

Ultrasound-assisted Extraction of Saponins from *Panax Notoginseng* Roots: Optimization, Antioxidant, and Anti-inflammatory evaluations

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Abstract

Panax notoginseng is a recognized Chinese medicinal herb widely used as a medicinal food and dietary supplement. *P. notoginseng* roots are rich in bioactive saponins with diverse pharmacological properties. Herein, the present aimed to optimize the ultrasound-assisted extraction of total saponin content from *P. notoginseng* roots using response surface methodology. Three independent variables, including EtOH concentration, extraction time, and solid-liquid ratio, were selected based on single-factor experiments. The optimal conditions were 26.7 % EtOH concentration, 52.1 min, and 1/22.6 (w/v) material-to-solvent ratio. Under these conditions, the TSC reached (17.327 ± 0.184) mg OA/g extract, closely agreeing with the predicted values and confirming the reliability of the model. Moreover, the optimized extract exhibited significant antioxidant and anti-inflammatory activities. These results suggested that *P. notoginseng* root extract, obtained from UAE method, could be used in various pharmaceutical applications.

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Keywords

Panax notoginseng; saponins; response surface methodology; antioxidant activities; anti-inflammatory activities.

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1 Introduction

Panax notoginseng (Burk.) Feng Huai Chen, a highly valued medicinal herb in traditional Chinese medicine, is widely recognised for its diverse pharmacological properties. This plant has been used in some traditional home remedies to promote blood circulation, stop bleeding, reduce swelling, relieve pain, and invigorate blood. These prominent therapeutic effects are primarily attributed to contain abundant saponin content [1].

Saponins, the principal bioactive constituents of *P. notoginseng*, are naturally occurring triterpene and

steroid glycosides with anticancer, immunomodulatory, hepatoprotective, anti-inflammatory, and antiviral activities. The structural variations in saponins support their use in pharmaceutical and nutraceutical formulations. In *P. notoginseng*, saponins contribute to vasodilation, blood pressure reduction, vascular anti-ageing, anti-thrombotic, antioxidant, and anti-inflammatory effects. Oxidative stress and inflammation are fundamental contributors to chronic diseases (cardiovascular and neurodegenerative disorders) and cancer [2]. Research has demonstrated that *P. notoginseng* saponins exhibited strong antioxidant

activities through the scavenging of free radicals and the upregulation of endogenous antioxidant mechanisms. Additionally, saponins exert anti-inflammatory effects due to the manipulation of significant signalling pathways, suppression of pro-inflammatory cytokines (TNF- α and IL-6), and downregulation of NF- κ B activity [3]. These complementary activities supported *P. notoginseng* saponins potential to alleviate oxidative damage and inflammation. Therefore, extraction methods should maximize yield while preserving bioactivity. Solvent concentration, extraction time, and solid-solvent ratio are crucial determinants of extraction efficiency and product quality.

In the present study, Response Surface Methodology (RSM) was employed to optimize the extraction conditions for saponins derived from *P. notoginseng* roots (PNR). Furthermore, the antioxidant capacity and anti-inflammatory efficacy of the optimized extract were evaluated through DPPH, ABTS, reducing power (RP), and Fenton radical scavenging assays, as well as protein denaturation and nitric oxide (NO) production inhibition assays. Findings from this study would enhance the extraction efficiency of PNR saponins and substantiate the prospective applications of this botanical in pharmaceutical and functional food industries.

2 Methods and Materials

Table 1 Experimental levels of factors considered in the BBD

Independent factors	Units	Factor levels		
		Low	Medium	High
EtOH concentration (X_1)	%, v/v	20	30	40
Extraction time (X_2)	min	40	50	60
Solid-liquid ratio (X_3)	g/mL	1/20	1/25	1/30

2.3 Determination of total saponin content

The vanillin-sulfuric acid assay was employed to quantify the TSC [5]. Briefly, 20 μ L of the extract was combined with 20 μ L of 8% vanillin solution and 200 μ L of 72% H_2SO_4 in a 96-well plate. The plate was subsequently sealed and incubated at 60 °C for 20 min, then cooled at room temperature for 5 min. Afterwards, the absorbance values were measured at

2.1 Plant materials and reagents

Vanillin, 2,2-diphenyl-1-picrylhydrazyl (DPPH), ascorbic acid (AA), oleanolic acid (OA), 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS), iron (III) chloride ($FeCl_3$), and potassium ferricyanide ($K_3Fe(CN)_6$), ethanol (EtOH) were purchased from Sigma-Aldrich (Germany). Unless otherwise specified, other reagents of analytical quality were used directly.

2.2 Optimization of ultrasound-assisted extraction (UAE) conditions and experimental design

2.2.1 Extraction process

The PNR powder, after being steamed at 120 °C for 4 h [4], was then mixed with EtOH. The effects of three extraction parameters on TSC were evaluated, including EtOH concentration (10-60)%, extraction time (20-70) min, and solid-liquid ratio (1/5-1/35) g/mL. The results from single-factor experiments were incorporated into the RSM design to optimize the extraction process.

2.2.2 Experimental Design and Statistical Analysis

A Box-Behnken Design (BBD) with three factors (EtOH concentration, extraction time, and solid-liquid ratio) was used to optimize TSC. The independent variables were coded in Table 1 and investigated at three levels in 17 experimental runs.

540 nm. A standard curve was constructed using OA at different concentrations ($y = 0.0072x + 0.1966$, $R^2 = 0.9961$). The TSC were expressed as milligrams of OA equivalents per gram of extract (mg OA/g extract).

2.4 Determination of antioxidant activity

2.4.1 Assay of DPPH radical scavenging activity

The RSA value of the samples was evaluated based on a previously established method [6]. Typically,

100 μL of the extract was mixed with 100 μL of a freshly prepared 0.1 mM DPPH solution. The mixture was incubated in darkness for 30 min. The absorbance was recorded at 517 nm. The concentration of extract required to quench 50% of the DPPH radicals was defined as the IC_{50} value, expressed in micrograms of dry sample per millilitre ($\mu\text{g}/\text{mL}$).

2.4.2 Assay of ABTS⁺ radical scavenging activity

The antioxidant activity of ABTS was determined with slight modifications [6]. The ABTS⁺ stock solution was pre-prepared by combining 7 mM ABTS with 2.45 mM $\text{K}_2\text{S}_2\text{O}_8$ solution and allowed to stand in the dark for 24 to 36 h prior to use. 2.0 mL of working solution was added to a test tube containing 150 μL of the sample, and the absorbance was measured at 734 nm after incubation in the dark for 5 min.

2.4.3 Assay of reducing power

The RP was evaluated based on the modified method [6]. Samples were combined with 2.5 mL of 0.2 M Na_3PO_4 buffer and 2.5 mL of 1% $\text{K}_3\text{Fe}(\text{CN})_6$ solution. The mixtures were then incubated at 50 °C for 20 min. The reaction was halted by adding 2.5 mL of 10% $\text{CCl}_3\text{CO}_2\text{H}$ solution and centrifuged at 3000 rpm for 10 min. The supernatant was collected and mixed with 0.1% FeCl_3 solution, then recorded at 700 nm.

2.4.4 Assay of hydroxyl radical scavenging activity

The hydroxyl radical-scavenging activity was evaluated according to a previously published method [6]. Briefly, FeSO_4 9 mM solution (1 mL), salicylic acid in ethanol (1 mL), and H_2O_2 8 mM (1 mL) were mixed with the tested sample. The reaction mixture was incubated at 37 °C for 30 min and measured at 510 nm.

2.5 Determination of anti-inflammatory activity

2.5.1 Assay of bovine serum albumin denaturation inhibition assay

The *in vitro* anti-inflammatory activity was assessed in accordance with the previously method [7]. A 5 mL reaction mixture was prepared, comprising 1 mL of bovine serum albumin, 3 mL of phosphate-buffered saline (PH = 6.6), and 1 mL of tested extracts. A control was prepared using an equivalent volume of dimethyl sulfoxide (DMSO). The mixtures were incubated at $(37 \pm 2)^\circ\text{C}$ for 20 min in a water bath, followed by denaturation at 60 °C for 30 min. Post-

incubation, samples were cooled to room temperature, and the absorbance was measured at 660 nm.

2.5.2 Assay of nitric oxide production inhibition

Nitric oxide production inhibition: the *in vitro* anti-inflammatory activity was determined using lipopolysaccharide (LPS)-stimulated RAW264.7 macrophage cells. Briefly, RAW264.7 cells (1×10^5 cells/mL) were seeded in 96-well plates for 24h at 37 °C. Cells were pre-treated with various concentrations of samples or DMSO 0.5% (negative control) and then stimulated with LPS (1 $\mu\text{g}/\text{mL}$). After 24 h at 37 °C incubation, 100 μL of the culture medium from each well was mixed with an equal volume of Griess reagent, kept stable at room temperature for 10 min and then measured at 540 nm. The nitrite contents were determined from a standard curve of sodium nitrite (NaNO_2) ($y = 0.0046x + 0.1343$, $R^2 = 0.9967$). The percentage inhibition of NO formation by extracts was calculated. To verify that the suppression of NO production of PNR was not attributable to harmful effects on macrophage cells, the cytotoxicity test was also conducted [8]. Indomethacin (Sigma-Aldrich, USA) at 100 μM was used as a positive control.

2.6 Statistical analysis

All samples were evaluated in triplicate, with the results expressed as mean values. The single-factor experimental data were subjected to statistical analysis using one-way ANOVA, performed with Minitab Statistical and GraphPad Prism 9 Software. Optimization and regression analyses were conducted utilizing Design-Expert® version 11.0. Statistical significance was determined at $p < 0.05$.

3 Results

3.1 Single-factor experiments affecting the extraction EtOH was selected as the extraction solvent because of its low toxicity, safety, and suitability for food and pharmaceutical applications. The EtOH concentration ranged from 10% to 60% to assess the impact on the saponin extraction efficiency. An increase in EtOH concentration from 10% to 30% resulted in a proportional rise in TSC, from 16.634 to 18.856 mg

OA/g extract (Figure 1A). The TSC remained relatively stable, beyond 30%, with no significant improvement. Although increasing EtOH concentration enhanced the solubility of saponins to a certain extent, excessively high concentrations may

alter solvent polarity, which can negatively affect solubility and reduce extraction efficiency [9]. Thus, to optimize yield while minimizing solvent usage, the EtOH concentration at 30% was selected for further optimization in the RSM model.

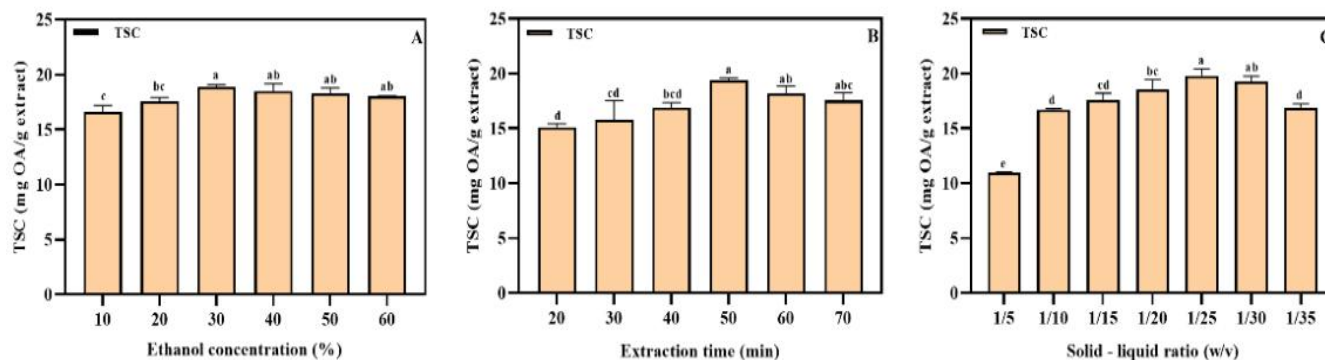


Figure 1 Single-factor experiments showed that the TSC was affected by EtOH concentration (A), extraction time (B), and solid-liquid ratio (C)

The ultrasonic extraction time was varied from 20 to 70 min to evaluate the factor on TSC. As showed in Figure 1B, the parameter increased significantly up to 50 min, with the TSC increasing from 15.121 to 19.392 mg OA/g extract. The value plateaued in the following 20 min, reaching 17.561 mg OA/g extract, indicating minimal additional extraction. The trend suggests that equilibrium was achieved as the solutes reached saturation in the solvent. Prolonging the extraction time beyond this point offered negligible gains while increasing energy consumption and production costs [6]. Therefore, an extraction time of 50 min was chosen as the baseline (0) for the following experiments.

Figure 1C demonstrates how changing the solid-liquid ratio affects saponin extraction efficiency. The yield increased as the solvent volume rose, reaching a maximum at a 1/25 (g/mL) ratio. Further increases in the solvent amount led to a gradual decline in yield.

Excessive solvent volumes tend to lower extraction efficiency and elevate operational costs [6]. In accordance with the BBD principles, a 1/25 (g/mL) solid-liquid ratio was chosen as the ideal condition for the following experiments.

Based on the results obtained from the preliminary investigation, the optimal conditions for UAE were identified as an EtOH concentration of 30%, an ultrasonic extraction time of 50 min, and a solid-liquid ratio of 1/25 (g/mL).

3.2 Optimization of the UAE condition

3.2.1 The model fitting and statistical analysis

Table 2 displayed both the experimental values from the 17 experimental runs. The results for the PNR showed that the TSC varied from (14.79 ± 0.63) to (16.92 ± 0.05) mg OA/g extract. Second-order polynomial equations were developed through RSM to define the relationships between the response variables and the independent variable:

$$Y_{TSC} = 16.6800 - 0.1107X_1 - 0.0129X_2 - 0.3227X_3 + 0.1510X_1X_2 - 0.0370X_1X_3 - 0.0670X_2X_3 - 0.3165X_1^2 - 0.0036X_2^2 - 1.0700X_3^2$$

Table 2 BBD model with independent values and responses

Runs	X ₁	X ₂	X ₃	TSC	Runs	X ₁	X ₂	X ₃	TSC
1	40	50	1/20	15.42 ± 1.08	10	40	40	1/25	16.17 ± 1.03
2	20	40	1/25	16.56 ± 2.08	11	30	50	1/25	16.65 ± 0.41
3	30	50	1/25	16.40 ± 1.04	12	30	60	1/20	15.94 ± 1.33

4	30	60	1/30	15.23 ± 1.24	13	30	50	1/25	16.92 ± 0.05
5	40	50	1/30	14.79 ± 0.63	14	30	40	1/20	15.84 ± 0.98
6	30	50	1/25	16.83 ± 0.06	15	20	60	1/25	16.23 ± 0.05
7	40	60	1/25	16.46 ± 1.05	16	30	40	1/30	15.39 ± 0.93
8	20	50	1/20	15.86 ± 0.66	17	30	50	1/25	16.56 ± 1.10
9	20	50	1/30	15.08 ± 2.07					

To evaluate the adequacy and significance of the developed models, ANOVA was conducted and summarised in Table 3. The results demonstrated that the regression model was statistically significant ($p < 0.05$), while the lack-of-fit was not significant ($p > 0.05$), thereby confirming model adequacy [10]. The F value for the TSC model was 22.86, suggesting that the model effectively captured the variation in the data and provided a good fit. The quadratic regression models demonstrated high reliability, with R^2 values of 0.9671 for TSC, reflecting strong agreement between observed and predicted results. The adjusted R^2 value was 0.9248, which is close to the corresponding R^2 values. This suggests a good fit with minimal loss of explanatory power after accounting

for the number of predictors [10]. Additionally, the low coefficients of variation (1.11%) implied a high level of precision, reproducibility, and reliability, confirming the suitability of these models for response optimization.

According to the p -values in Table 3, the significant effects were observed for the linear term X_3 and the quadratic terms (X_1^2 and X_3^2), while the linear terms X_1 and X_2 , interaction terms (X_1X_2 , X_1X_3 , and X_2X_3), and the quadratic term (X_2^2) did not show statistically significant effects ($p > 0.05$). Overall, the results indicate that among the independent variables, X_3 (solid-liquid ratio), along with the quadratic terms X_1^2 and X_3^2 had a significant impact on the response variable TSC.

Table 3 ANOVA for the multiple regression model

Source	Y (Total saponin content)				
	Sum of Squares	Degree of freedom	Mean Square	F -value	p -value
Model	6.5	9	0.7226	22.86	0.0002
X_1	0.098	1	0.098	3.1	0.1216
X_2	0.0013	1	0.0013	0.042	0.8434
X_3	0.8329	1	0.8329	26.35	0.0013
X_1X_2	0.0912	1	0.0912	2.89	0.1331
X_1X_3	0.0055	1	0.0055	0.1748	0.6884
X_2X_3	0.018	1	0.018	0.5684	0.4755
X_1^2	0.4219	1	0.4219	13.35	0.0081
X_2^2	0.0001	1	0.0001	0.0017	0.9678
X_3^2	4.84	1	4.84	153.2	0.0001
Residual	0.2212	7	0.0316		
Lack of Fit	0.0474	3	0.0158	0.364	0.7837
Pure Error	0.1738	4	0.0434		
Cor Total	6.72	16			
R^2	0.9671				
Adj R^2	0.9248				
C.V. %	1.11				

3.2.2 Response surface plots analysis

Three-dimensional response surface plots were constructed using Design-Expert 11.0 software to

explore and optimize the influence of independent variables EtOH concentration (X_1), extraction time (X_2), and solid-liquid ratio (X_3) on TSC of PNR.

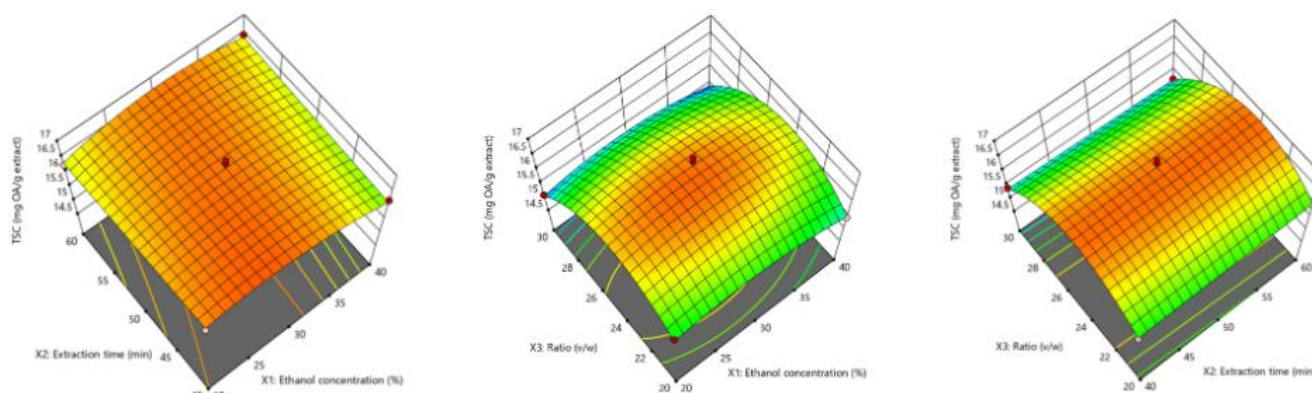


Figure 2 Response surface plots for the impact of independent variables on TSC

As illustrated in Figure 2, the effects of variable interactions on TSC exhibited a quadratic trend. The TSC demonstrates an increasing trend in response to the rising EtOH concentration, reaching a maximum value of around 30%. Beyond this threshold, the TSC plateaued or decreased. This phenomenon can be explained by the existence of an optimal solvent polarity range that promotes efficient saponin solubilization. Exceeding this range, especially at higher EtOH concentrations, adversely affects solubility due to increased solvent-polarity mismatches or saturation effects. The response surface analysis also revealed that a moderate solid-liquid ratio, around 1/25 g/mL, was optimal for extraction efficiency. Deviations from this ratio, whether lower or higher, resulted in declined extraction efficacy, most likely due to constrained diffusive processes at lower liquid volumes or dilution effects at higher volumes that reduce the concentration gradient required for effective mass transfer.

Overall, these 3D plots validate the suitability of the quadratic regression model for predicting optimal conditions. The general trend across all responses showed an initial increase in TSC with increasing factor levels, followed by a decline, confirming the presence of an optimal operational window for UAE of *P. notoginseng* root constituents.

3.2.2 Determination and validation of optimized UAE condition

Numerical optimization was conducted to establish a comprehensive extraction model for experimental responses under UAE conditions. The independent variables were maintained within their specified ranges, while the target response was set to be maximized (Table 4). The optimized extraction conditions included EtOH concentration of 26.7%, an extraction time of 52.1 min, and a solid-liquid ratio of 1/22.6 g/mL. The resulting model demonstrated a high level of reliability, with a desirability score of 0.933, confirming the robustness of the predicted conditions.

Table 4 Experimental and predictive values of the response under optimal conditions

Factor	X_1	X_2	X_3	TSC
Predictive	26.748	52.053	1/22.624	16.589
Actual	27	52	1/23	17.327 ± 0.184
% error				4.449

Validation experiments were conducted in triplicate, and the results were expressed as mean values with standard deviations. The experimental data are similar to the predicted outcomes, showing only a minimal percentage error of 4.449%, thereby confirming the accuracy of the model.

3.3 Effect of *P. notoginseng* on antioxidant activities

Antioxidants scavenge and neutralize free radicals, thereby alleviating oxidative stress and maintaining cellular integrity and function. As excessive ROS can

overwhelm endogenous antioxidant defenses and cause oxidative damage, cellular dysfunction, and genetic mutations, antioxidants from foods, dietary supplements, pharmaceuticals, and medicinal plants have attracted considerable research interest [11]. The antioxidant activities of the optimized PNR extract were evaluated using four common *in vitro* methods, including DPPH, ABTS, RP, and Fenton assays. All the results were summarized in Table 5 and compared to the reference standard AA.

Table 5 The antioxidant activities of optimized PNR

Sample	DPPH	ABTS	RP	Fenton
PNR ($\mu\text{g/mL}$)	273.506 ± 0.283	527.2 ± 0.111	442.5 ± 0.053	1160 ± 2.114
AA ($\mu\text{g/mL}$)	4.805 ± 0.014	6.442 ± 0.091	5.293 ± 0.020	122.685 ± 0.426

DPPH and ABTS⁺ radicals are relatively stable radicals that can accept electrons or hydrogen atoms to form non-radical molecules [12]. The optimized extract PNR and AA illustrated concentration-dependent DPPH and ABTS⁺ radical scavenging activities. Their respective IC₅₀ values were (273.506 ± 0.283) $\mu\text{g/mL}$ and (4.805 ± 0.014) $\mu\text{g/mL}$ in the DPPH assay, and (527.2 ± 0.111) $\mu\text{g/mL}$ and (6.442 ± 0.091) $\mu\text{g/mL}$ in the ABTS assay.

The hydroxyl radical generated through the Fenton reaction is highly reactive ROS that can cause oxidative damage and mitochondrial dysfunction. PNR and AA scavenged hydroxyl radicals in a concentration-dependent manner, with IC₅₀ values found to be (1160 ± 2.114) $\mu\text{g/mL}$ and (122.685 ± 0.426) $\mu\text{g/mL}$, respectively. Moreover, both samples exhibited

concentration-dependent reducing capacity, with EC_{0.5} values of (442.5 ± 0.053) $\mu\text{g/mL}$ for the extract and (5.293 ± 0.020) $\mu\text{g/mL}$ for AA. These results suggested that PNR can donate electrons and convert free radicals into more stable, non-reactive species.

Prior research has claimed that the antioxidant activities of *Panax* genus medicinal plants are associated with various compounds such as flavonoids, saponins, and polysaccharides. Previous studies have also demonstrated correlations between the saponin and flavonoid contents of *P. notoginseng* extracts and their antioxidant activities [2, 13]. Therefore, the antioxidant potential of the optimized PNR extract may be attributed to its high TSC.

3.4 Effect of *P. notoginseng* on anti-inflammatory activities

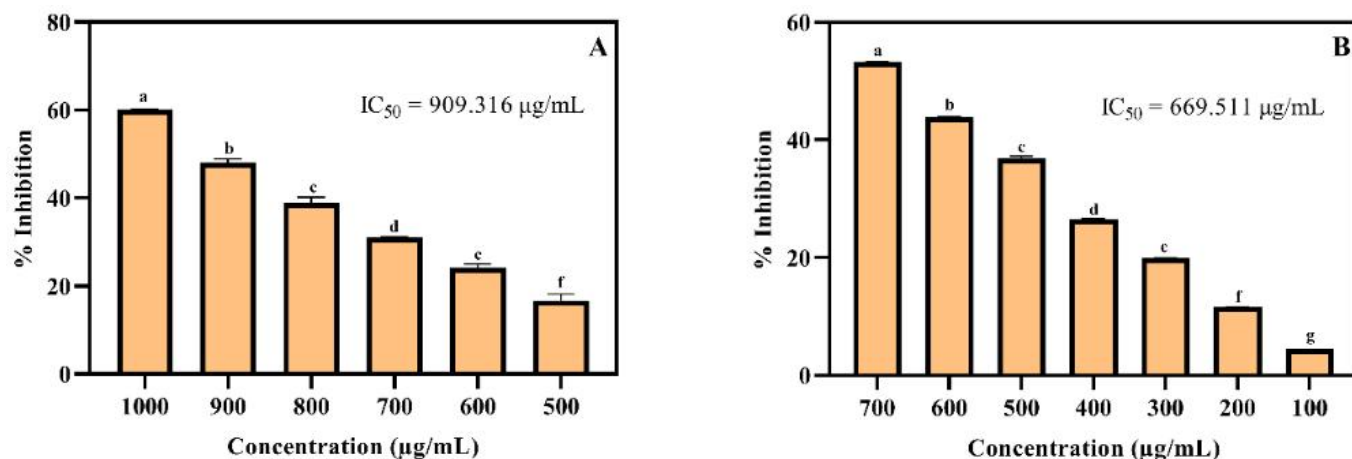


Figure 3 The BSA inhibitory activity of PNR (A) and sodium diclofenac (B)

To preliminarily evaluate the anti-inflammatory potential of PNR, a protein denaturation assay was employed. Protein denaturation, which is associated with inflammatory disorders such as rheumatoid arthritis, involves the disruption of electrostatic, hydrogen, hydrophobic, and disulfide bonds [2]. As showed in Figure 3, PNR indicated significant

concentration-dependent inhibition and effectively protected protein structures from denaturation induced by heat and alkaline conditions, with IC_{50} values of $909.316 \pm 1.087 \mu\text{g/mL}$, compared with $669.511 \pm 1.016 \mu\text{g/mL}$ for sodium diclofenac. These findings prompted further investigation using an LPS-induced RAW264.7 macrophage model.

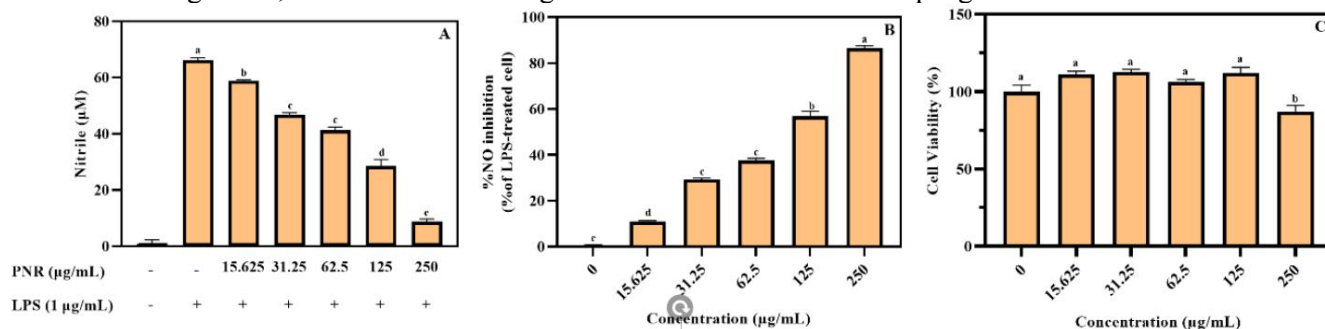


Figure 4 The in vitro anti-inflammatory activity of PNR. (A) Effects of PNR on LPS-induced nitrite overproduction in RAW264.7 cells. (B) The percentage inhibition of LPS-induced NO production compared to LPS-treated cells. (C) Effects of PNR on RAW264.7 cells viability

Macrophages are key regulators of inflammation and produce pro-inflammatory mediators such as NO. Although NO contributes to host defense, its excessive generation is associated with inflammatory disorders, including atherosclerosis, hypertension, ischemia-reperfusion injury, and septic shock [3]. As showed in Figure 4A and 4B, the PNR significantly inhibited LPS-induced NO production at a range of concentrations of (15.625-250) $\mu\text{g/mL}$. The greatest inhibition was observed at 250 $\mu\text{g/mL}$ ($86.630 \pm 1.619\%$), exceeding that of 100 μM indomethacin (60.38%), while maintaining cell viability at ($87.151 \pm 3.981\%$). Notably, cell viability remained above 85% at all tested

concentrations (Figure 4C), confirming that the inhibition of NO production was not attributable to cytotoxicity. These findings were consistent with previous studies reporting that *P. notoginseng* extracts maintained or promoted RAW264.7 cell viability at comparable concentrations [2, 14].

Consequently, PNR inhibited protein denaturation and reduced macrophage-mediated NO production without cytotoxicity. Together with antioxidant activity, these findings suggest that the saponin-rich PNR extract may alleviate oxidative and inflammatory activities, supporting its potential application as a natural therapeutic agent.

4 Conclusion

A combination of single-factor experiments and RSM was applied to optimize the extraction of saponins from PNR, with the optimal parameters including the ethanol concentration of 26.7%, extraction time of 52.1 min, and the ratio of 1/22.6 g/mL. The TSC was (17.327 ± 0.184) mg OA/g extract. The optimized extracts demonstrated moderate antioxidant and notable in vitro anti-inflammatory activities, indicating their potential as bioactive agents. Notably, saponins present in PNR contribute to the observed biological effects. These

findings underscore the value of PNR as a promising natural source for developing functional foods or plant-based anti-inflammatory agents, highlighting an effective strategy for utilizing agricultural resources in health-related applications.

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Conflict of interest

The authors declared no conflict of interest with respect to the research, authorship, and/or publication of this article.

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Tối ưu hóa điều kiện tách chiết saponin có hỗ trợ sóng siêu âm từ rễ Tam thất Bắc bằng phương pháp bề mặt đáp ứng, kết hợp đánh giá hoạt tính kháng oxy hóa và kháng viêm

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Tóm tắt *Panax notoginseng* là dược liệu quý của y học cổ truyền Trung Quốc, đồng thời được sử dụng rộng rãi như một loại thực phẩm dược liệu và thực phẩm bổ sung. Rễ của *P. notoginseng* chứa hàm lượng cao các saponin có hoạt tính sinh học với nhiều đặc tính dược lý đa dạng và quan trọng. Nghiên cứu này nhằm tối ưu hóa quá trình chiết xuất saponin tổng từ rễ *P. notoginseng* bằng phương pháp chiết xuất hỗ trợ siêu âm, kết hợp đánh giá các hoạt tính sinh học thông qua phương pháp bề mặt đáp ứng. Giá trị của ba biến độc lập gồm nồng độ ethanol, thời gian chiết và tỷ lệ nguyên liệu/dung môi được xác định dựa trên các thí nghiệm khảo sát đơn yếu tố. Điều kiện chiết xuất tối ưu được xác định là nồng độ ethanol 26,7 %, thời gian chiết 52,1 phút và tỷ lệ nguyên liệu/dung môi 1/22,6 (w/v). Trong điều kiện tối ưu, hàm lượng saponin tổng thu được từ rễ *P. notoginseng* đạt $(17,327 \pm 0,184)$ mg OA/g cao chiết, phù hợp với giá trị dự đoán và độ tin cậy của mô hình. Bên cạnh đó, dịch chiết tối ưu thể hiện hoạt tính kháng oxy hóa và kháng viêm đáng kể. Những kết quả này cho thấy dịch chiết giàu saponin từ rễ *P. notoginseng* thu nhận bằng phương pháp UAE có tiềm năng ứng dụng trong nhiều lĩnh vực dược phẩm khác nhau.

Từ khóa *Panax notoginseng*; saponin; phương pháp bề mặt đáp ứng; hoạt tính kháng oxy hóa; hoạt tính kháng viêm.