fruit shape index. The hardness was determined using a GY-4 digital display fruit hardness meter (Shandong Hengmei Electronic Technology Co., Ltd., Jinan, China). Whole cherry tomatoes were ground in a blender for 3 min. The resulting puree was analyzed for pH and total soluble solids content. The content of total soluble solids was measured by a RX-5000i refractometer (ATAGO Co., Ltd., Tokyo, Japan) at 20 °C [21]. The pH value was measured with a PHS-2F pH meter (Shanghai Yidian Scientific Instrument Co., Ltd., Shanghai, China) at 20 °C [21]. The total acid content was determined by titration [21].

2.3. Determination of Moisture, Protein, Fat, Starch, and Total Dietary Fiber Contents of Cherry Tomatoes

The contents of moisture, protein, fat, starch, and total dietary fiber content in cherry tomatoes were determined in accordance with relevant national standards in China [22]. The content of moisture was determined using the direct drying method (GB 5009.3-2016 First standard). The Kjeldahl method (GB 5009.5-2016 First standard) was adopted to detect the content of protein. The content of fat was measured by the Soxhlet extraction method with petroleum ether as the extraction reagent (GB 5009.6-2016 Second method). The content of starch was determined by the acid hydrolysis method (the starch was hydrolyzed into reductive monosaccharides with hydrochloric acid and then measured as reductive sugars) (GB 5009.9-2016 Second standard). The content of total dietary fiber was determined by the enzymatic gravimetric method (GB 5009.88-2014): cherry tomatoes with high moisture content should be dehydrated firstly, some of which were placed in a vacuum drying oven at 70 °C and −0.085 MPa till the weight was constant. After that, the dried sample was transferred to a desiccator for use. The high sugar content in the dried tomatoes may have affected the determination of total dietary fiber, so they were stripped of excess sugar and three times eluted with 85% ethanol. The desugarized samples were enzymatically digested by α-amylase, protease, and glucosidase to remove protein and starch. The remaining residue was washed with ethanol and acetone and dried to obtain the total dietary fiber. The contents of all the above components were measured three times and expressed as weight per 100 g of fresh cherry tomatoes.

2.4. Estimates of the Amount of Glucose, Fructose, Maltose, Lactose, and Sucrose in Cherry Tomatoes

Glucose, fructose, maltose, lactose, and sucrose contents in cherry tomatoes were measured by high-performance liquid chromatography (Agilent 1200, Agilent Technologies Co., Ltd., Palo Alto, CA, USA) with evaporative light scattering detector (ELSD-2000ES, Alltech International GroupR, INC., Lexington, KY, USA) [23]. Ten grams of cherry tomatoes were accurately weighed and after ground, transferred to a 100 mL volumetric flask, dissolved in approximately 50 mL of distilled water and slowly 5 mL of zinc acetate solution and 5 mL of potassium ferricyanide solution were added. Next, the mixture was diluted with distilled water to a volume of 100 mL, sonicated for 30 min, and allowed to stand for 20 min. Then, it was centrifuged at 3000 g for 10 min to collect the supernatant, which was filtered with a 0.22 μmol aqueous microporous membrane with the filtrate serving as liquid chromatography analysis. The filtrate was isocratic elution separated by an Ultimate® XB-NH_2 column (250 mm × 4.6 mm, 5 μm, Welch Technology Co. Ltd., Shanghai, China). The selected conditions were acetonitrile–water (70:30, v/v) for the mobile phase, 1.0 mL/min

for the flow rate of mobile phase, 20 µL for the sample amount, and 40 °C for the column temperature, where the resolution was greater than 1.5. The contents of all the above components were measured by three experiments and expressed as the weight of each 100 g of fresh cherry tomatoes.

2.5. Mineral Elements in Cherry Tomatoes Determined

The contents of sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), zinc (Zn), and copper (Cu) in cherry tomatoes were determined by inductively coupled plasma mass spectrometry (ICAP Qc, Thermo Fisher, Waltham, MA, USA) [24]. One gram of cherry tomatoes was weighed into a microwave digestion tube and 5 mL of nitric acid was added. The sample was allowed to stand overnight, then digested in a microwave at 190 °C for 30 min, and then heated to remove the acid. Finally, the solution was fixed in deionized water to 100 mL for the measurement. The solution to be measured is determined by the collision pattern of the inductively coupled plasma mass spectrometer. The calibration was performed undertaking a standard solution of indium 1 µg/L as the internal standard. For the inductively coupled plasma mass spectrometry, the radio-frequency power was 1500 W; and the flow rates for the plasma gas, carrier gas, auxiliary gas, and helium were 15 L/min, 0.80 L/min, 0.40 L/min, and 4 mL/min, respectively. The amount of all the above ingredients was measured by repeating the experiment three times and was expressed as the weight per 1000 g of fresh cherry tomatoes.

2.6. Determination of Lycopene, β-Carotene, and Lutein in Cherry Tomatoes

The determinations of contents of lycopene, β-carotene, and lutein contents in cherry tomatoes were performed by modifying the previous methods [25]. Lycopene was extracted from cherry tomatoes using a solution of pyrogenic gallic acid–dichloromethane. The extracting solution was filtered with a 0.22 µmol microporous membrane. The lycopene content was determined using a high-performance liquid chromatograph. Determination of β-carotene content was as follows. First, the cherry tomatoes were pre-processed with anhydrous ethanol containing ascorbic acid, followed by saponification with a potassium hydroxide solution. After that, the saponified solution was first extracted with petroleum ether and then with dichloromethane, and was passed through a 0.45 µmol microporous membrane by taking the filtrate for liquid chromatography analysis. The following procedure was used to determine the lutein content. The cherry tomatoes were extracted with ether–hexane–cyclohexane (40:40:20, *v*/*v*) for lutein, and the extracts were purified by a neutral aluminum chloride solid-phase extraction column, separated by reversed-phase chromatography, and detected by an ultraviolet detector. The quantities of all the above ingredients were measured and averaged by repeating the experiment three times, and were expressed as the weight per 1000 g of fresh cherry tomatoes.

2.7. Estimation of GSH, Vitamin C, Rutin, and Esculeoside A Contents in Cherry Tomatoes

The GSH content was determined by the high-performance liquid chromatography method [26]. After ultrasound and centrifugation, the cherry tomatoes extracts were passed through a 0.45 µmol microporous membrane, and the filtrate was used for liquid chromatographic analysis. The GSH content was determined at 210 nm by an ultraviolet detector using potassium dihydrogen phosphate, sodium octanesulfonate, and acetonitrile as mobile phases. Vitamin C levels can be detected using the following procedure. Vitamin C was extracted from cherry tomatoes by ultrasonics using a solution of meta-phosphoric acid. The extracts were passed through 0.45 µmol microporous membrane, and the filtrate was used for liquid chromatographic analysis [27]. Rutin levels can be detected using the following method. Rutin was extracted from cherry tomatoes by ultrasonics using a solution of methanol. The extracts were passed through 0.45 µmol microporous membrane. The rutin content was determined by a high-performance liquid chromatograph [28]. The determination of esculeoside A content was performed by high-performance liquid chromatography with an evaporative light scattering detector methods [17]. Using methanol,

cherry tomatoes were extracted by ultrasonic methods. The extract was filtered through a 0.45 μmol microporous membrane, and the filtrate was used for liquid chromatography analysis. The contents of all the above components referred to the means of three experimental results and were expressed as weight per 1000 g of fresh cherry tomatoes.

2.8. Determination of In Vitro Antioxidant Activity in Cherry Tomatoes

2.8.1. Preparation of Samples

Tomatoes contain various water-soluble components (e.g., vitamin C, rutin, and t esculeoside A) and fat-soluble components (e.g., lycopene, β-carotene, and lutein). The water-soluble components of cherry tomatoes were prepared using the following procedure [29]. The cherry tomatoes were washed with distilled water, and the remaining water on the surface was absorbed with gauze. Then, 100 g of cherry tomato sauce were accurately weighed, centrifuged at 3000× *g* for 10 min at 4 °C to collect the supernatant, which was passed through a 0.45 μmol microporous membrane. The filtrate was stored at −20 °C, protected from light, and used to determine antioxidant activity. The tomato fat-soluble component is prepared by the following operation [30]. The precipitate after the above centrifugation was immersed in anhydrous ethanol for 2 h and then centrifuged again at 4 °C for 10 min at 3000× *g* to discard the supernatant. The remaining precipitate was extracted by ultrasonication with an acetone solution. Extraction conditions were set as follows: the ratio of sample to acetone solvent was 3:1 (weight volume ratio g/mL), extraction temperature was 40 °C, and the extraction time was 3 h. The extract was first filtered through gauze and then filtered through a 0.45 μmol microporous membrane to obtain the filtrate, which was stored at −20 °C and protected from light for the determination of in vitro antioxidant activity.

2.8.2. Determination of DPPH Radicals Scavenging Ability of Cherry Tomatoes

DPPH radical scavenging ability was determined according to a previous method with some modifications [31]. The acetone solvent was chosen to dilute the previously obtained filtrate of the lipid-soluble component of cherry tomatoes to obtain 2-, 4-, 8-, and 16-fold sample dilutions. Then, 0.5 mL of sample solution was aspirated precisely into a reaction tube and added with 1.5 mL of DPPH solution (0.1 mM, dissolved in anhydrous ethanol). They were vortexed and mixed well to react in a water bath at 37 °C for 30 min in the dark, and then the absorbance was measured at 517 nm. Acetone solvent was used as a blank nulling tube and all samples were run three times in parallel. The antioxidant capacity was calculated as follows:

$$\text{DPPH radicals scavenging activity (\%)} = [A_0 - (A_1 - A_2)/A_0] \times 100\% \quad (1)$$

where A_0 and A_1 denoted the absorbance without and with the sample, respectively, and A_2 referred to the absorbance of the sample background.

Determination of the DPPH radicals scavenging ability of water-soluble components of cherry tomatoes. Before the start of the experiment, the filtrate of tomato water-soluble components obtained earlier was replenished with distilled water to the same volume as the filtrate of the fat-soluble component of the tomato, and then determined with reference to the method for determination of the DPPH free radicals scavenging ability of tomato fat-soluble components.

2.8.3. Determination of Hydroxyl Radicals Scavenging Capacity in Cherry Tomatoes

The hydroxyl free radical scavenging ability was determined using the Fenton reaction with some modifications [32]. Acetone solvents were used to dilute the filtrate of tomato fat-soluble components obtained in the previous stage to obtain 2-, 4-, 8- and 16-fold sample dilutions. Then, 0.2 mL of sample solution was placed in a reaction tube, then successively added with 1 mL of ferrous sulfate solution (9 mM, dissolved in deionized water), 1 mL of salicylic acid solution (9 mM, dissolved in anhydrous ethanol), 11.8 mL of deionized water, and 1 mL of H_2O_2 solution (9 mM, dissolved in deionized water). The mixture

was vortexed and mixed well to react in a water bath at 37 °C for 30 min in dark. After that, the absorbance was measured at 510 nm. The acetone solvent was used as a blank null adjustment tube, and all samples were tested three times in parallel. The antioxidant capacity was calculated as follows:

$$\text{Hydroxyl radicals scavenging activity (\%)} = [A_0 - (A_1 - A_2)/A_0] \times 100\% \quad (2)$$

where A_0 and A_1 represented the absorbance without and with the sample, respectively, and A_2 referred to the absorbance of the sample background.

The hydroxyl radicals scavenging capacity of the water-soluble components of cherry tomatoes was determined. Before the experiment, the filtrate of the water-soluble component of the tomato obtained earlier was replenished with distilled water to the same volume as the filtrate of the fat-soluble component of the tomato, and then determined using the method described above.

2.9. Determination of In Vivo Antioxidant Activity in Cherry Tomatoes

2.9.1. Preparation of Samples

The preparation of cherry tomato powder is described below [33]. The freeze-drying of cherry tomatoes was performed in a freeze-drying machine. The lyophilized cherry tomatoes are then pulverized into a powder form using a grinder.

2.9.2. Animals

Male C57BL/6J mice (18–22 g) were obtained from the Hunan SJA Laboratory Animal Co., Ltd. (Changsha, China). The animals were kept in large, clean polypropylene cages in an environment at 45–55% relative humidity and 22 ± 2 °C under a 12 h dark/12 h light cycle [34]. The animals were given free access to the standard commercial chow diet (Hunan SJA Laboratory Animal Co., Ltd., Changsha, China) and water. The study protocol was approved by the Institutional Animal Ethical Committee of the Guangxi Institute of Botany, Guangxi Zhuang Autonomous Region and the Chinese Academy of Science (protocol code: GXZW2022082001).

2.9.3. Experimental Design and Index Determination

After the acclimation period of a week, male C57BL/6J mice were randomly divided into 5 groups, and 12 mice were assigned to each treatment [35]. Control group (CG) and model group (MG) were fed a standard commercial chow diet. Qianxi cherry tomato group (QCT-G) received a tomato supplemented diet (standard commercial chow diet with 10% Qianxi cherry tomato powder). Jinbi cherry tomato group (JCT-G) received a tomato supplemented diet (standard commercial chow diet with 10% Jinbi cherry tomato powder). Lvfeicui cherry tomato group (LCT-G) received a tomato supplemented diet (standard commercial chow diet with 10% Lvfeicui cherry tomato powder). Seven days later, CG was administered olive oil (2 mL/kg, i.p.), and the other 4 groups received CCl_4-olive oil (1:1, 2 mL/kg, i.p.). All animals were anesthetized by pentobarbitone sodium (intraperitoneally, 50 mg/kg) on day 9. The liver is carefully dissected and cleaned to remove extraneous tissue. Parts of the same region of liver were homogenized using a glass homogenizer, followed by 15 min of centrifugation at 3000 rpm at 4 °C. We then collected supernatants for analysis of the antioxidant capacity index. The SOD, CAT, GSH, and MDA levels were obtained using a commercial kit following the methodology described by the manufacturer.

2.10. Statistical Analysis

All experimental data were presented as means ± standard deviation. One-way analysis of variance (ANOVA) was employed to compare the mean values of multiple samples. Statistical analysis was performed by using the GraphPad Prism 8 (GraphPad Software, San Diego, CA, USA) program and $p < 0.05$ was considered statistically significant.

3. Results and Discussion

3.1. Morphological Characteristics, pH Value, Total Soluble Solid Content, and Total Acid Content of Cherry Tomatoes

The metrics for morphological characteristics of cherry tomatoes included longitudinal fruit diameter, transverse fruit diameter, fruit color, fruit weight, and fruit hardness, which were directly related to consumer purchases and were based on evaluating the quality of cherry tomato. Table 1 revealed that all three cherry tomato varieties were oval, with the shape index of the Lvfeicui variety being around 1.13, indicating that it was closer to a round shape. Of the three types of cherry tomatoes, the Jinbi variety showed the highest fruit size and weight, followed in order by the Lvfeicui variety and Qianxi variety. Commonly, three cherry tomato varieties were favored by consumers due to their moderate size and weight. Fruit hardness was one of the prominent indicators of fruit ripeness and storage quality. The Lvfeicui variety showed the highest fruit hardness, and the remaining two cherry tomatoes also exhibited excellent hardness (as shown in Table 1). It indicates that they all were suitable for storage and transportation, which is an important reason for the fact that they were cultivated on a large scale. The pH value was highest in the Jinbi variety (4.98) and lowest in the Qianxi variety (4.52). Total acid content was significantly higher in the Qianxi variety (0.39%) than in the other two varieties (0.35% and 0.32%). In contrast, the total soluble solid content was highest in the Lvfeicui variety (7.89%) and lowest in the Qianxi variety (5.42%). The three cherry tomato varieties differ not only in color, fruit size, and fruit hardness, but also in pH, total acid content, and total soluble solids.

Table 1. Morphological characteristics, pH value, total soluble solid content, and total acid content of cherry tomatoes.

Item	Qianxi	Jinbi	Lvfeicui
Exterior color of mature fruit	Red	Yellow	Green
Average fruit weight (g)	14.82 ± 1.21^{c}	22.43 ± 2.13^{a}	18.53 ± 1.62^{b}
Average longitudinal fruit diameter (cm)	3.43 ± 0.22^{b}	3.94 ± 0.31^{a}	3.53 ± 0.22^{b}
Average transverse fruit diameter (cm)	2.54 ± 0.24^{b}	3.13 ± 0.22^{a}	3.12 ± 0.13^{a}
Average fruit shape index	1.36 ± 0.15^{a}	1.26 ± 0.19^{a}	1.13 ± 0.11^{a}
Predominant fruit shape	Oval-shaped	Oval-shaped	Oval-shaped
Average fruit hardness (kg/cm^2)	1.48 ± 0.25^{c}	1.92 ± 0.28	2.35 ± 0.21^{a}
pH value	4.52 ± 0.16^{b}	4.98 ± 0.13^{a}	4.66 ± 0.15^{b}
Total soluble solid content (%)	5.42 ± 0.13^{c}	6.52 ± 0.18^{b}	7.89 ± 0.19^{a}
Total acid content (%)	0.39 ± 0.02^{a}	0.35 ± 0.02^{b}	0.32 ± 0.01^{c}

Values were expressed as mean ± standard deviation, (n = 8). The same superscript (a, b, or c) in the same line represents no significant differences between values ($p < 0.05$).

3.2. Nutrient Composition of Cherry Tomatoes

The macronutrient composition of the three cherry tomato varieties is given in Table 2. The moisture content was 91.53 g/100 g fresh weight (FW) in the Qianxi variety, 91.64 g/100 g FW in the Jinbi variety, and 90.92 g/100 g FW in the Lvfeicui variety, which are consistent with the values reported in the literature for cherry tomatoes and lower than the values reported in the literature for common tomatoes [3,36]. Fat and protein are the main nutrients; the Jinbi variety showed the highest protein content (0.82 g/100 g FW) and fat content (0.33 g/100 g FW). A previous study reported that the tomato variety Mongol F1 from Burkina Faso had lipid and protein contents ranging from 0.30 percent to 0.77 percent and 1.71 percent to 2.50 percent, respectively. Tomatoes from Tianyang County contain less protein and fat than those from Burkina Faso [37]. The sugar compound is the main source of energy required by all living organisms to sustain their life activities [38]. Table 2 demonstrates that all three cherry tomato varieties contain high levels of fructose and glucose, small amounts of sucrose, and no maltose and lactose, in agreement with previous studies [3,36]. Jinbi variety showed the highest fructose and glucose content of all three varieties, approximately 3.43 g/100 g FW and 3.02 g/100 g FW, respectively, which may be one reason for the greatest sweetness of the Jinbi variety. Starch is one of the main

sources of carbohydrates. In all three types of cherry tomatoes, only extremely small amounts of starch are present, and sugar is the dominant carbohydrate in cherry tomatoes. In addition, dietary fiber is an essential component of nutritional elements. It cannot be digested and absorbed by the gastrointestinal tract and can only produce little energy, but stimulates the production of digestive juices, promotes intestinal peristalsis, absorbs the water swelling, improves the microbial composition of the intestine, and plays vital physiological functions [39]. Table 2 also reveals that all three cherry tomato varieties contain high levels of dietary fiber, with the Lvfeicui variety having the highest content (2.82 g/100 g FW). Of the three types of cherry tomatoes, the Jinbi variety showed the highest energetic value (36.69 kcal/100 g FW), followed in order by the Lvfeicui and Qianxi varieties. Macronutrients indicate that cherry tomatoes have a high moisture content, moderate carbohydrate and protein content, in contrast to low fat levels, making cherry tomatoes suitable for incorporation into a low-calorie diet.

Table 2. Macronutrient and mineral composition of three different types of cherry tomatoes.

Item	Qianxi	Jinbi	Lvfeicui
Macronutrient			
Moisture (g/100 g FW)	91.53 ± 2.12 ^{a}	91.64 ± 1.98 ^{a}	90.92 ± 1.83 ^{a}
Proteins (g/100 g FW)	0.64 ± 0.03 ^{b}	0.82 ± 0.01 ^{a}	0.56 ± 0.02 ^{c}
Fat (g/100 g FW)	0.28 ± 0.01 ^{b}	0.33 ± 0.01 ^{a}	0.30 ± 0.01 ^{b}
Starch (g/100 g FW)	0.01 ± 0.00 ^{a}	0.01 ± 0.00 ^{a}	0.01 ± 0.00 ^{a}
Total fiber (g/100 g FW)	2.11 ± 0.14 ^{b}	2.34 ± 0.15 ^{b}	2.82 ± 0.11 ^{a}
Fructose (g/100 g FW)	3.21 ± 0.32 ^{a}	3.43 ± 0.28 ^{a}	2.85 ± 0.33 ^{b}
Glucose (g/100 g FW)	2.89 ± 0.25 ^{a}	3.02 ± 0.15 ^{a}	2.98 ± 0.23 ^{a}
Sucrose (g/100 g FW)	0.02 ± 0.00 ^{a}	0.01 ± 0.00 ^{a}	0.01 ± 0.00 ^{a}
Maltose (g/100 g FW)	Not detected	Not detected	Not detected
Lactose (g/100 g FW)	Not detected	Not detected	Not detected
Energy (kcal/100 g FW)	33.80 ± 1.92 ^{b}	36.69 ± 1.58 ^{a}	33.91 ± 1.77 ^{b}
Mineral			
Sodium (Na) (mg/Kg FW)	125.33 ± 3.92 ^{b}	132.64 ± 4.12 ^{a}	133.91 ± 3.21 ^{a}
Potassium (K) (mg/Kg FW)	1380.32 ± 29.63 ^{a}	990.92 ± 22.73 ^{c}	1107.93 ± 31.22 ^{b}
Calcium (Ca) (mg/Kg FW)	95.58 ± 4.21 ^{a}	78.34 ± 3.13 ^{b}	93.77 ± 2.82 ^{a}
Magnesium (Mg) (mg/Kg FW)	129.51 ± 3.32 ^{a}	106.20 ± 2.92 ^{b}	96.54 ± 3.63 ^{c}
Iron (Fe) (mg/Kg FW)	3.05 ± 0.18 ^{a}	2.22 ± 0.21 ^{b}	2.89 ± 0.11 ^{a}
Zinc (Zn) (mg/Kg FW)	1.92 ± 0.12 ^{a}	1.89 ± 0.13 ^{a}	1.57 ± 0.09 ^{b}
Copper (Cu) (mg/Kg FW)	0.51 ± 0.04 ^{c}	0.73 ± 0.03 ^{a}	0.59 ± 0.03 ^{b}

Values were mean of triplicate experiments ± standard deviation. Macronutrient (g/100 g FW), energy (kcal/100 g FW) and mineral (mg/Kg FW). The same superscript (a, b, or c) in the same line represents no significant differences between values ($p < 0.05$).

Mineral elements maintain the body's physiological activity by participating in metabolism and various biological and chemical reactions. For example, they can promote the synthesis and enhance the activity of enzymes that are fundamental to the various activities of the body and the maintenance of vital activities. In addition, they can scavenge free radicals, prevent oxygenated stress damage, participate in hormone synthesis, transfer biological information, and maintain cellular vitality and the normal functioning of human senses [40]. Some mineral elements, such as calcium (Ca), potassium (K), sodium (Na), magnesium (Mg), Phosphorus (P), Sulfur (S), and Chlorine (Cl), are essential for the body and are supplemented at an average of >50 mg daily; hence, they were determined as the major mineral elements [41]. For example, K is excreted in large amounts, so it needs to be supplemented daily at around 2000 mg. All three types of cherry tomatoes presented high K contents, which were 1380.32 mg/Kg FW for Qianxi variety, 990.92 mg/Kg FW for Jinbi variety, and 1107.93 mg/Kg FW for Lvfeicui variety. Therefore, consumption of cherry tomatoes is an excellent way to replace the missing K in the body. The data presented here suggest that all three cherry tomato varieties contain high levels of Mg, and are therefore excellent sources of Mg. Himsona tomato powder (Syngenta AG) contains Mg 126 mg

and K 2805.8 mg per 100 g. Tomatoes from Tianyang County contain less K and about the same amount of Mg as those from Himsona [42]. Therefore, 500 g of tomatoes a day may meet one-third of a person's daily physiological requirements for K and Mg. Zn and Cu are heavy metals and can accumulate in the body after consumption [43], which is harmful to health. As shown in Table 2, all three cherry tomato varieties contain low levels of Zinc (Zn) and Copper (Cu), so chronic consumption would not result in chronic heavy metal poisoning.

3.3. Bioactive Components of Cherry Tomatoes

Lycopene is widely found in tomatoes, watermelons, grapefruit, and other fruits, and is the main pigment in ripe tomatoes [44]. Lycopene is a long-chain polyunsaturated olefin that enables strong scavenging of free radicals and antioxidant capacity. The lycopene content of the three cherry tomato varieties is shown in Table 3: 56.25 mg/Kg FW in Qianxi variety, 5.13 mg/Kg FW in Jinbi variety, and 1.53 mg/Kg FW in Lvfeicui variety. This suggests that not all tomatoes are rich in lycopene, and that this is related to their color: red cherry tomatoes (Qianxi variety) have high levels of lycopene, while green cherry tomatoes (Lvfeicui variety) have low levels. Some studies have reported that black and yellow tomatoes also have high levels of lycopene [3,36]. However, Jinbi variety, the yellow tomato in our study, had only about 1/10 of the lycopene content of the red tomato (Qianxi variety), which may be related to the different varieties. β-carotene is a type of carotenoid that is an antioxidant [45]. The β-carotene contents in the three cherry tomato varieties were similar to those of lycopene, with the highest level in Qianxi variety (6.85 mg/Kg FW) and the lowest amount in Lvfeicui variety (0.54 mg/Kg FW). Lutein is also a carotenoid. The lutein content in tomatoes was low, 1.68 mg/Kg FW in the Jinbi variety and less than 1 mg/Kg FW in the remaining two species (Table 3). A previous study reported that tomatoes are also abundant in polyphenolic components, which are one of the main components of their antioxidant effects [46]. Rutin is one of the most prominent polyphenolic ingredients in tomatoes. The rutin contents in the three cherry tomato varieties are listed in Table 3. It was 9.84 mg/Kg FW in Qianxi variety, 12.31 mg/Kg FW in Jinbi variety, and 11.12 mg/Kg FW in Lvfeicui variety. It was clear that all three cherry tomato varieties contained high levels of rutin, in agreement with previous studies [46]. Esculeoside A was first isolated from cherry tomatoes, and further investigations have shown that esculeoside A and its aglycone esculeogenin A inhibit the formation of foam cells in vitro [46]. Esculeoside A is a major saponin component of tomatoes and has both hypoglycemic and hypolipidemic effects, as well as an inhibitory effect on the formation of atherosclerotic plaques [34,47]. The esculeoside A contents in the three cherry tomato varieties were 687.43 mg/Kg FW in Qianxi variety, 433.32 mg/Kg FW in Jinbi variety, and 357.40 mg/Kg FW in Lvfeicui variety (Table 3). Esculeoside A was found to be substantially higher in cherry tomatoes than lycopene, in agreement with previous findings [34,47]. A large amount of esculeoside A is contained in the cherry tomatoes, so it is one of the main biological activities of cherry tomatoes. GSH helps the body to maintain normal immune system function and exerts antioxidant and detoxifying effects [48]. All three cherry tomato varieties exhibited high levels of GSH: 1894.33 mg/Kg FW in Qianxi variety, 2013.90 mg/Kg FW in Jinbi variety, and 2664.54 mg/Kg FW in Lvfeicui variety. This suggests that cherry tomatoes can be a good source of GSH. Vitamin C is a common water-soluble vitamin with antioxidant, anti-free radical, and tyrosinase inhibiting properties, and is also required in numerous important biosynthetic processes in the body [49]. Vitamin C is found mainly in food-borne fresh fruits and vegetables. Vitamin C deficiency can cause scurvy and may be involved in cancer and cardiovascular disease [50]. Daily intake of enough vitamin C is very important. The vitamin C content of the three cherry tomato varieties is shown in Table 3: 578.33 mg/Kg FW in Qianxi variety, 656.63 mg/Kg FW in Jinbi variety, and 692.72 mg/Kg FW in Lvfeicui variety. Cherry tomatoes from Tianyang County contain a significantly higher level of vitamin C than those from most other regions [3,20]. This suggests that cherry tomatoes may also be a good source of vitamin C.

Table 3. Bioactive components of three different kinds of cherry tomatoes.

Item	Qianxi	Jinbi	Lvfeicui
Lycopene (mg/Kg FW)	56.25 ± 2.41 [a]	5.13 ± 0.22 [b]	1.53 ± 0.11 [c]
β-carotene (mg/Kg FW)	6.85 ± 0.18 [a]	0.78 ± 0.03 [b]	0.54 ± 0.02 [c]
Lutein (mg/Kg FW)	0.79 ± 0.01 [b]	1.68 ± 0.03 [a]	0.33 ± 0.01 [c]
Rutin (mg/Kg FW)	9.84 ± 0.15 [c]	12.31 ± 0.21 [a]	11.12 ± 0.29 [b]
Esculeoside A (mg/Kg FW)	687.43 ± 13.22 [a]	433.32 ± 16.54 [b]	357.40 ± 15.12 [c]
GSH (mg/Kg FW)	1894.33 ± 52.61 [c]	2013.90 ± 40.84 [b]	2446.54 ± 50.12 [a]
Vitamin C (mg/Kg FW)	578.33 ± 21.22 [c]	656.63 ± 18.71 [b]	692.72 ± 22.62 [a]

Values were mean of triplicate experiments ± standard deviation. Bioactive components (mg/Kg FW). The same superscript (a, b, or c) in the same line represents no significant differences between values ($p < 0.05$).

3.4. DPPH Radicals Scavenging Activity of Cherry Tomatoes

DPPH is a steady-state radical with unpaired electrons. Ethanol or methanol solutions of DPPH are purple in color and exhibit a strong absorption peak at 517 nm. When free radical scavengers are present, the DPPH accepts electrons or hydrogen atoms and the color gradually tends to fade, based on which antioxidant function can be assessed [51]. The scavenging abilities of the three cherry tomato varieties against DPPH radicals is shown in Table 4. It demonstrated that both water- and fat-soluble components of cherry tomatoes scavenged DPPH radicals in a dose-dependent manner, with the scavenging effect increasing with sample concentration. In terms of fat-soluble components of cherry tomatoes, Qianxi variety showed the strongest ability to scavenge DPPH radicals, with undiluted extracts scavenging 94.54% of DPPH radicals, which may be related to the higher content of lycopene. DPPH radical clearance rates were approximately 73.72% and 74.83% for the Jinbi variety and Lvfeicui variety undiluted extract, respectively. In terms of the water-soluble components of cherry tomatoes, Qianxi and Lvfeicui varieties were comparable in their ability to scavenge DPPH radicals, with values of 78.21% and 79.70% of DPPH radicals, respectively, while Jinbi variety had a slightly stronger ability to scavenge DPPH radicals than Qianxi variety and Lvfeicui variety, which was 89.51%. The ability of the water-soluble and fat-soluble components of tomatoes to scavenge DPPH radicals is different in the same variety. For example, the fat-soluble components scavenged DPPH radicals better than the water-soluble components in Qianxi variety; the fat-soluble components that scavenged DPPH radicals were weaker than the water-soluble components in Jinbi variety; and the fat-soluble and water-soluble components showed a similar ability to scavenge the DPPH radicals in Lvfeicui variety. The above findings suggest that both the water-soluble and fat-soluble components of cherry tomatoes have excellent DPPH free radicals scavenging activity. A previous study determined antioxidant activity in the pulp of ten regular, six medium-sized, and two small cherry tomato cultivars from South Korea. They found that vitamin C and lycopene content showed a high positive correlation with DPPH radical scavenging activity for both lipophilic and hydrophilic extracts [52]. Our results are similar to those observed with a previous study and suggest that vitamin C is a major functional activity component of the water-soluble component and lycopene is a major functional activity component of the fat-soluble component.

3.5. The Ability of Cherry Tomatoes to Scavenge Hydroxyl Free Radicals

Hydroxyl free radical acts on proteins, nucleic acids, and lipids in the body, damaging the cell structure and function, thus leading to metabolic disorders [53]. The ability to scavenge the hydroxyl free radicals can be based on judging the antioxidant capacity of the cherry tomatoes. The scavenging ability of the three cherry tomato varieties against hydroxyl radicals is shown in Table 5. It reveals that both water- and fat-soluble components scavenge hydroxyl radicals in a dose-dependent manner, with the scavenging effect increasing with sample concentration, and the results are similar to scavenge the DPPH radicals. A previous study reported that tomato juice can scavenge hydroxy free radicals and the ability was increased as the amount of the tomato juice increased [29]. The

results are the same as in our study. Among the fat-soluble components, Qianxi variety showed the strongest ability to scavenge hydroxyl radicals, with an 89.31% ability for the undiluted extract, which may be related to the high lycopene content. It has been reported that lycopene can scavenge the hydroxyl free radicals effectively [54]. Jinbi variety and Lvfeicui variety contain less lycopene, as explained above, so their ability to scavenge hydroxyl radicals is weaker. The ability of the undiluted extract to scavenge hydroxyl radicals was 39.63% and 37.23% for the Jinbi variety and Lvfeicui variety, respectively. Among the water-soluble components, the ability of the three cherry tomato varieties to scavenge hydroxyl radicals was weaker, with 45.72%, 43.21%, and 41.51% in the undiluted extracts of cherry tomatoes from Qianxi, Jinbi, and Lvfeicui varieties, respectively. The water-soluble components of cherry tomatoes have a weak ability to scavenge hydroxyl radicals, mainly because they do not contain lycopene.

Table 4. Effects of scavenging DPPH radicals from three different cherry tomato varieties.

Item	DPPH Radicals Scavenging Activity (%)				
	16-Fold Dilution	8-Fold Dilution	4-Fold Dilution	2-Fold Dilution	Extract Solution
Qianxi					
Fat-soluble constituents	33.92 ± 1.21 ^{a}	52.13 ± 1.42 ^{a}	69.73 ± 2.13 ^{a}	88.42 ± 1.91 ^{a}	94.54 ± 1.51 ^{a}
Water-soluble components	18.84 ± 0.82 ^{d}	29.54 ± 1.53 ^{c}	45.72 ± 1.82 ^{d}	63.33 ± 1.14 ^{c}	78.21 ± 2.12 ^{c}
Jinbi					
Fat-soluble constituents	25.71 ± 1.12 ^{b}	35.32 ± 1.92 ^{b}	52.24 ± 1.83 ^{c}	65.52 ± 1.40 ^{c}	73.72 ± 2.14 ^{d}
Water-soluble components	30.62 ± 1.21 ^{a}	48.13 ± 1.32 ^{a}	59.44 ± 1.63 ^{b}	76.42 ± 1.31 ^{b}	89.51 ± 1.62 ^{b}
Lvfeicui					
Fat-soluble constituents	21.50 ± 1.12 ^{c}	36.42 ± 2.13 ^{b}	50.51 ± 0.90 ^{c}	62.22 ± 1.41 ^{c}	74.83 ± 2.32 ^{d}
Water-soluble components	19.43 ± 0.80 ^{d}	32.53 ± 1.61 ^{b,c}	48.21 ± 2.13 ^{c,d}	63.32 ± 1.54 ^{c}	79.70 ± 1.41 ^{c}

Values were mean of triplicate experiments ± standard deviation. The same superscript (a, b, c, or d) in the same column represents no significant differences between values ($p < 0.05$).

Table 5. Hydroxyl free radicals scavenging activity of three different cherry tomato varieties.

Item	Hydroxyl Free Radicals Scavenging Activity (%)				
	16-Fold Dilution	8-Fold Dilution	4-Fold Dilution	2-Fold Dilution	Extract Solution
Qianxi					
Fat-soluble constituents	28.21 ± 1.53 ^{a}	45.32 ± 1.24 ^{a}	61.63 ± 2.10 ^{a}	71.92 ± 1.64 ^{a}	89.31 ± 2.22 ^{a}
Water-soluble components	21.14 ± 1.12 ^{b}	25.92 ± 1.40 ^{b}	33.63 ± 2.14 ^{b}	40.61 ± 1.32 ^{b}	45.72 ± 1.93 ^{b}
Jinbi					
Fat-soluble constituents	18.51 ± 1.12 ^{b}	23.80 ± 0.91 ^{b,c}	28.33 ± 0.71 ^{c}	33.52 ± 0.92 ^{c}	39.63 ± 1.33 ^{c}
Water-soluble components	21.22 ± 0.64 ^{b}	25.13 ± 0.52 ^{b}	30.70 ± 0.70 ^{b,c}	35.62 ± 0.60 ^{c}	43.21 ± 0.92 ^{b,c}
Lvfeicui					
Fat-soluble constituents	19.13 ± 0.32 ^{b}	22.04 ± 0.31 ^{c}	26.82 ± 0.64 ^{c}	32.33 ± 0.42 ^{c}	37.23 ± 0.52 ^{c}
Water-soluble components	21.70 ± 0.21 ^{b}	25.81 ± 0.42 ^{b}	30.33 ± 0.60 ^{b,c}	35.23 ± 0.52 ^{c}	41.51 ± 0.71 ^{b,c}

Values were mean of triplicate experiments ± standard deviation. The same superscript (a, b, or c), in the same column represents no significant differences between values ($p < 0.05$).

3.6. Effects of Cherry Tomatoes on Antioxidant Capacity in Mice

The toxicity of tetrachloromethane (CCl_4) results from its production of highly reactive trichloroethylene radicals. Radical derivatives of CCl_4 have been reported to cause lipid peroxidation [55]. As displayed in Figure 1, the MG mice after injection of CCl_4 presented remarkably decreased antioxidant capacity of liver, relative to the CG mice. SOD, CAT, and GSH are key antioxidants in biological systems that inhibit the formation of free radicals, and they are commonly used as biomarkers to indicate the production of reactive oxygen species. SOD is a highly significant endogenous antioxidant, as it is the only enzyme defense system that breaks down superoxide anions into hydrogen peroxide [56]. GSH

primarily helps to maintain the intracellular detoxification of electrophilic metabolites and thiol states, and functions as an antioxidant by scavenging oxygen free radicals during lipid peroxidation [57]. CAT plays a key role in the metabolism of hydrogen peroxide into oxygen and water [58]. MDA is one of the end products of lipid peroxidation, and its level in the liver reflects the degree of lipid peroxidation in the hepatocytes [59]. As can be seen in Figure 1A, the administration of Qianxi cherry tomato or Lvfeicui cherry tomato led to an increase in SOD activity in the liver in mice receiving CCl4 treatment ($p < 0.05$), and the Jinbi cherry tomato had no effect on liver SOD activity. As depicted in Figure 1B, relative to the MG mice, the mice in QCT-G, JCT-G, and LCT-G presented a loss in the liver MDA ($p < 0.05$). As can be seen in Figure 1C, the administration of Qianxi cherry tomato, Lvfeicui cherry tomato, and Jinbi cherry tomato led to an increase in the liver GSH content in mice receiving CCl4 treatment ($p < 0.05$). As shown in Figure 1D, the activity of CAT in the liver was increased after administration of Qianxi cherry tomato, Lvfeicui cherry tomato, and Jinbi cherry tomato with respect to MG mice, but there was no statistically significant change. Previous experiments have revealed the ability of tomato powder to prevent H_2O_2-induced elevated serum and liver MDA, and it performs significantly better than lycopene in terms of antioxidant effects [7]. The results are the same as in our study. Its activity in preventing lipid peroxidation is revealed by the fact that the cherry tomatoes of Qianxi, Lvfeicui, and Jinbi have reduced MDA levels and increased levels of GSH, SOD, and CAT.

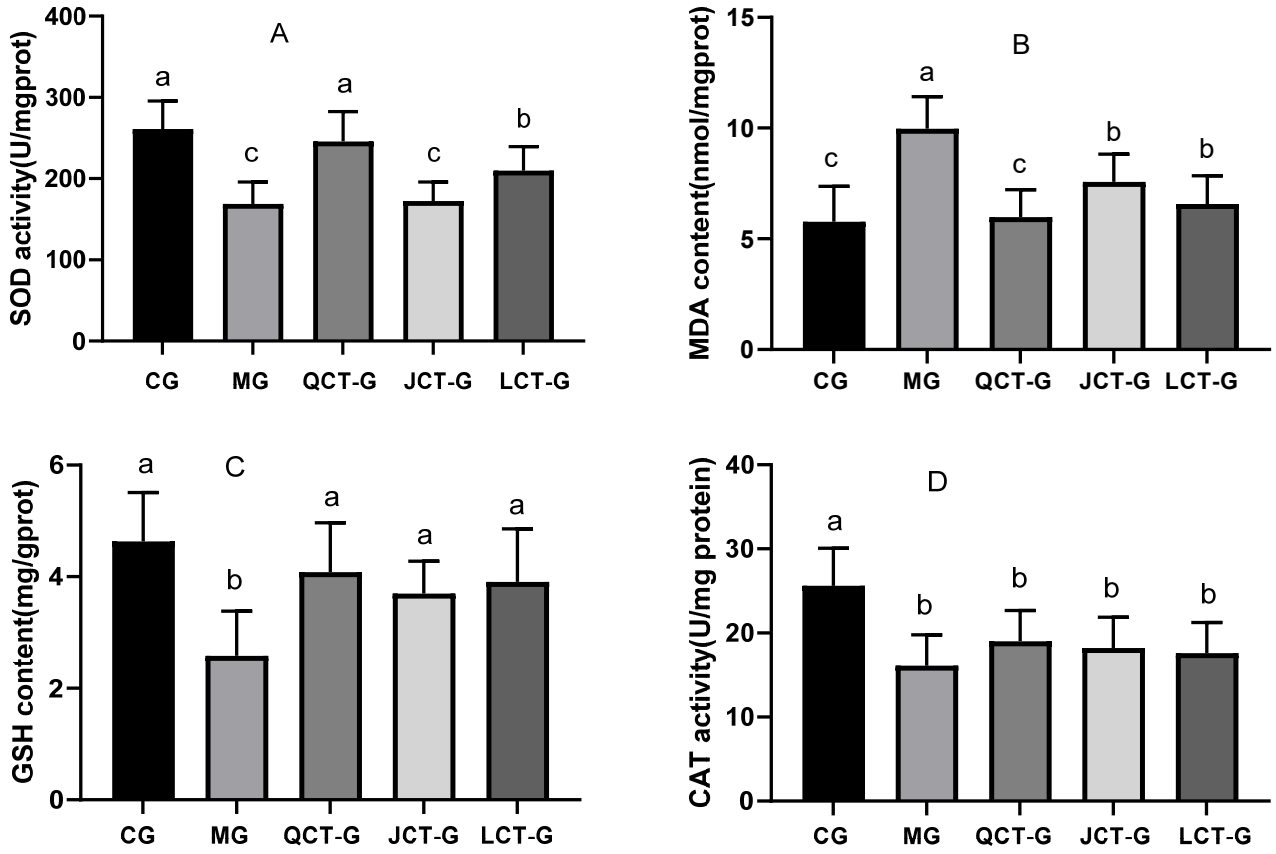

Figure 1. SOD, MDA, GSH, and CAT levels in the liver of mice: (**A**) SOD activity in the liver of mice; (**B**) MDA content in the liver of mice; (**C**) GSH contents in the liver of mice; (**D**) CAT activity in the liver of mice. Values are expressed as mean ± standard deviation ($n = 12$ in each group). The same superscript (a, b, or c) in the same column represents no significant differences between values ($p < 0.05$).

4. Conclusions

This study provided data on the nutrients, bioactive components, and antioxidants of three representative cherry tomatoes from Tianyang County, Guangxi. We found that all three cherry tomato varieties showed high levels of water, moderate levels of sugar, protein and dietary fiber, and low levels of fat, suggesting that cherry tomatoes are a low-calorie diet food. All three cherry tomato varieties exhibited high levels of K and Mg, making them excellent sources of mineral elements. Thus, it was shown that the regular consumption of cherry tomatoes can be an effective supplement of nutrients and mineral elements. In addition, all three cherry tomato varieties contained high levels of GSH, esculeoside A, vitamin C, and rutin, and the Qianxi variety presented a high level of lycopene, which may be the material basis for the good physiological functions of cherry tomatoes. In vitro scavenging of DPPH and hydroxyl free radicals showed that all three cherry tomatoes had strong free radical scavenging activity, which was the most obvious in red cherry tomato (Qianxi variety). Experimental results suggested that cherry tomatoes prevented liver lipid peroxidation in mice. Vitamin C is a potent antioxidant. Cherry tomatoes from Tianyang County contain a significantly higher level of vitamin C than those from most other regions. Tianyang cherry tomatoes have excellent antioxidant properties in vitro and in vivo, which may be related to their high vitamin C content. This study suggests that cherry tomatoes are not only a nutritious fruit, but also a low-calorie functional food with antioxidant properties.

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