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Protective Effect of Lemon Peel Extract on Oxidative Stress in H9c2 Rat Heart Cell Injury

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Aim: Lemon peel, a traditional Chinese medicine, was tested in this study for its novel application in inhibiting cellular oxidative stress, and the effect of lemon peel extract (LPE) on protecting H9c2 rat heart cells from oxidative stress was investigated.

Methods: The scavenging effects of LPE on 1,1-diphenyl-2-picrylhydrazyl (DPPH) and 2,2'-azino-bis (3-ethylbenzthiazoline-6-sulfonic acid) (ABTS) free radicals were measured in extra-cellular experiments. The 3-(4,5-dimethyl-2-thiazolyl)-2,5-diphenyl-2-h-tetrazolylammonium bromide (MTT) assay was used to detect the cell survival rate. The cell supernatant and intracellular oxidation-related indicators were detected by a kit, and the mRNA expression in H9c2 cells was detected by quantitative polymerase chain reaction (qPCR). The chemical substances of LPE were analyzed by high-performance liquid chromatography (HPLC).

Results: The results showed that LPE exhibited better DPPH and ABTS free radical scavenging abilities than vitamin C. Compared with the cells in the normal state (control group), the cell survival rate in the model group decreased, and the level of lactate dehydrogenase (LDH) increased, the levels of superoxide dismutase (SOD), catalase (CAT), and glutathione (GSH) decreased, and the content of malondialdehyde (MDA) increased. Compared with the control group, the expression of Bcl-2-related X protein (Bax), caspase-3, nuclear factor erythroid 2-related factor 2 (Nrf2), and heme oxygenase-1 (HO-1) in the model group was increased, and the expression of B-cell lymphoma-2 (Bcl-2) was reduced. Compared with the model group, LPE treatment improved the cell survival rate, reduced the levels of LDH and MDA, increased the levels of SOD, CAT, and GSH, downregulated the expression of Bax, caspase-3, Nrf2 and HO-1, and upregulated the expression of Bcl-2. The composition analysis showed that LPE contained catechin, rutin, naringin, quercetin, and hesperidin.

Conclusion: The results indicated that LPE could protect H9c2 cells from oxidative stress through five active components. LPE has the potential to be developed into natural medicine or health food for the inhibition of cell oxidative damage.

Keywords: lemon peel, oxidative stress, H9c2 rat heart cell, mRNA expression, HPLC

Introduction

As a high-yield crop, lemon is a widely eaten fruit. Lemon is also processed into juice, fruit wine, and other foods.¹ Lemons are planted in southern China, among which Sichuan Province produces the largest yield of lemons.² Lemon pulp contains fiber, vitamin C, vitamin B, flavonoids, limonin, trace elements, and other active ingredients.³ Lemon can also reduce blood sugar, blood lipid levels, and blood pressure. Lemons are also effective in decreasing the harmful effects of cardiovascular diseases, some inflammation, tumors, and other malignant diseases. Each part of the lemon has a good antioxidant effect and shows antiviral effects and

enhanced immunity.⁴ The juice of a lemon is the primary target of processing. Because the lemon peel is too thick and tough to be widely processed in traditional applications, it is often treated as useless waste in juice production. However, a small part of the peel is used to make traditional Chinese medicine.⁵ Lemon peel also has a variety of chemical compositions, such as abundant flavonoids,³ which can be further developed and used for their health benefits.

In the human body, oxidative stress resulting from the imbalance between oxidation and antioxidation causes oxidative damage in the body, causes inflammatory infiltration of neutrophils, and produces various oxidative intermediate harmful products. Oxidative stress produces free radicals in the body that are generally considered to be an important factor in promoting aging and disease.⁶ Oxidative stress can damage cells and impair the oxidative balance.⁷ Oxidative stress plays an important role in pulmonary fibrosis, epilepsy, hypertension, atherosclerosis, Parkinson's disease, and sudden death.⁸ In many disease states, a large number of free radicals produced by oxidative stress are detected in myocardial tissue, leading to myocardial injury. Moreover, oxidative stress may cause apoptosis or necrosis of myocardial cells, resulting in heart disease.⁹ Nuclear factor erythroid 2-related factor 2 (Nrf2) is an oxidative stress regulator that can control antioxidant protein expression, thereby inhibiting oxidative stress. Moreover, the heme oxygenase-1 (HO-1) gene is a Nrf2-dependent gene, and its product is a strong antioxidant. Regulation of the Nrf2/HO-1 pathway can reduce oxidative stress.¹⁰ H₂O₂-induced oxidative stress in H9c2 cells is a mature in vitro cell model used to test the protective effect of active substances on cardiomyocytes.¹¹ At the same time, many studies have used this model to test the mechanism by which the Nrf2/HO-1 signaling pathway protects the myocardium.^{12–15} Therefore, the present study used this model to test the effects of LPE and preliminarily verify the mechanism of LPE.

The present study aimed to investigate the in vitro cell protection effects of lemon peel, which can be used as a novel application in traditional Chinese medicine, and to preliminarily explore the underlying mechanism. This manuscript first analyzed the compounds of lemon peels and established evidence of cardiomyocyte damage and in vitro oxidative stress in cell models. To provide a theoretical basis for the better use of lemon peels, the present study observed the inhibitory effect of lemon peel extract (LPE) on oxidative stress-induced damage in

cardiomyocytes, analyzed the composition of LPE, and analyzed the mechanism of LPE by activating the Nrf2/HO-1 signal to inhibit the myocardial protection of oxidative stress.

Materials and Methods

LPE Extraction

The lemons (Eureka lemon; Tongnan, Chongqing, China) were washed, and the pulp was removed to obtain lemon peel slices. Lemon peel samples were freeze-dried, crushed, and passed through a 60-mesh sieve. Lemon peel powder (50 g) was weighed, combined with 480 mL of 70% ethanol (v/v), and mixed uniformly. The mixture was extracted for 4 h in a 60°C water bath, and the extract was filtered for later use.⁴ After passing evenly through a filter column containing FL-3 macroporous resin (Shanghai Yiji Biology Co., Ltd., Shanghai, China), the filtrate was collected, and the solvent was subjected to rotary evaporation to obtain the LPE. The extracted LPE mainly contained flavonoids and other antioxidant active substances, as the impurities were removed.

Preparation of Standard Solution

Catechin, rutin, naringin, hesperidin, and quercetin standards were placed in centrifuge tubes, and a methanol solution was added to prepare a standard solution with a concentration of 1.0 mg/mL, which was then passed through a 0.22- μ m organic filter membrane and placed in a 1.5-mL brown sample bottle for later use.

High-Performance Liquid Chromatographic Detection of LPE Ingredients

The LPE was diluted 1000 times with methanol and detected under the following chromatographic conditions: Accucore C18 (4.6 mm \times 250 mm, 5 μ m) (Agilent, Santa Clara, CA, USA) as the chromatographic column; 0.5% acetic acid aqueous solution as mobile phase A; acetonitrile solution as mobile phase B; flow rate at 0.5 mL/min; column temperature at 30°C; UV-Vis detector; detection wavelength of 285 nm; injection volume of 10 μ L; and 60 min run time. The ingredient contents in the lemon peels were calculated using the external standard method with the following formula: $M_x = C_r \times A_x / A_r \times C$, where M_x (mg/g) represents the content of the ingredient, C_r (mg/mL) represents the mass concentration of the standard product, A_x represents the measured peak area of the sample, A_r

represents the measured peak area of the standard, and C (1.0 mg/mL) represents the original concentration of the sample. The linear regression relationships (regression coefficients) of catechin, rutin, naringin, quercetin, and hesperidin standards were $y=0.0285x-0.2828$ ($R^2=0.9875$), $y=0.0348x-0.3363$ ($R^2=0.9860$), $y=0.0348x-0.3547$ ($R^2=0.9889$), $y=2.0254x+0.3644$ ($R^2=0.9997$), and $y=1.1892x-0.6226$ ($R^2=0.9990$), respectively.

DPPH Free Radical Scavenging Ability Measurement

DPPH reagent (Solarbio, Beijing, China) was weighed (0.01 g) and placed in a 250-mL volumetric flask, and absolute ethanol was then added to adjust the concentration of the DPPH solution to 0.1 mol/L. Different volumes of active LPE ingredients were added separately into the test tube, and ultrapure water was added to a final volume of 0.1 mL. DPPH radical solution (4.00 mL of 0.1 mol/L) was then added, and after shaking well, the solution was set aside for 30 min in the dark. In place of the sample, absolute ethanol was used for the control. The final reaction solution (200 μ L) was collected, and the absorbance was measured with a spectrophotometer at a wavelength of 517 nm.¹⁶ The measured absorbance value was calculated using the following formula for the scavenging ability of LPE on DPPH free radicals: DPPH clearance rate (%) = $[1-(A_1-A_2)/A_0] \times 100\%$, where A_0 is the absorbance value of absolute ethanol and 4.00 mL of DPPH blank control, A_1 is the absorbance value after the reaction of 0.1 mL of sample solution and 4.00 mL of DPPH, and A_2 is the absorbance value of 0.1 mL of sample solution and 4.00 mL of absolute ethanol.

ABTS Free Radical Scavenging Ability Measurement

Five milliliters of 7 mmol/mL 2,2'-azino-bis (3-ethyl-benzthiazoline-6-sulfonic acid) (ABTS) (Solarbio, Beijing, China) and 88 μ L of 140 mmol/mL potassium superphosphate aqueous solution were mixed well and reacted for 12 hours in the dark to keep the free radical ions in a stable state to prepare the ABTS free radical working solution. Different volumes of active ingredient LPEs were added separately into the test tube, and 0.1 mL of ultrapure water was added. Subsequently, 4.00 mL of prepared ABTS free radical working solution was added. After shaking well, the mixture reacted at room temperature for 10 min. An equal volume of absolute ethanol was used as a control, and the

absorbance was measured at a wavelength of 734 nm.¹² To determine the scavenging ability of LPE on ABTS free radicals, the measured absorbance value was calculated using the following formula: ABTS clearance rate (%) = $[1-(A_1-A_2)/A_0] \times 100\%$, where A_0 is the absorbance value of absolute ethanol and 4.00 mL of ABTS is the blank control; A_1 is 0.1 mL of sample solution and 4.00 mL of ABTS after reaction; and A_2 is the absorbance value of 0.1 mL of sample solution and 4.00 mL of absolute ethanol.

Cell Experiment Grouping

H9c2 rat cardiomyocytes (Procell Life Science & Technology Co., Ltd., Wuhan, Hubei, China) grown in the logarithmic phase were divided into five groups as follows: the control group, model (H_2O_2 -induced) group, vitamin C (Vc) group, low LPE concentration group (LPEL), and high LPE concentration group (LPEH). After resuspension in DMEM containing 10% fetal bovine serum, H9c2 cells were cultured in a constant-temperature incubator containing 5% CO_2 at 37°C for 24 h. Cells grew by adhering to the well (Chen et al). After 24 h, the original culture medium was discarded. A new culture medium was added to the control group to maintain the normal growth of H9c2 cells, and oxidative damage to H9c2 cells was induced in the model group. After H9c2 cells adhered to the wall, DMEM with a final concentration of 100 μ mol/L H_2O_2 was added to the culture for 4 h. After H9c2 cells in the Vc group were treated with H_2O_2 as the model group, the culture medium was discarded and replaced with culture medium containing 100 μ mol/L Vc, and cells were cultured for another 12 hours. After H9c2 cells in the LPEL and LPEH groups were treated with H_2O_2 as the model group, the culture medium was discarded and replaced with medium containing 50 μ mol/L and 100 μ mol/L LPE, respectively, and cells were incubated for another 12 h (Table 1).

Detecting Cell Viability Using the MTT Method

After treatment of the cells, 20 μ L of MTT solution (Thermo Fisher Scientific) was added to the cell culture well at a concentration of 5 g/L, and cells were placed in the incubator for 4 h. After removing the medium, 150 μ L of DMSO was added to the treated wells. After shaking, cells were kept in the dark for 20 minutes, and the OD value was measured at a wavelength of 490 nm. The cell survival rate was determined according to the following

Table 1 Experimental Grouping and Processing Methods

Group	100 $\mu\text{mol/L}$ H_2O_2 Treatment (4 h)	Vc Treatment (12 h)	LPE Treatment (12 h)
Control	/	/	/
Model	200 μL	/	/
Vc	200 μL	100 $\mu\text{mol/L}$, 200 μL	/
LPEL	200 μL	/	50 $\mu\text{mol/L}$, 200 μL
LPEH	200 μL	/	100 $\mu\text{mol/L}$, 200 μL

formula: cell survival rate (%) = (OD value of treatment action group/OD value of untreated group) \times 100%.¹⁷

Determining LDH, SOD, MDA, GSH, and CAT Levels in Cells

After treatment of the cells with the above method, the supernatant and cells were collected. An ultrasonic cell pulverizer was then used to break the cells in an ice water bath. An ultrasound scan was performed once every 3 to 5 seconds for four intervals. The LDH level of the cell supernatant was measured following the manufacturer's instructions of the LDH kit (Table 2), and the absorbance was measured at 450 nm and was calculated from a standard curve. The SOD, MDA, GSH, and CAT levels in each group of cells were measured with

a multifunctional microplate reader (VarioskanLUX, Thermo Fisher Scientific) following the manufacturer's protocols of the SOD, MDA, GSH, and CAT kits (Nanjing Jiancheng Bioengineering Institute, Nanjing, Jiangsu, China). The WST-1 method,¹⁸ TBA method,¹⁹ microplate method²⁰ and ammonium molybdate method²¹ were used to determine and calculate the absorbance values at 450 nm, 532 nm, 405 nm, and 405 nm, respectively.

Cell Survival Evaluation

Cells (5×10^6) were seeded in 6-well plates, cultured for 48 h, and then treated with LPE. The survival status of H9c2 cells was observed under an inverted fluorescence microscope (CKX53, Olympus, Tokyo, Japan) with a calcein AM/PI double staining kit (Solarbio, Beijing, China). The living cells were labeled with green fluorescence, and the dead cells were labeled with red fluorescence.

Quantitative Polymerase Chain Reaction Experiment

Cells were treated and collected, and an ultrasonic cell pulverizer was used to break the cells in a 4°C ice water bath. An ultrasound scan was performed once every 3 to 5 seconds for four intervals. RNA was separated from the cells with TRIzol™ (Solarbio, Beijing, China) and diluted to 1 $\mu\text{g}/\mu\text{L}$. Diluted RNA (1 μL) was used to obtain cDNA via reverse transcription according to the reverse transcription kit. cDNA template (1 μL) was mixed with 10 μL of SYBR Green PCR Master Mix (Thermo Fisher Scientific), 1 μL of each primer of

Table 2 Determination Steps of LDH Kit

Treatment	Blank	Standard	Text	Control
Double distilled water (μL)	25	5		
0.2 $\mu\text{mol/mL}$ pyruvate standard solution (μL)		20		
Tested sample (μL)			20	20
Matrix buffer (μL)	25	25	25	25
Coenzyme I (μL)			5	
Mix well and take a 37°C water bath for 15 min				
2,4-dinitrophenylhydrazine (μL)	25	25	25	25
Mix well and take a 37°C water bath for 15 min				
0.4 mol/L NaOH solution (μL)	250	250	250	250
Absorbance was measured at 450 nm after 5 min at 25°C				

Table 3 qPCR Primer Sequences

Gene	Primer Sequence
<i>Bcl-2</i>	F: 5'-ATGTGTGTGGAGAGCGTCAACC-3' R: 5'-CAGAGACAGCCAGGAGAAATCAA-3'
<i>Bax</i>	F: 5'-CCCGAGAGGTCTTTTTCCGAG-3' R: 5'-CCAGCCCATGATGGTTCTGAT-3'
<i>Caspase-3</i>	F: 5'-CATGGAAGCGAATCAATGGACT-3' R: 5'-CTGTACCAGACCGAGATGTCA-3'
<i>Nrf2</i>	F: 5'-ATTGCCTGTAAGTCCTGGTCA-3' R: 5'-ACTGCTCTTTGGACATCATTTGCG-3'
<i>HO-1</i>	F: 5'-AACTTTCAGAAGGGCCAGGT-3' R: 5'-CTGGGCTCTCCTTGTTC-3'
<i>GAPDH</i>	F: 5'-CTGGGCTACACTGAGCACC-3' R: 5'-AAGTGGTCGTTGAGGGCAATG-3'

forward primers and reverse primers (Table 3; Solarbio, Beijing, China), and 7 μ L of sterilized distilled water. The following thermocycler program was used: 95°C for 60 s; and 40 cycles of 95°C for 15 s, 55°C for 30 s, 72°C for 35 s, 95°C for 30 s and 55°C for 35 s (Stepone Plus, Thermo Fisher Scientific). The expression intensity relative to the control group was calculated using the $2^{-\Delta\Delta C_t}$ method, and the GAPDH housekeeping reference gene was used for normalization.²²

Statistical Analysis

Three parallel experiments were performed to obtain the average value, which was determined using SPSS 23 statistical software and compared between groups using independent-sample t tests and a one-way analysis of variance

method. Significant differences between groups were observed at the $P < 0.05$ level.

Results

DPPH and ABTS Radical Scavenging Abilities of LPE

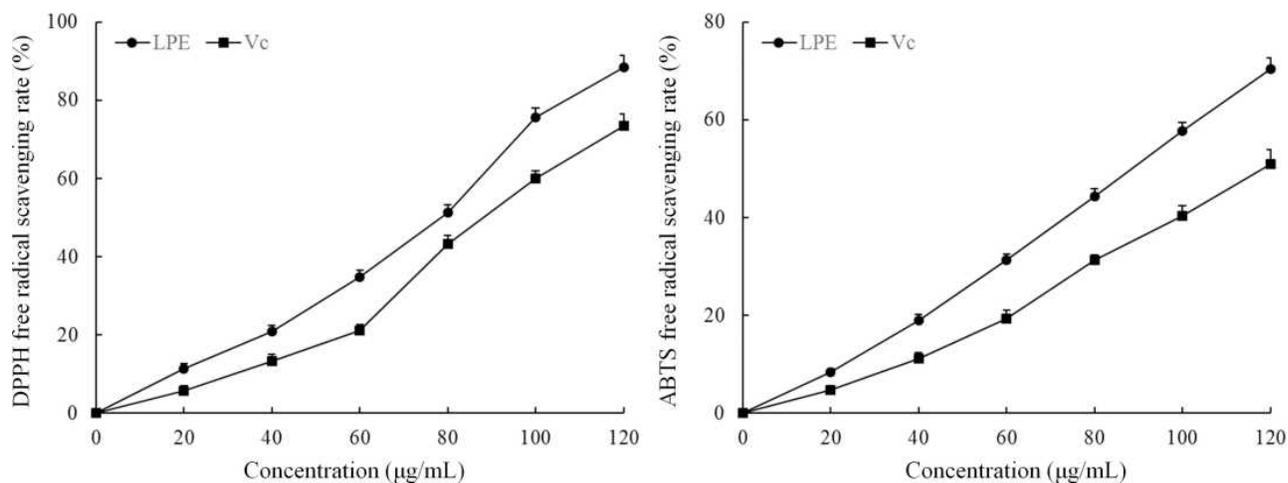
Figure 1 shows the dose-response relationship of DPPH and the ABTS radical scavenging ability of LPE. The ability of LPE to scavenge DPPH and ABTS radicals increased with increasing concentrations of LPE from 0 to 120 μ g/mL. Moreover, the Vc positive control group had lower DPPH and ABTS radical scavenging abilities than LPE.

Viability of H9c2 Cells with Oxidative Damage Induced by LPE Treatment

The survival rate of the H9c2 cell model group was lower than that of the control group, and the difference was statistically significant (Figure 2, $P < 0.05$). Compared with the model group, the survival rate of H9c2 cells with oxidative damage treated with VC and LPE was increased ($P < 0.05$), and the effect of LPE was dose-dependent. The effect of LPE on the survival rate of H9c2 cells with oxidative damage was stronger than that of Vc at the same concentration.

LDH Level in the Supernatant of LPE-Treated H9c2 Cells with Oxidative Damage

The control group had a lower level of LDH (118.36 ± 8.32 U/L) than the other groups, while the model group had a higher level of LDH (539.47 ± 20.36 U/L) than the other groups (Figure 3). LPE reduced the LDH level of

**Figure 1** Scavenging activity of lemon peel extract on DPPH and ABTS free radicals.

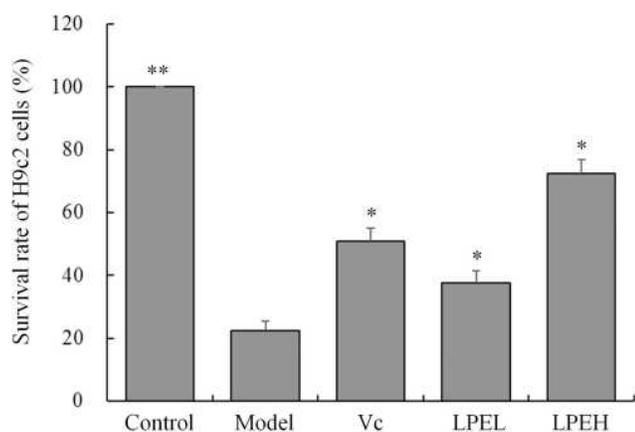


Figure 2 Effect of lemon peel on the survival rate of H9c2 cells with oxidative damage. *There was a significant difference between the experience group and the model group at the level of $P < 0.05$. **There was a significant difference between the experience group and the model group at the level of $P < 0.01$. Control: untreated H9c2 cells; model: H_2O_2 -treated H9c2 cells; Vc: H_2O_2 and 100 $\mu\text{mol/L}$ vitamin C-treated H9c2 cells; LPEL: H_2O_2 and 50 $\mu\text{mol/L}$ LPE-treated H9c2 cells; LPEH: H_2O_2 and 100 $\mu\text{mol/L}$ LPE-treated H9c2 cells.

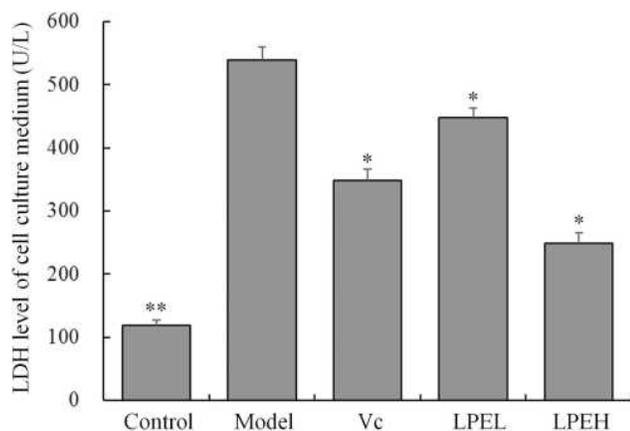


Figure 3 Effect of lemon peel on LDH levels in H9c2 cells with oxidative damage. *There was a significant difference between the experience group and the model group at the level of $P < 0.05$. **There was a significant difference between the experience group and the model group at the level of $P < 0.01$. Control: untreated H9c2 cells; model: H_2O_2 -treated H9c2 cells; Vc: H_2O_2 and 100 $\mu\text{mol/L}$ vitamin C-treated H9c2 cells; LPEL: H_2O_2 and 50 $\mu\text{mol/L}$ LPE-treated H9c2 cells; LPEH: H_2O_2 and 100 $\mu\text{mol/L}$ LPE-treated H9c2 cells.

cells with oxidative damage. Higher concentrations of LPE resulted in lower LDH levels. The effect of LPE on the LDH level was better than that of the VC antioxidant.

SOD, MDA, GSH, and CAT Levels of LPE-Treated H9c2 Cells with Oxidative Damage

The SOD, GSH, and CAT levels of H9c2 cells with oxidative damage (model group) were lower than those of the other groups, but the MDA level was higher than that of

Table 4 Effect of Lemon Peel Extract on SOD, MDA, GSH and CAT Levels of H9c2 Cells with Oxidative Injury

Group	SOD (U/gprot)	MDA (nmol/gprot)	GSH ($\mu\text{mol/mg}$)	CAT (U/gprot)
Control	191.36 $\pm 10.83^{**}$	0.80 $\pm 0.05^{**}$	65.69 $\pm 4.36^{**}$	155.30 $\pm 12.69^{**}$
Model	52.05 ± 4.99	7.02 ± 0.42	21.52 ± 3.25	41.03 ± 4.09
Vc	117.62 $\pm 8.01^{**}$	3.89 $\pm 0.29^*$	40.82 $\pm 3.75^*$	90.36 $\pm 6.32^*$
LPEL	90.83 $\pm 6.12^*$	5.11 $\pm 0.34^*$	31.02 $\pm 2.79^*$	63.25 $\pm 5.29^*$
LPEH	151.08 $\pm 10.20^{**}$	1.44 $\pm 0.27^{**}$	53.06 $\pm 3.86^{**}$	121.36 $\pm 7.33^{**}$

Notes: *There was a significant difference between the experience group and the model group at the level of $P < 0.05$. **There was a significant difference between the experience group and the model group at the level of $P < 0.01$. Control: untreated H9c2 cells; model: H_2O_2 -treated H9c2 cells; Vc: H_2O_2 and 100 $\mu\text{mol/L}$ vitamin C-treated H9c2 cells; LPEL: H_2O_2 and 50 $\mu\text{mol/L}$ LPE-treated H9c2 cells; LPEH: H_2O_2 and 100 $\mu\text{mol/L}$ LPE-treated H9c2 cells.

the other groups ($P < 0.05$, Table 4). After treatment with LPE and Vc, the SOD, GSH, and CAT levels of H9c2 cells with oxidative damage were increased, but the MDA level was reduced. In addition, these levels in the LPEH group were the most similar to those in the control group.

H9c2 Cell Survival Status

As shown in Figure 4, the H9c2 cell survival status was observed under an inverted fluorescence microscope. The numerous control H9c2 cells were full, polygonal, and abundantly cytoplasmic with a large number of viable cells visualized by fluorescent staining. H9c2 cells in the model group appeared shrunken and decreased in number with cell damage and cell death. LPE was able to inhibit H_2O_2 -induced H9c2 cell damage and death. The number of H9c2 cells increased with an increasing concentration of LPE, and cell damage and death were alleviated. Thus, these findings demonstrate that LPE could effectively inhibit H9c2 cell damage and cell number reduction caused by H_2O_2 , indicating that LPE plays a role in protecting cells.

Bcl-2, Bax, Caspase-3, Nrf2, and HO-1 mRNA Expression in LPE-Treated H9c2 Cells with Oxidative Damage

The control H9c2 cells had lower Bax, caspase-3, Nrf2, and HO-1 mRNA expression but higher Bcl-2 expression

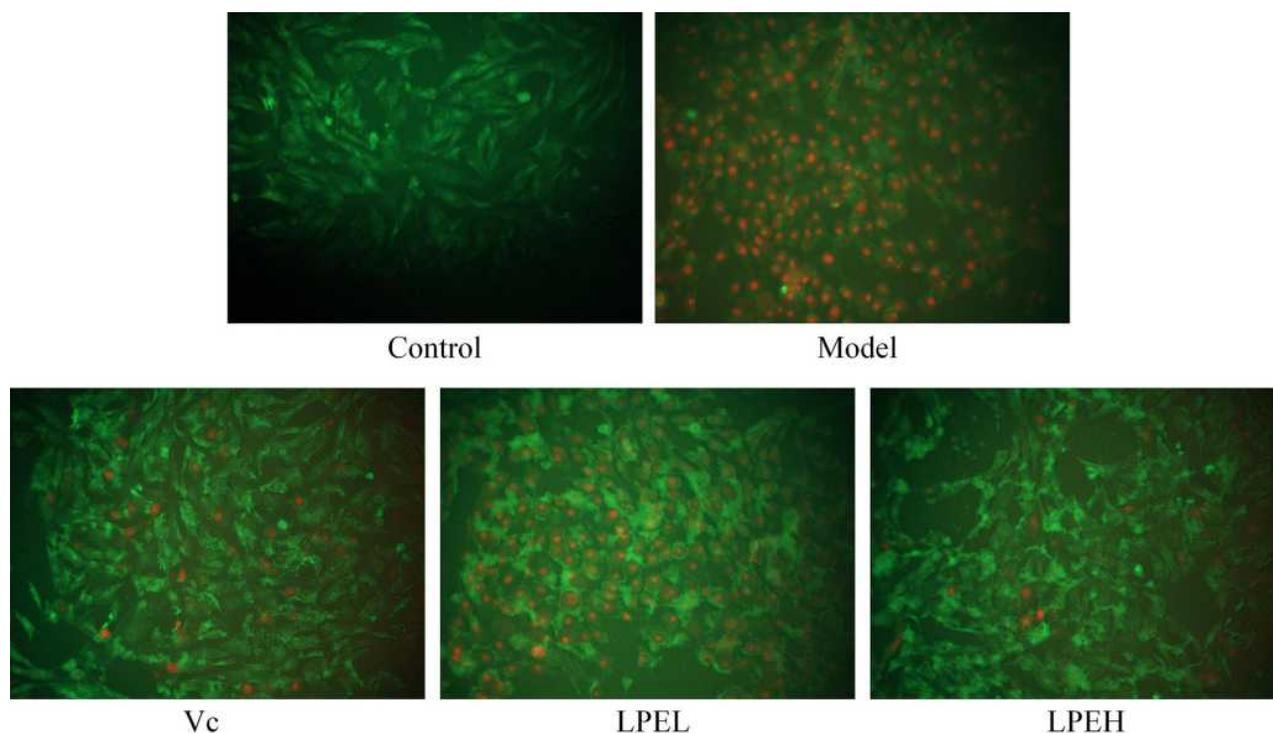


Figure 4 Effects of lemon peel on the survival of H9c2 cells (200 ×). Living cells were labeled with green fluorescence, and dead cells were labeled with red fluorescence. Control: untreated H9c2 cells; model: H₂O₂-treated H9c2 cells; Vc: H₂O₂- and 100 μmol/L vitamin C-treated H9c2 cells; LPEL: H₂O₂- and 50 μmol/L LPE-treated H9c2 cells; LPEH: H₂O₂- and 100 μmol/L LPE-treated H9c2 cells.

than the other groups. Moreover, the model group H9c2 cells had higher Bax, caspase-3, Nrf2, and HO-1 expression but lower Bcl-2 expression than the other groups (Figure 5). Vc, LPEL and LPEH increased Bcl-2 expression but decreased Bax, caspase-3, Nrf2, and HO-1 expression in H9c2 cells with oxidative damage (model group), and the effects of LPEH were stronger than those of LPEL and Vc.

Chemical Composition of LPE

According to the chemical composition measurements in the experiments, the most important active ingredients in the peels of lemons produced in Yueyang, Sichuan were catechin, rutin, naringin, quercetin, and hesperidin (Figure 6) with contents of 206.54 mg/g, 44.60 mg/g, 5.68 mg/g, 187.75 mg/g, and 25.11 mg/g, respectively. Importantly, these five components all have good antioxidant effects. These results indicate that the most important active substances were catechin and quercetin.

Discussion

DPPH and ABTS are commonly used to detect the antioxidant activity of active substances.^{16,17} In this study,

LPE had good DPPH and ABTS scavenging abilities in extracellular experiments, suggesting that LPE may have a strong antioxidant effect.

Although early thrombolysis, percutaneous coronary intervention, and coronary artery bypass grafting have reduced the mortality of acute myocardial infarction, acute myocardial infarction is still the main cause of death and disability worldwide. After acute myocardial infarction, patients inevitably experience left ventricular remodeling mediated by oxidative stress and cardiomyocyte apoptosis. Inhibition of oxidative stress and cardiomyocyte apoptosis might reduce the degree of remodeling after acute myocardial infarction.^{23,24} The essence of oxidative damage is the massive production of ROS, which exceeds the self-clearing ability, resulting in damage to lysosomes and mitochondria.²⁵ H₂O₂ is an oxidative metabolite in the human body, and it reacts with free iron ions in the nucleus and generates more reactive oxygen radicals, leading to cell damage, which in turn induces apoptosis and ultimately cell death.²⁶ The present study confirmed that H₂O₂ can reduce the survival rate of H9c2 cells and that LPE can protect

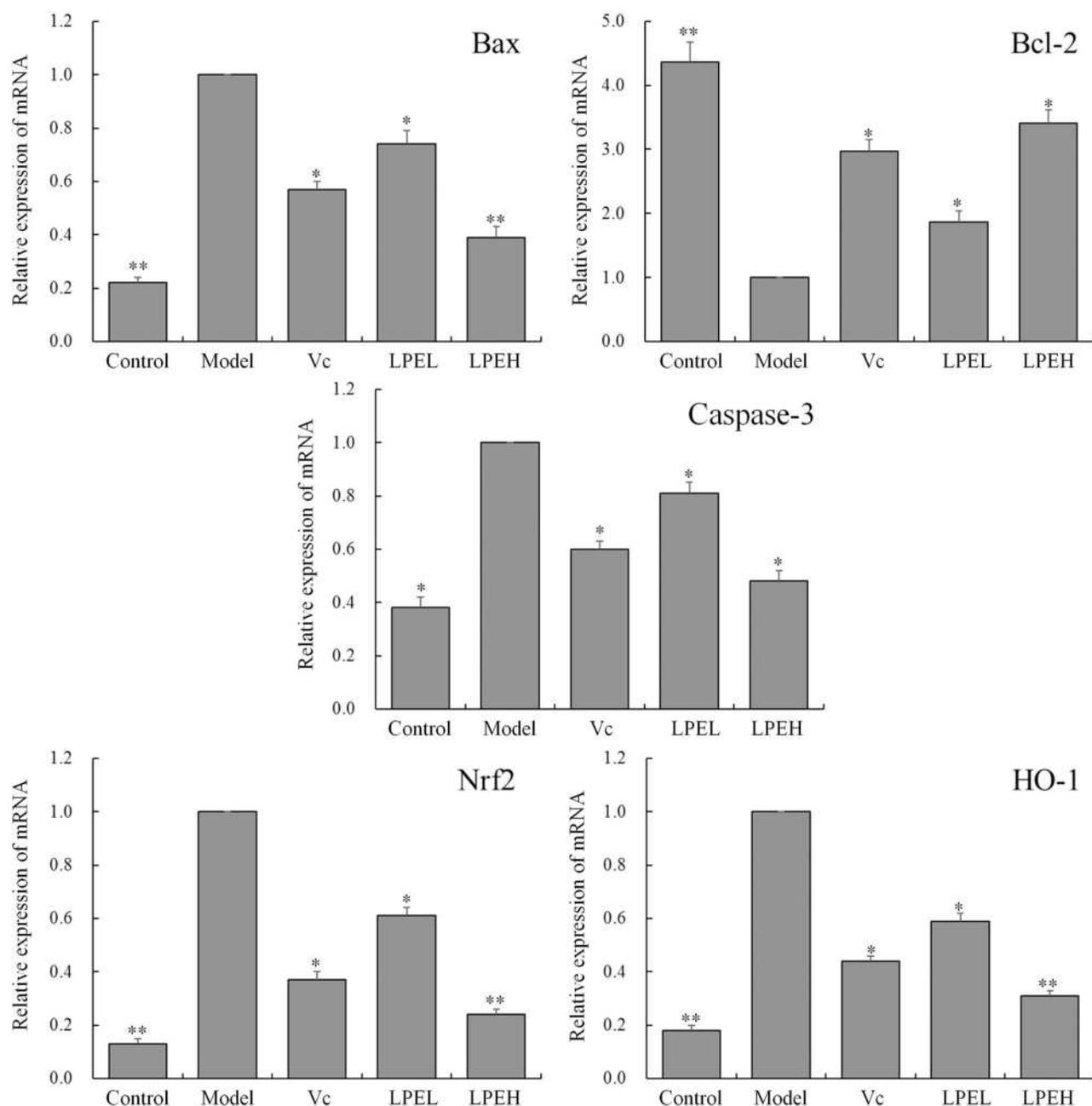


Figure 5 Effects of lemon peel on Bcl-2, Bax, Caspase-3, Nrf2, and HO-1 mRNA expression. *There was a significant difference between the experience group and the model group at the level of $P < 0.05$. **There was a significant difference between the experience group and the model group at the level of $P < 0.01$. Control: untreated H9c2 cells; model: H_2O_2 -treated H9c2 cells; Vc: H_2O_2 and 100 $\mu\text{mol/L}$ vitamin C-treated H9c2 cells; LPEL: H_2O_2 and 50 $\mu\text{mol/L}$ LPE-treated H9c2 cells; LPEH: H_2O_2 and 100 $\mu\text{mol/L}$ LPE-treated H9c2 cells.

against H_2O_2 -induced oxidative damage in H9c2 cells as indicated by an increased survival rate.

When the body is under normal conditions, serum and body fluids have low levels of LDH, but a large amount of LDH in the cells is released after the cell membrane is damaged.²⁷ LDH can damage and inhibit damaged and repaired cells. SOD, as the main endogenous antioxidant,

can also reduce mitochondrial damage and maintain cell stability by scavenging excessive oxygen free radicals.²⁸ GSH and CAT are also important antioxidant enzymes in vivo. Under oxidative stress, these enzymes play the role of strong antioxidants, reduce the cell and tissue damage caused by oxidative damage, and repair the abnormalities caused by oxidative damage.²⁹ MDA is

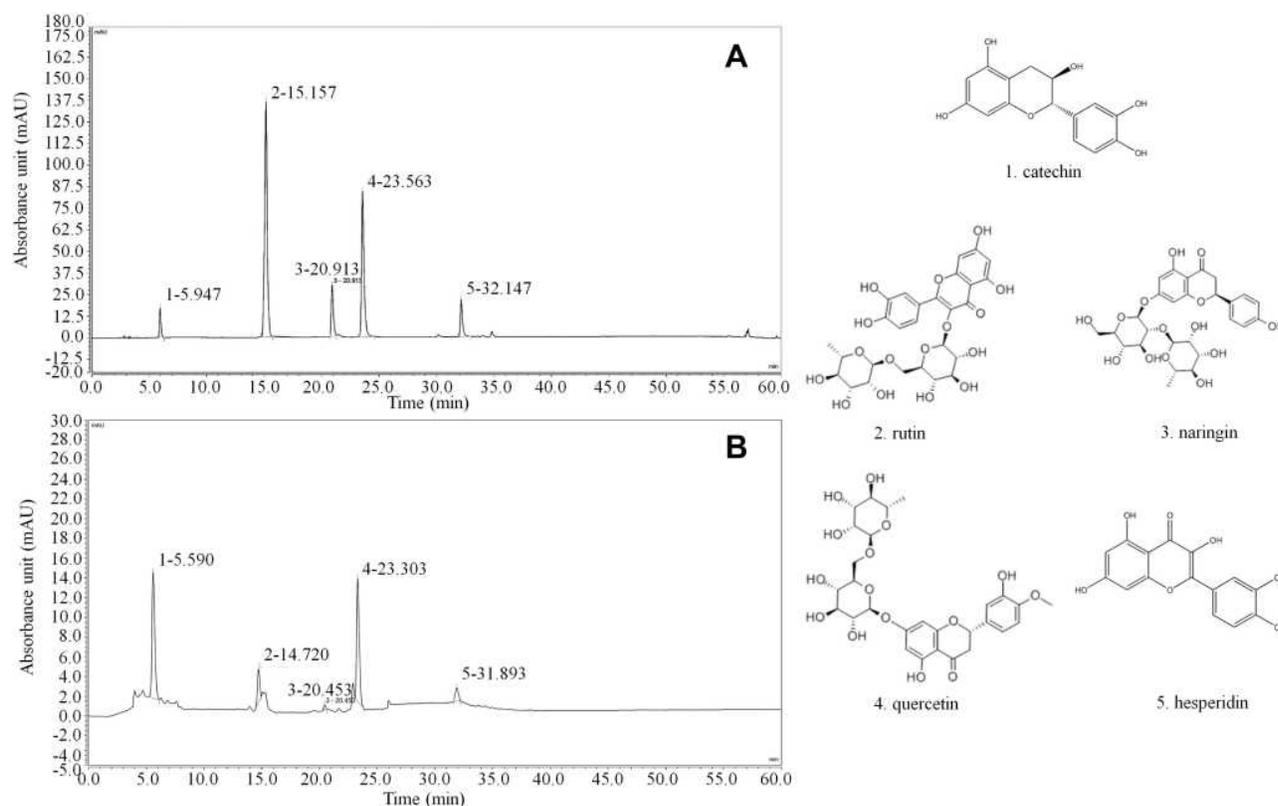


Figure 6 Chemicals of lemon peel extract. **(A)** Standard chromatograms. **(B)** Lemon peel extract chromatograms.

representative of a series of oxidative damage products, and a large amount of MDA strengthens the degree of oxidative damage.³⁰ This study also showed that LPE can regulate the LDH, SOD, MDA, GSH, and CAT levels in oxidatively damaged cardiomyocytes, thereby protecting cells and inhibiting oxidative damage.

Apoptosis is a common form of programmed cell death in the body.³¹ The main mechanism of myocardial cell death is metabolism, and Bax and Bcl-2 are involved in this process. The degree of cell necrosis and death is determined by the ability of the membrane to adjust.³² The caspase family plays an important role in cell death. When Bax binds to the membrane, the concentration of the ions between the inner and outer membrane changes, leading to cytochrome C release into the cell, cleavage of caspase-9, and activation of Caspase-3, resulting in cell death.³³ The qPCR results showed that LPE increased Bcl-2 mRNA expression but decreased Bax and Caspase-3 mRNA expression, indicating that LPE might protect myocardial cells by suppressing myocardial infarction.

Nrf2, as a factor that regulates stress, could suppress stress, and its level is adjusted by HO-1.³⁴ Normally, Nrf2 and Keap1 are in nonactive forms in cells. After damage,

Nrf2 is quickly separated from Keap1 and enters the nuclear core, where it plays a protective role through regulating downstream genes and the expression of HO-1.³⁵ At the same time, research has shown that Nrf2 can also regulate the expression of Bcl-2, SOD, and CAT, which have antiaging effects.³⁶ Nrf2, as a central transcription factor of the endogenous antioxidant pathway, can regulate the expression of antioxidants and Phase II enzymes, and it can be one of the targets of cardiac protection. H₂O₂-treated cardiomyocytes could induce the expression of Nrf2 and its downstream genes, thereby protecting the cells against adriamycin-induced apoptosis. Adenovirus-mediated Nrf2 gene transfection increases the expression of NQO1 in cardiomyocytes.^{37,38} After H₂O₂ treatment, cardiomyocytes regulate antioxidants to inhibit oxidative stress, and as oxidative stress is inhibited, Nrf2 expression decreases.³⁹ qPCR also found that LPE had an anti-inflammatory effect by increasing the mRNA levels of Nrf2 and HO-1. This result suggested that the anti-inflammatory effect of BCP might be related to the Nrf2/HO-1 signaling pathway.

Some experiments have confirmed that catechin, rutin, naringin, and quercetin have protective effects on the heart

and cardiomyocytes.^{40–42} Catechin has a strong antioxidant effect and plays a variety of roles, such as antiviral and fungicidal activities as well as the prevention of various types of inflammation.⁴³ Rutin can be used as a food antioxidant and nutrition enhancer, but it also has anti-inflammatory effects and can play a role in protecting the skin. At the same time, because of its strong antioxidant activity, rutin can inhibit the formation of lipid peroxides.⁴⁴ Naringin is also a strong antioxidant with anti-inflammatory, antiviral, anticancer, antimutation, anti-allergy, antiulcer, analgesic, and antihypertensive activities. Naringin can lower blood cholesterol, reduce thrombosis, improve local microcirculation, and improve nutrition supply, and it can be used in the prevention and treatment of cardiovascular and cerebrovascular diseases.⁴⁵ Quercetin can resist complex or capture free radicals and prevent lipid peroxidation. In addition, quercetin can reduce blood pressure, enhance capillary resistance, reduce capillary fragility, lower blood lipids, expand coronary arteries, and increase coronary blood flow. Quercetin also has adjuvant treatment effects on patients with coronary heart disease and hypertension.⁴⁶ Hesperidin has good antioxidant, anti-inflammatory, and antibacterial effects. Hesperidin can also increase venous tension and protect the cardiovascular system by prolonging the time of noradrenalin-induced venous contraction.⁴⁷ Thus, these findings suggest that the protective effect of LPE on cardiomyocytes is mainly derived from the antioxidant capacity, cardiovascular protection, and regulatory effects of these components.

Conclusion

In summary, LPE had a protective effect on damaged H9c2 cells, and the effect of high-concentration LPE (LPEH) was better than that of low-concentration LPE (LPEL), which showed that the effect of LPE was positively correlated with the concentration. The mechanism might be related to the five active substances in LPE, which may regulate the signaling pathway of Nrf2/HO-1, to increase the activity of SOD, GSH, CAT, and other anti-inflammatory components in myocardial cells to prevent cell death. The purpose of this study was to elucidate the chemical mechanism of LPE and clarify the targeting effect of LPE to provide a theoretical basis for the further development and use of lemon peel. However, the present study was limited to in vitro experiments. Because in vivo animal experiments

would more accurately show the effect and mechanism of LPE, future research will strengthen the results of the present study.

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Disclosure

Mr Wanchao Zhang reports grants from Ministry of Science and Technology, during the conduct of the study. The authors report no other conflicts of interest in this work.

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