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Review

Effects of steaming process on rare saponins and efficacy of *Panax ginseng*, *Panax notoginseng* and *Panax quinquefolium*

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ABSTRACT

The steamed *Panax ginseng* C. A. Mey., *Panax notoginseng* (Burk.) F. H. Chen, and *Panax quinquefolium* L. not only facilitate storage, but also increase the content of rare saponins and enhance their clinical application value. The traditional steaming process has high energy consumption, low efficiency, and lacks standardized operating procedures and unified standards. This paper retrieves the research literature on the steaming process parameters, rare saponin increments, and efficacy enhancement results of ginseng plants. By summarizing the effects of different steaming processes on rare saponins and pharmacodynamics in *P. ginseng*, *P. notoginseng* and *P. quinquefolium*, we explored new steaming methods and established a new quality evaluation system to provide guarantee for the effectiveness and safety of clinical medication and provide scientific basis for its rational use.

Contents

1. Introduction

Panax ginseng C. A. Mey., *Panax notoginseng* (Burk.) F. H. Chen and *Panax quinquefolium* L. have the effects of tonifying vital energy, generating fluids, quenching thirst, and benefiting the spleen and lungs (Zhang, 2022). *P. notoginseng* has the functions of dispelling blood stasis, stopping bleeding, reducing swelling and pain, and is used for various internal and external bleeding, chest and abdominal pain, falling and swelling pain, etc (Duan, Zhang, Zhang, Zhang, & Li, 2023; Xiao et al., 2002). *P. quinquefolium* has the effects of nourishing yin and moistening the lungs, clearing the heart and calming the mind. It is used for yin deficiency, dry cough, coughing up blood, restlessness, palpitations, insomnia, and mental confusion (Liu, Lu, Hu, & Fan, 2020). Fresh ginseng is the fresh root of ginseng with high water content. Sun-dried ginseng is dried from fresh ginseng after natural processing (Sun, 2022). Heating steaming is one of the traditional Chinese medicine processing methods. *P. ginseng* steamed can not only prolong the

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storage time, but also produce rare saponins, enhance its efficacy, and improve its application value (Sun, Pan, & Sung, 2011; Sun et al., 2011). Red ginseng is steamed and processed from fresh ginseng, whose color changes from white to red. It can greatly supplement the vitality, restore the pulse, replenish qi and control blood. Black ginseng is made from raw ginseng, which is steamed at 98–100 °C for 3 h, dried in the sun or dried, and repeated for 9 times (Jin et al., 2015). For example, the content of rare saponins Rh_2 in red ginseng obtained by steaming fresh ginseng at 100 °C for 6 h increases, and the immune efficacy was significantly improved (Bai, 2020). After steaming *P. notoginseng* at 120 °C for 4 h, *S*-Rg_3 and *R*-Rg_3 increased by 11.09 mg/g and 8.61 mg/g, respectively, enhancing its anti-tumor effect (Sun, Pan, & Sung, 2011; Sun et al., 2011). In this paper, the effects of different steaming processes on rare saponins and efficacy in *P. ginseng*, *P. notoginseng* and *P. quinquefolium* were summarized by consulting a large number of literatures, in order to provide reference for the scientific application of steaming products of ginseng plants.

2. Effect of steaming process on rare saponins and efficacy

Steaming can promote the production of rare saponins. Comparing the conversion of saponins among the three medicinal materials, it can be concluded that after steaming, the three medicinal materials were converted to rare ginsenoside 20(*S*/*R*)-Rg_3, Rk_1, Rg_5, Rk_3, Rh_4, Rh_1 and Rh_2. We sorted out the general formula of saponin transformation in the steaming process of *P. ginseng*, *P. notoginseng* and *P. quinquefolium* as shown in Fig. 1. The total content of the above seven ginsenosides in steamed *P. notoginseng* was higher than that in steamed *P. ginseng* and *P. quinquefolium*. In addition, ginsenosides Rg_6 and F4 can only be detected in high-temperature steamed ginseng, which have anti-tumor (Chen, Shen, Zhang, Cheng, & Jia, 2013), hypoglycemic (Zhao et al., 2023), antioxidant (Pu et al., 2021), and anti-inflammatory effects (Lee, Lim, Shehzad, Kim, & Kim, 2014; Paik et al., 2019), expanding the application range of steamed ginseng.

2.1. Effects of steaming process on rare saponins and efficacy of P. ginseng

Numerous studies have indicated that different steaming times, temperatures, and other factors may have certain effects on the conversion of ginsenosides, thereby affecting their efficacy. According to the presence of hydroxyl groups on the 6-position carbon, ginsenosides are divided into protopanaxadiol type (PPD) and protopanaxatriol type (PPT). PPD-type ginsenosides include Rb_1, Rd, Rg_3, Rk_1 and Rg_5, and PPT-type ginsenosides include Re, Rg_6, F4, Rk_3 and Rh_4. According to research, after heating and steaming, most of the prototype saponins undergo dehydration and isomerization at the C-20 position, while rare saponins are also produced after sugar chain breakage at the C-3 and C-6 positions. The conversion pathways of PPD and PPT type ginsenosides are illustrated in Fig. 2.

The conversion amount of rare saponins in ginseng under different steaming processes was different, resulting in different synergistic results. For example, the content of rare saponins *S*-Rh_2 and *R*-Rh_2 in red ginseng increased by 0.16 μg/g and 0.05 μg/g respectively compared with the original fresh ginseng after steamed at 100 °C for 6 h, so that red ginseng had better effect on cellular immunity. Fresh ginseng was steamed at 120 °C for 3 h, which the contents of Rg_3, Rk_1, Rg_5, Rs_5 and Rs_4 in steamed ginseng increased by 6.1%, 2.9%, 3.3%, 0.02% and 0.03% compared with the original fresh ginseng, which increased the cytotoxicity to liver cancer cells. Others participated in the heating steaming process parameters, conversion of rare saponins and synergistic results were shown in Table 1.

From Table 1, it can be seen that with the extension of heating steaming temperature and time and the decrease of pH value of the reaction environment, the content of rare saponins (Rg_3, Rh_4 and Rk_1) in ginseng was increased, and the tumor inhibition rate, antioxidant and antibacterial activity were enhanced. The substance that enhanced the efficacy of ginseng was rare saponins.

2.2. Effects of steaming process on rare saponins and efficacy of P. notoginseng

Modern steaming methods of *P. notoginseng* can be divided into high-pressure steaming and normal-pressure steaming, and *P. notoginseng* can be steamed with water or black bean juice or other auxiliary materials (Di et al., 2016). Modern researchers have optimized the heating and steaming process of *P. notoginseng* to convert prototype saponins into rare saponins. This article compares the effects of different steaming processes on the content changes of rare saponins in *P. notoginseng* and the results of enhancing the activity of rare saponins. Table 2 displays the heating and steaming process parameters, rare saponin conversion amount and potentiation results of *P. notoginseng*.

From Table 2, it can be seen that with the increase of steaming temperature and the acidity of the reaction environment, as well as the prolonger of time, the content of rare saponins Rh_1, Rh_4, Rk_3, and Rg_3 in *P. notoginseng* increases to varying degrees, which enhances its anticoagulant and blood nourishing activities. Therefore, the enhanced therapeutic effect of *P. notoginseng* is closely related to the production of rare saponins.

2.3. Effects of steaming process on rare saponins and efficacy of P. quinquefolium

Compared to *P. ginseng* and *P. notoginseng*, research on *P. quinquefolium* mainly focuses on white ginseng and aboveground parts,

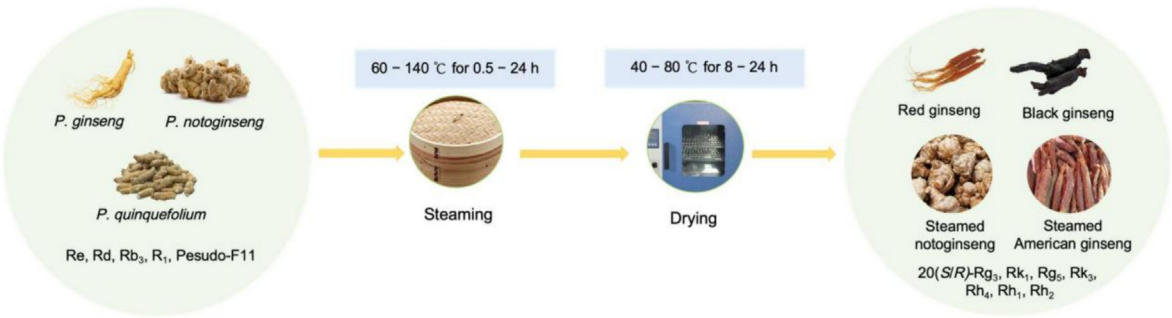

Fig. 1. General formula of saponin conversion in steaming process.

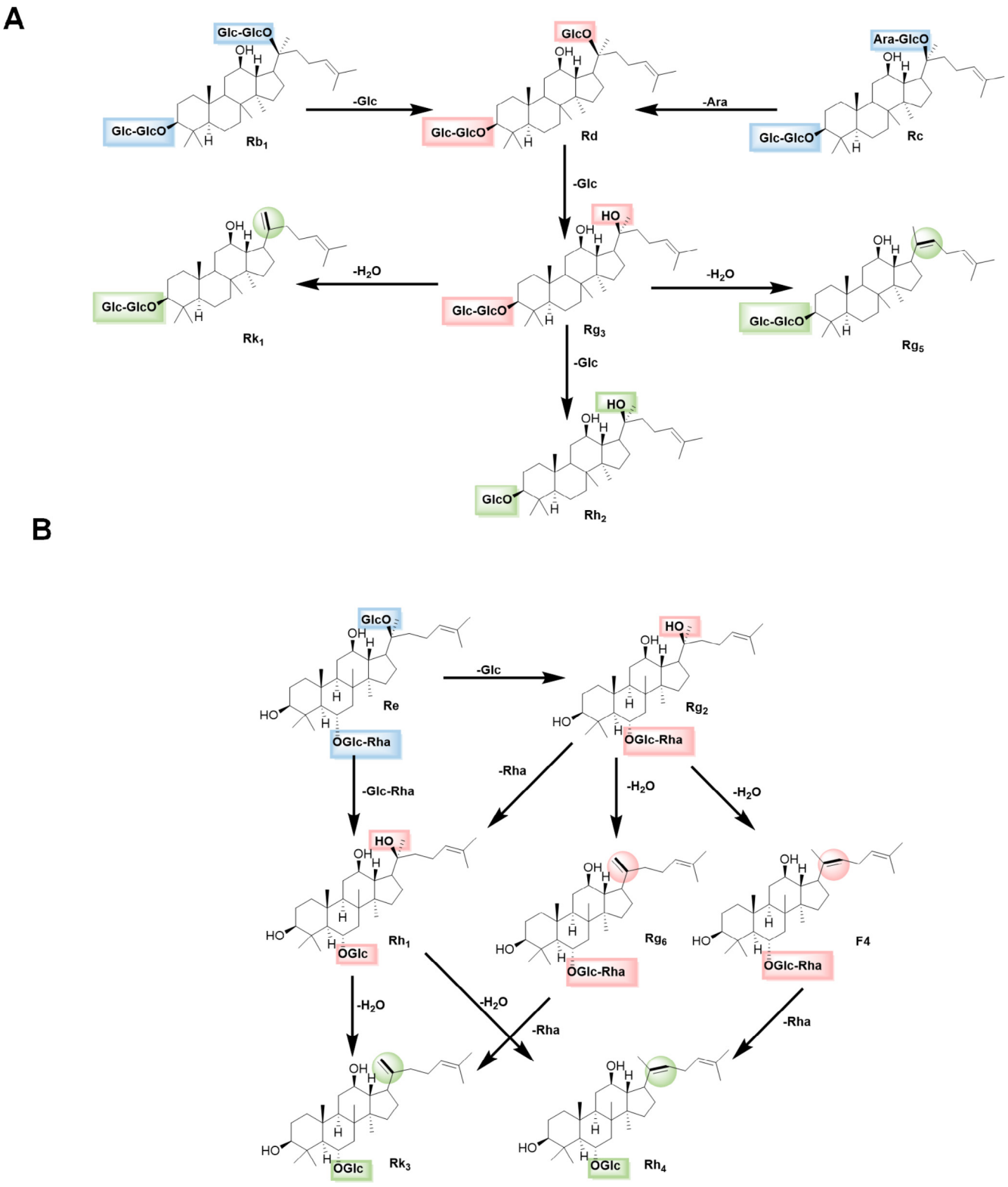

Fig. 2. Conversion pathways during ginseng steaming process. (A) PPD type ginsenoside (B) PPT type ginsenoside. Blue: Starting compounds; Red: intermediates; Green: final products.

with relatively little research on American red ginseng. This article summarizes the effects of multiple heating and steaming processes on the content changes of rare saponins in American ginseng, as well as the synergistic effect of producing rare saponins. The heating and steaming process parameters, rare saponin conversion amount, and efficiency enhancement results of American ginseng are illustrated in Table 3.

We can infer from Table 3 that with the increase of heating and steaming temperature and the prolonger of time, the content of rare saponins such as Rh_1, Rh_2, and Rg_3 in American ginseng

Table 1
P. ginseng steaming process parameters, rare saponins conversion and synergistic results.

No.	Steaming process parameters	Rare saponin conversion rates	Efficiency	References
1	Steamed at 100 °C for 6 h	μg/g: *S*-Rh_2: 0.16, *R*-Rh_2: 0.05	The cellular immune function was enhanced.	Bai, 2020
2	Steamed at 120 °C for 0, 2, 4, 8 h	/	The anti-inflammatory effect was improved.	Qian et al., 2015
3	Steamed at 120 °C for 2 h	mg/g: S-Rg_3: 1.281, Rg_5: 0.127, Rk_1: 0.458, Rk_3: 1.669	The testicular damage caused by HS was alleviated.	Liu, 2019
4	Steamed at 120 °C for 3 h	%: Rg_3: 6.1, Rk_1: 2.9, Rg_5: 3.3, Rs_5: 0.02, Rs_4: 0.03	The cytotoxic effect on SK-Hep-1 hepatoma cells was amplified.	Park et al., 2002
5	Steamed at 98 °C for 0.5 h Steamed at 120 °C for 0.5, 1, 2, 4 h	%: *S*-Rh_1: 0.029, *R*-Rh_1: 0.032, Rg_6: 0.041, Rk_3: 0.129, Rh_4: 0.209, *R*-Rg_3: 0.224, Rk_1: 0.443	The tumor inhibition rate of red ginseng steamed at 120 °C was greater than that of red ginseng steamed at 98 °C, and red ginseng (98 °C) was greater than fresh ginseng.	Zhang, 2015
6	Steamed at 100 °C for 1.5, 3, 6 h	/	The secretion of G-CSF after 6 h of steaming was induced, and the activity of G-CSF is the highest when steaming for 9 h.	Ding, Tabuchi, & Makino, 2022
7	Steamed at 95 ± 5 °C for 3, 6, 9 h	mg/g: Rg_3: 1.87, Rg_5: 22.21, Rk_1: 18.76, Rh_1: 0.49	Samples with different steaming times don't cause significant changes in body temperature and blood pressure in rats	Cho, Kim, Lee, & Kim, 2017
8	Heated at 60, 80, 100, 120 °C for 1 h; Heated at 100 °C for 1, 2, 4, 8, 16 h	mg/g: *S*/*R*-Rg_3: 0.69, CK: 0.255, Rh_2: 0.001	Heating at 100 °C for 2 h and 16 h, the antibacterial activity reached the maximum, respectively.	Na, Kim, Rhee, & Oh, 2017
9	Steamed at 100, 110, and 120 °C for 2 h	%: F_4: 0.23, Rg_5: 0.64, Rg_3: 1.32	The effect to induce endothelium dependent relaxation and free radical scavenging activity was improved.	Kim et al., 2000
10	*Trap ginseng for 3 d, moisten ginseng for 0.5 h, steam ginseng for 3 h	/	The H_2O_2-induced oxidative stress in rat cardiomyocytes was attenuated.	Li, Zhang, Ji, & Zhao, 2019
11	Soak dried ginseng in garlic juice for 12 h, steam it at high temperature, pressure for 2 h	%: Rh_1: 0.29, Rg_3: 0.34, Rh_2: 0.96	Enhance the exercise endurance of mice and delay fatigue.	Zhang, 2016
12	Soak in garlic juice for 12 h, steam for 2 h	/	Improve anti-fatigue effect.	Zhao, 2016
13	*P. ginseng*, *P. quinquefolium*, *P. notoginseng* roots, stems and leaves were steamed at 120 °C for 12 h, maintained for 24 h	mg/g: *P.* ginseng: Rk_3: 1.68, Rh_4: 3.48, Rg_3: 5.77, Rk_1: 3.42, Rg_5: 10.99; American ginseng: Rk_3: 1.72, Rh_4: 2.59, Rg_3: 7.17, Rk_1: 5.76, Rg_5: 17.26; *P. notoginseng*: Rk_3: 10.31, Rg_3: 10.02, Rk_1: 6.29, Rg_5: 18.62, *S*-Rh_1: 11.63, *R*-Rh_1: 8.5	High temperature steaming of *P. notoginseng* had the strongest tumor cell cytotoxicity.	Gu, Zeng, Zhang, Wang, & Zhang, 2021
14	Steamed at 120 °C with glutamic acid, arginine, and distilled water for 0.5, 1, 2, 4 h; Steamed at 98 °C with glutamic acid, arginine, distilled water for 2 h	mg/g: *R*-Rg_3: 0.41, *S*-Rg_3: 0.36, Rg_5: 0.49, Rg_6: 0.32, Rk_1: 0.45, Rk_3: 0.29, Rh_4: 0.27	Ginseng steamed with arginine exhibited higher antioxidant activity.	Xia, 2017
15	Steam fermented ginseng powder for 7 h, dried for 8 h, and circulated 5 times	mg/g: Rg_3: 2.12, Rg_6: 1.27, Rh_1: 0.69	Black ginseng total saponins inhibit Hela cells in a concentration dependent manner.	Liu, 2015
16	Dried at 50 °C, steamed at 140 °C, 3 kg/cm^2 for 20 min	mg/g: *R*-Rh_1: 0.14, Rg_3: 1.71	The lipolysis and lipid oxidation in C2C12 myotubes were promoted.	Yu et al., 2016
17	Heat vietnamese ginseng powder at 120 °C for 2, 4, 8, 12, 16 h	/	The 12 h sample had the strongest protective effect on renal cells	Kim et al., 2019

Note: Unless otherwise specified, the default raw material was fresh ginseng; *Trap ginseng: refers to loss of certain moisture after fresh ginseng is harvested and placed in an indoor cold warehouse for a period of time. Moistening ginseng: to make fresh ginseng easier to clean, need to have a certain early infiltration time.

Table 2
P. notoginseng steaming process parameters, rare saponins conversion and synergistic results.

No.	Steaming process parameters	Rare saponin conversion rates	Efficiency	References
1	Steamed under high pressure at 120 °C for 0, 2, 4, 8 h	mg/g: Rh_1: 4.58, Rh_4: 127.26, F_2: 4.94, Rk_3: 33.57, Rg_3: 6.38	The anticoagulant activity was enhanced.	Di et al., 2016
2	Steam the stems and leaves at 121 °C for 8 h	/	The *L*-glutamic acid-induced cell damage was alleviated.	Zhang, 2022
3	Steamed at 105, 110, and 120 °C for 2, 4, 6, 8, and 10 h	%: *P. notoginseng* taproot: Rh_1: 0.799, Rh_4: 2.066, Rk_3: 0.926, *S*-Rg_3: 1.068, *R*-Rg_3: 0.982; *P. notoginseng* fibrous root: Rh_1: 0.519, Rh_4: 1.552, Rk_3: 0.668, *S*-Rg_3: 0.620, *R*-Rg_3: 0.582	The blood tonifying effect was enhanced.	Wu, 2016
4	Steam the total saponins of *P. notoginseng* stems and leaves at 140 °C for 3 h	%: Rk_1: 6.97, Rg_5: 12.09, Rg_3: 1.53, *R*-Rg_3: 2.05, Rh_2: 8.65	The antioxidant and neurotransmitter regulatory effects were enhanced.	Ma, 2020
5	The moistening temperture was 60 °C for 24 – 27 h, drying at 40 °C, steaming 6 h	/	More effective in enhancing immunity and tonifying *qi*.	Zhou, 2014
6	Steamed for 3 h with water separation	/	The inhibitory activity of angiotensin-converting enzyme was reduced.	Sun, Chen, Wang, Liu, & Di, 2016
7	Steamed under high pressure at 110 °C for 3 h	/	The blood-enriching effect was increased.	Wu, 2021
8	Moisturized for 24 h, steamed at 110 °C for 3 h	Rh_4, *S*-Rg_3, Rg_3 adducts close to10 mg/g	The tonifying impact was enhanced, the growth of Lewis lung cancer was prevented and the toxic and side effects with chemical medications were reduced.	He, 2016
9	Steamed at 110 °C for 3 h	%: *S*-Rh_1: 0.53, *R*-Rh_1: 0.181, Rk_3: 0.346, Rh_4: 2.244, *S*-Rg_3: 0.361, *R*-Rg_3: 0.148, Rg_5: 0.226	The tonifying effect was boosted.	Wang, 2020
10	Steam *P. notoginseng* powder at 120 °C for 2 h	/	The immunomodulatory, antioxidant and anti-anemic properties were strengthened.	Hu et al., 2018
11	*P. notoginseng* powder was heated and steamed at 120 °C in 3 %acidic amino acids for 1 h	All prototype saponins are converted into rare saponins	The liver protection in mice was enhanced.	Zhang, 2021
12	Steam *P. notoginseng* powder at 120 °C for 5 h	/	The hematopoietic effect was boosted.	Zhou et al., 2020
13	Steam *P. notoginseng* powder at 120 °C for 2, 6, 9 h	/	The antiplatelet and anticoagulant effects were improved.	Lau et al., 2009
14	*P. notoginseng* rooting powder is steamed under high pressure at 120 °C for 2, 6, 9, 15, and 24 h	/	The inhibitory action of liver cancer cells was enhanced.	Toh et al., 2011
15	Steamed at 120 °C for 2 h	/	The antioxidant activity and hematopoietic function were strengthened.	Hu et al., 2018
16	Steamed at 120 °C for 4 h	mg/g: Rh_1: 10.57, Rh_2: 0.3, Rh_4: 15.6, *S*-Rg_3: 11.09, *R*-Rg_3: 8.61, Rk_3: 11.0, Rk_1: 10.8, Rg_5: 15.3	The antiproliferative and pro- apoptotic effects on cancer cells were enhanced.	Sun, Pan, & Sung, 2011; Sun et al., 2011
17	Steamed at 120 °C for 6 h	/	The overall hematopoiesis was promoted and the progression of renal function was inhibited to alleviate damage in RA mice.	Gao et al., 2022

Note: Unless otherwise specified, the default raw material was fresh *P. notoginseng.*

Table 3
P. quinquefolium steaming process parameters, rare saponins conversion and synergistic results.

No.	Steaming process parameters	Rare saponin conversion rates	Efficiency	References
1	Steamed at 120 °C for 2 h	/	The antioxidant and antiproliferative activities were enhanced.	An et al., 2020
2	Steamed at 120 °C for 4 h	/	Antioxidants or inhibitors of NF-jB pathway can boost the anticancer impacts.	Li, Wang, He, Yuan, & Du, 2010
3	Steamed at 120 °C for 2 h	%: Rg_3: 5.84	The anti proliferative effects were significantly enhanced.	Luo et al., 2008
4	Steamed at 100 °C for 0.5, 1, 1.5, and 2 h	/	The activity of free radical scavenging, SOD and CAT was enhanced, and the lipid peroxidation was inhibited.	Wang et al., 2007
5	Steamed at 100, 120 °C for 1 h; Steamed at 120 °C for 0.5, 1, 2, 3, 4 h	%: Rh_1: 0.049, Rh_2: 0.059, Rg_3: 1.222	The antiproliferative effects were markedly increased.	Kim et al., 2007
6	Steamed at 120 °C for 2, 4 h	%: Rh_2: 1.14, Rg_3: 7.74	The antiproliferative activities were obviously enhanced.	Wang et al., 2009

Note: Unless otherwise specified, the default ingredient was fresh *P. quinquefolium*.

increases, and its anti-cancer cell proliferation activity is correspondingly enhanced. The generation of rare saponins is the material basis for the enhanced therapeutic effect of American ginseng.

3. Innovative research on steaming process

The research on modern Chinese medicine processing technology is based on standard processing techniques, improving and perfecting traditional techniques. Numerous studies have shown that the steaming of *P. ginseng*, *P. notoginseng*, and *P. quinquefolium* produced rare saponins, which enhance their antioxidant, anti fatigue, anti-cancer, and cellular immune effects, improved the commercial value of steamed products, promoted the extensive research and development of steamed ginseng plant health foods and drugs, developing various high-tech and equipment. Gong et al. (Gong, Sun, & Zhang, 2013) has developed an automatic processing equipment based on a programmable logic controller (PLC), which integrates steaming and drying, greatly improving the efficiency of steaming ginseng. Cai et al. used a series of processes such as hot immersion to treat raw materials such as American ginseng and longan to make American ginseng and longan paste (Cai, Zhang, Li, & Xiao, 2003). The product has a nourishing effect, but in order to improve the appearance and taste of longan paste, pectin was added on the basis of the original preparation process to stabilize the product and better exert its health benefits. Meng et al. used a high-pressure steam sterilization pot to improve the ginseng processing technology, which can achieve the best process effect by evenly and quickly transferring temperature (Meng, Yao, Yu, & Tian, 2021). Xiao & Wang adopted pressure maintaining steaming, which is easy to control under certain conditions, with less time consumption, low loss, and good quality (Xiao & Wang, 2012). Li et al. invented a new processing technology for steamed *P. notoginseng*, which can control the heating rate at each stage, helping to control the quality of steamed *P. notoginseng* and improve its therapeutic effect (Li, Liu, & Xu, 2022). Wang et al. invented a method for processing American ginseng based on steam explosion technology (Wang, Ma, & Yu, 2023). The method used saturated steam to pressurize the freeze-dried American ginseng system after rehydration for 1 – 3 min, and then instantaneously released pressure for steam explosion treatment. This invention not only helps to promote the dissolution of chemical substances, improve biological activity, and has the advantages of environmental protection and efficiency, but also reduces the bitterness of American black ginseng, thereby increasing compliance.

4. Conclusion and prospect

The steaming process can have a significant impact on the increment and pharmacological effects of rare saponins in ginseng plants. After processed, *P. ginseng*, *P. notoginseng*, and *P. quinquefolium* had longer storage time, increased content of rare saponins, enhanced efficacy and improved application value (Metwaly, Zhu, Huang, & Dou, 2019). At present, due to the high energy consumption, low level of automation and intelligence in traditional steaming processes, non-standard steaming methods, inconsistent process parameters, and lack of standardized operating procedures and unified standards (Gong, Sun, & Zhang, 2013), the appearance quality and commercial value of steamed products are affected.

The traditional steaming process requires reform and innovation. By changing production conditions, innovating methods, establishing standardized and intelligent process flows, and automatically controlling temperature and time, it can provide guarantees for controlling product quality and improving steaming efficiency.

The fusion and analysis techniques of multidisciplinary methods were used to study the changes in chemical composition and efficacy of ginseng plants before and after steaming. Multiple complex data analysis methods were used to analyze the structure–activity relationship of the chemical components and biological activities before and after steaming, in order to identify the rare saponin components and compositions that change the efficacy of *P. ginseng*, *P. notoginseng*, and *P. quinquefolium* after steaming. And this is an indicator component to detect and evaluate the quality of steamed products and guide the steaming process, which is of great significance to the standardization of the steaming process of medicinal herbs and the stability control of the quality of medicinal materials. This review summarizes the changes in rare ginsenosides of *P. ginseng*, *P. notoginseng* and *P. quinquefolium* before and after steaming, as well as their correlation with pharmacological activity. It helps guide the optimization of the steaming process of *P.ginseng*, *P. notoginseng* and *P. quinquefolium*, providing scientific basis for quality control and clinical rational drug use, and improving the application value of *P. ginseng*, *P. notoginseng*, *P. quinquefolium* and their steamed products.

CRediT authorship contribution statement

Wenjie Zhao: Writing – original draft. **Linlin Han:** Writing – original draft, Writing – review & editing. **Tao Li:** Supervision. **Jungjoon Lee:** Supervision. **Yuqing Zhao:** Writing – review & editing, Conceptualization, Project administration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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