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REVIEW PAPER

Chemical characteristics, functional properties and health benefits of *Panax ginseng*: An updated review

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Abstract

Panax ginseng (C.A. Meyer) is a highly valued medicinal plant widely recognized for its bioactive compounds and health-promoting properties. The roots, leaves, and berries of *P. ginseng* contain a complex mixture of bioactive constituents, including ginsenosides, polysaccharides, polyacetylenes, flavonoids, peptides, and phenolic compounds. Ginsenosides, the primary pharmacologically active components, are triterpenoid saponins classified into protopanaxadiol (PPD) and protopanaxatriol (PPT) types based on their aglycone structures, with major forms including Rg1, Rb1, Re, Rc, and Rd. Other secondary metabolites, such as ginseng polysaccharides and polyacetylenes (e.g., panaxydol and panaxynol), contribute complementary antioxidant, anti-inflammatory, and immunomodulatory effects. The chemical composition and concentration of these metabolites vary between plant parts and species, influencing their functional properties and therapeutic efficacy. Experimental studies have demonstrated that *P. ginseng* exhibits a wide range of biological activities. Its antioxidant properties mitigate oxidative stress by scavenging free radicals and enhancing endogenous defense mechanisms. Ginseng also modulates immune responses by affecting macrophages, natural killer cells, dendritic cells, and T and B lymphocytes, thereby supporting resistance to infections and improving immune regulation. Additionally, ginseng has been reported to enhance cognitive function, including memory, attention, and mood, while reducing mental fatigue and promoting overall vitality. Polysaccharides and ginsenosides contribute to metabolic regulation, including improved insulin sensitivity and blood glucose control. Emerging evidence also suggests potential anticancer benefits, with ginsenosides influencing cell cycle regulation, inhibiting abnormal cell proliferation, and mitigating chemotherapy-induced side effects. This review consolidates current knowledge on the chemical composition, functional properties, and health benefits of *Panax ginseng*. It emphasizes the need for high-quality standardized extracts and rigorous clinical studies to validate therapeutic effects and fully realize the medicinal potential of this traditional herb.

Keywords: Antioxidant, Bioactive compounds, Clinical trials, Ginsenosides, Immune modulation, *Panax ginseng*

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Introduction

Ginseng, a member of the genus Panax in the family Araliaceae, is one of the most renowned herbal medicinal plants in East Asia, valued for its remarkable therapeutic properties (Ratan et al., 2021; Potenza et al., 2022). Among East Asian countries particularly Korea, China, and Japan, ginseng holds a prominent place as one of the most significant medicinal herbs (Zhang et al., 2020). The Panax genus includes about 17 recognized species, of which *P. ginseng*, *P. quinquefolius*, and *P. notoginseng* are the most commonly used species for both medicinal and functional food applications (Ichim & de Boer, 2021; Zheng et al., 2022). The name Panax, given by Russian botanist Carl A. Meyer, comes from the Greek words pan meaning 'all' and akos meaning 'cure' or 'medicine', reflecting the traditional belief that ginseng serves as a universal remedy (Foster, 2016). The English name 'ginseng' comes from the Chinese word renshen, which means 'human root' because the root looks like a human body (Mandal, 2023). In the ancient Chinese pharmacopeia Shennong's Herbal Classic, herbs were categorized based on their toxicity levels. Ginseng is considered a safe herb and is recommended for regular use to boost energy and vitality. The World Health Organization reports that almost 80% of people worldwide rely on herbal medicine for additional or alternative healthcare (Ekor, 2014).

Medicinal plants are widely recognized as rich sources of bioactive secondary metabolites, many of which exhibit strong antioxidant, anti-inflammatory, and therapeutic properties. Numerous studies have demonstrated that the chemical composition of medicinal plants contributes significantly to their health-promoting effects, particularly through metabolites such as phenolics, flavonoids, and saponins. For example, Khan et al. (2020) highlighted the remarkable antioxidant potential of plant-derived secondary metabolites, emphasizing their importance in modern phytotherapeutic research. The pharmacological mechanism of ginseng remained unclear until 1963, when researchers isolated ginsenosides, its key bioactive secondary metabolites. Since then, extensive studies have focused on understanding the functions and mechanisms of individual ginsenosides, as their composition varies among Panax species (Park et al., 2017). These secondary metabolites are largely responsible for ginseng's diverse medicinal effects, contributing to its importance in both traditional and modern medicine (Lee et al., 2006; Tsutsumi et al., 2011).

Emerging evidence indicates that ginsenosides, also known as ginseng saponins, are the principal bioactive compounds of ginseng (Shi et al., 2019). The root of Panax ginseng typically contains about 2–3% ginsenosides, with Rg1, Rc, Rd, Re, Rb1, Rb2, and Rb0 being the most abundant forms (Lü et al., 2009; Mohanan et al., 2018). Among different ginseng species, Asian ginseng (*Panax ginseng*) generally exhibits higher total ginsenoside content than American ginseng varieties (Chen et al., 2020). Structurally, ginsenosides possess a tetracyclic triterpenoid backbone similar to that of steroids, with attached sugar moieties (Yu et al., 2025). To date, researchers have identified more than 40 different ginsenosides from *P. ginseng* roots. These compounds typically possess two or three hydroxyl groups, which may exist in free form or be linked to mono-, di-, or trisaccharide chains (Wang et al., 2023). Differences in the orientation of the hydroxyl substituent at the C-20 position can also produce stereoisomeric variants (Ye et al., 2023). Based on the structure of their aglycones, ginsenosides are generally categorized into two major groups: protopanaxadiols (PPD) and protopanaxatriols (PPT). In PPD-type ginsenosides, sugar residues are most commonly attached at the C-3 position of the dammarane triterpene nucleus, a group that includes Rb1, Rb2, Rc, Rd, Rg3, Rh2, and Rh3. In contrast, PPT-type ginsenosides feature carbohydrate attachments at the C-6 position, represented by compounds such as Re, Rf, Rg1, Rg2, and Rh1 (Gwak et al., 2019). Besides ginsenosides, *P. ginseng* contains several other important bioactive constituents that contribute to its pharmacological activity. These include ginseng polysaccharides, which exhibit immunomodulatory and antioxidant effects; polyacetylenes such as panaxydol and panaxynol with reported anticancer and anti-inflammatory properties; phenolic compounds with more antioxidant capacity; and ginseng peptides that support antioxidant defense and cellular protection. Although ginsenosides remain the major characteristic components, these additional metabolites play complementary roles and enhance the overall biological efficacy of ginseng (Hyun et al., 2020; Valdés-González et al., 2023; Song et al., 2025).

More recently, previously unreported ginsenosides including 25-OH-PPD and 25-OH-PPT have been discovered and isolated from ginseng fruits (Kim et al., 2018a). Notably, 25-OH-PPD has demonstrated protective effects against cancer cell proliferation (Wang et al., 2009). In addition, malonyl-ginsenosides such as Rb1, Rb2, Rc, and Rd have been reported, alongside other acidic ginsenosides like Ro. These acidic and neutral ginsenosides collectively contribute to the diverse pharmacological properties of ginseng (Kim et al., 2016; Yao et al., 2017; Kim et al., 2018b).

Chemical constituents of *Panax ginseng* berry

Panax ginseng, commonly known as Korean ginseng, has long been recognized worldwide as an important medicinal plant (Zhang et al., 2020). While extensive research has focused on the chemical composition and biological activities of *P. ginseng* roots, recent studies have highlighted that the berries of *P. ginseng* also possess significant biological and pharmacological potential (Lee et al., 2010; Song et al., 2025). However, compared to roots, the chemical profile of *P. ginseng* berries remains relatively understudied (Lee et al., 2010). The berries of Korean ginseng can be harvested earlier than the roots, providing an additional medicinal resource without compromising root yield (Park et al., 2019). Phytochemical analyses have revealed that ginseng berries contain a wide array of bioactive constituents. The major compounds include ginsenosides such as Rb1, Rb2, Rc, Rd, Re, Rg1, Rg2, Rg3, and Rh1, many of which differ in proportion from those found in roots (Hyun & Jang, 2017; Song et al., 2025). In addition to ginsenosides, *P. ginseng* berries are rich in polysaccharides, which contribute to immunomodulatory and antioxidant activities, and phenolic compounds, which exhibit strong free radical scavenging potential (Choi et al., 2017). Flavonoids and polyacetylenes, such as panaxydol and panaxynol, are also present and are believed to play roles in anti-inflammatory and anticancer effects (Attele et al., 2002; Yuan et al., 2012). Other minor constituents, including amino acids, organic acids, and fatty acids, may also contribute to the overall pharmacological profile of ginseng berries (Song et al., 2025). Notably, extracts from ginseng berries have demonstrated antihyperglycemic and metabolic regulatory effects, supporting their potential use in the development of novel antidiabetic and functional food products (Attele et al., 2002; Yuan et al., 2012; Choi et al., 2017). Continued research into the chemical and biological properties of *P. ginseng* berries will not only expand understanding of their medicinal value but also encourage exploration of new applications and mechanisms of action in this emerging field.

Breeding approaches used in developing ginseng cultivars

The reproduction of ginseng is a challenging process due to its long life cycle and low seed productivity. It typically takes around four years for ginseng plants to produce viable seeds, and even then, the yield is relatively low. Because of this, breeding programs for *Panax ginseng* require extensive time and careful management (Zhang et al., 2020). To improve genetic traits, researchers have utilized local landraces and wild populations as valuable genetic resources for selection (Bohra et al., 2022). Cultivars such as 'Hwangsuk', 'Chungkyung', and 'Jakyeong' have been developed through this approach (Zhang et al., 2020).

In traditional breeding programs, superior individual plants are selected and grown separately across multiple generations. Their progenies are carefully evaluated, and the best-performing lines are retained for further propagation. Subsequently, the pure-line selection method was adopted for the development of improved *P. ginseng* cultivars (Ramadevi et al., 2024). This method generally involves two approaches: line selection and propagation, and hybridization. In the hybridization approach, selected elite plants are crossed to combine desirable traits, and the resulting progenies are evaluated through several generations of selection (Shahiba et al., 2023). Because of ginseng's slow growth rate, the complete development of a new cultivar using this method usually requires five to six generations, taking approximately 20 to 24 years to complete a full breeding cycle (Zhang et al., 2020).

To overcome this long life cycle, modern molecular and biotechnological tools now offer new opportunities for precision breeding (Aziz & Masmoudi, 2025). The integration of genomic data, molecular markers, and tissue culture techniques can significantly accelerate the development of high-yielding, disease-resistant, and pharmacologically enhanced ginseng cultivars, ensuring the sustainability and competitiveness of ginseng cultivation worldwide (Jarallah et al., 2025). Tissue culture methods are widely used in ginseng breeding and propagation. Through *in vitro* culture, elite genotypes can be multiplied quickly while preserving their genetic characteristics (Xu et al., 2023). In addition, somaclonal variation, genetic variations that arise during the tissue culture process provides a useful source of novel traits that can be selected for cultivar improvement (Jing, 2024). Regeneration from callus or somatic embryos sometimes produces lines with modified secondary metabolite contents, including altered ginsenoside compositions. These variants are screened and selected for potential commercial use (Lee et al., 2023). Progress in molecular genetics has made it possible to use DNA markers to assess genetic variation and to assist in selecting superior ginseng genotypes. Techniques such as RAPD (Random Amplified Polymorphic DNA), AFLP (Amplified Fragment Length Polymorphism), SSR (Simple Sequence Repeats), and SNP (Single Nucleotide Polymorphism) have been widely applied to analyze genetic diversity and clarify relationships among Panax ginseng accessions (Bohar et al., 2020; Hasan et al., 2021; Nair & Pandey, 2021). Marker-assisted selection (MAS) allows breeders to detect and choose alleles linked to key traits such as disease resistance and increased ginsenoside contents without relying exclusively on observable characteristics. This approach accelerates breeding progress and enhances the accuracy of developing improved cultivars (Collard & Mackill, 2007). Recent genomic studies, including the sequencing of the *P. ginseng* genome, have further facilitated the identification of genes associated with metabolic pathways and stress responses, opening the door for genome-assisted breeding (Mohanan et al., 2023). Although modern biotechnological tools, including CRISPR/Cas9 gene editing, transgenic approaches, and metabolic engineering, hold promise for modifying genes involved in ginsenoside biosynthesis or disease resistance (Choi et al., 2022), but practical implementation in ginseng remains challenging. *Panax ginseng* is highly recalcitrant to genetic transformation due to its slow growth, low regeneration efficiency, and sensitivity to *in vitro* culture conditions. These limitations reduce transformation efficiency and make stable gene integration difficult. Nevertheless, progress with Agrobacterium-mediated transformation, hairy root cultures, and somatic embryogenesis has provided potential platforms for targeted improvement, though further optimization is required to achieve reliable and scalable genetic modification (Choi et al., 2022).

Ginseng composition

Ginseng contains a complex mixture of bioactive compounds, including over 30 ginsenosides (triterpenoid saponins), polysaccharides such as Ginsan, flavonoids, amino acids, peptides, and essential oils. The concentration and ratios of these compounds vary by species (*P. ginseng* vs. *P. quinquefolius*) and plant part, influencing their pharmacological effects (Fatoki, 2021). The concentration and balance of these ginsenosides vary significantly among different ginseng species (Li et al., 2022). Understanding these compositional differences, particularly between *Panax ginseng* C.A. Meyer (Asian ginseng) and *Panax quinquefolius* (American ginseng), are especially important for accurately assessing their pharmacological efficacy and safety profiles (Li et al., 2022). Traditional Eastern medicine describes these two ginseng types through the yin-yang concept: American ginseng is associated with a yin or "cooling" effect that helps relieve stress (Yue et al., 2007), while Asian ginseng is considered yang, providing a "warming" and stimulating effect (Xu et al., 2018). These contrasting physiological effects are believed to stem from the distinct ginsenoside compositions found in the two species (Azike et al., 2011). Beyond ginsenosides, researchers have also identified other bioactive constituents, such as an acidic polysaccharide known as Ginsan, which exhibits notable immunomodulatory properties (Kim & Yang, 2018; Wang et al., 2021; Valdés-González et al., 2023). To ensure consistency in research, recent studies have utilized standardized and authenticated ginseng samples from both Asian and North American sources (Ichim & de Boer, 2020). Among the numerous ginseng-based products present, six have been recognized as key markers for evaluating the quality and concentration of ginseng-based products (Piao et al., 2020). Although the root remains the traditional source of ginsenosides, significant quantities are also found in the leaves and berries, expanding potential applications for product formulation (Kang & Kim, 2016). Ginseng extracts are often incorporated into multivitamin and mineral supplements; however, such combinations may alter the biological activity or bioavailability of their compounds (Ratan et al., 2021; Frazer et al., 2025). Studies have shown that the oral absorption of certain ginsenosides, such as Rg1 and Rg2, is relatively low. The minimal recovery of these parent compounds in fecal samples suggests that extensive metabolic or microbial transformations occur in the gastrointestinal tract (Han & Fang, 2006). Interestingly, some of these ginsenoside metabolites have demonstrated antigenotoxic and bioactive properties, implying that the health effects of ginseng may depend more on these metabolic derivatives than on the original compounds themselves (Nag et al., 2012).

Panax ginseng cultivars in China

Most of China's *Panax ginseng* varieties originate from the Fusong and Ji'an areas, which together make up nearly half of the nation's total ginseng-growing region. Between the 1960s and 1990s, ginseng breeding primarily focused on improving yield, root morphology, and ginsenoside content (Zhang et al., 2020). However, with increasing deforestation and the subsequent shortage of suitable forest land for cultivation in the late 1990s, breeding priorities shifted toward developing cultivars that could thrive in farmland environments and tolerate continuous cropping conditions. Developing a forest-type ginseng cultivar requires almost fifty years, which is why China currently has only one officially registered forest ginseng variety (Zhang et al., 2020). Among the cultivated Panax ginseng types, Jishen 01, Fuxing 01, and Fuxing 02 are notable for their high-yield performance. Additionally, the cultivars Xinkaihe 01 and Xinkaihe 02, which possess elongated primary roots, were specifically developed for the production of Biantiao-type ginseng. A unique variety, Jilin Huangguo Renshen, produces yellow fruits unlike all other registered cultivars that bear red fruits. Kangmei 01 demonstrates strong adaptability to farmland cultivation, while Zhongnong Huangfengshen shows exceptional resistance to the adverse effects of continuous cropping. Additionally, Zhongda Linxiashen is prized for its visually appealing root shape, making it a favored option for producing premium wild-simulated ginseng (Zhang et al., 2020).

Chemical structures and classifications of Ginsenosides

Ginsenosides, or ginseng saponins, are the primary bioactive compounds in ginseng, typically comprising 2–3% of the root, with Rg1, Rc, Rd, Re, Rb1, Rb2, and Rb0 among the most abundant (Lü et al., 2009; Leung & Wong, 2010; Shi et al., 2019; Yu et al., 2019). Structurally, they consist of a steroid-like tetracyclic core bound to one or more sugar units (Fig. 1) (Li et al., 2024), and over 40 distinct ginsenosides have been identified in Panax ginseng roots. Each molecule contains two or three hydroxyl groups, which may be linked to mono-, di-, or trisaccharides, with variations at the C-20 hydroxyl position generating different stereoisomers (Sun et al., 2005; Lü et al., 2009; Wang et al., 2023). Based on the aglycone (sapogenin) structure, ginsenosides are classified into two main types: protopanaxadiol (PPD) ginsenosides, where sugars attach at the C-3 position of the dammarane-type triterpene backbone, including Rb1, Rb2, Rc, Rd, Rg3, Rh2, and Rh3, and protopanaxatriol (PPT) ginsenosides, with sugars linked at C-6, such as Re, Rf, Rg1, Rg2, and Rh1 (Nag et al., 2012; Gwak et al., 2019; Tong et al., 2022). Recently, novel ginsenosides such as 25-OH-PPD (25-hydroxy-protopanaxadiol) and 25-OH-PPT (25-hydroxy-protopanaxatriol) have been isolated from ginseng fruits (Lü et al., 2009; Hou et al., 2021). Interestingly, 25-OH-PPD has demonstrated protective and anticancer effects in experimental studies. In addition to these, acidic ginsenosides such as ginsenoside Ro and malonyl derivatives of Rb1, Rb2, Rc, and Rd have also been reported (Nag et al., 2012; Li et al., 2023). These compounds, along with neutral ginsenosides, contribute to the overall pharmacological diversity of ginseng and its wide range of biological activities (Zhang et al., 2025).

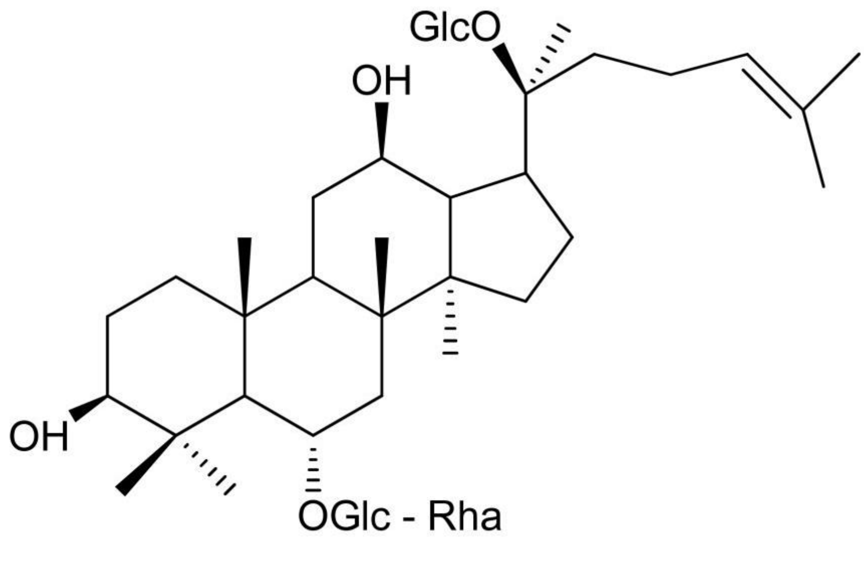

Fig. 1 Chemical structure of ginsenoside

Genome wide identification of novel genes in *P. gensing*

To determine the functional classification of the *PgERF* gene family, a total of 397 transcripts corresponding to 189 *PgERF* genes identified were analyzed using Blast2GO software. Of these, 195 *PgERF* transcripts were successfully annotated, while 202 remained unclassified, indicating that a significant portion of the *PgERF* gene family in *Panax ginseng* may have novel or uncharacterized functions (Jiang et al., 2024). The annotated *PgERF* genes were categorized into three main Gene Ontology (GO) domains: molecular function (MF), biological process (BP), and cellular component (CC). Among the 195 annotated sequences, 186 transcripts were associated with all three domains. Certain genes showed associations with only two categories, such as PgERF069, linked to BP and CC, and *PgERF135-1* and *PgERF135-3*, connected to BP and MF (Ding et al., 2018). Additionally, six genes, *PgERF152-1*, *PgERF152-2*, *PgERF152-3*, *PgERF152-4*, *PgERF105-3*, and *PgERF087* were related to both BP and CC. At the Level 2 GO classification, the 195 PgERF genes were further divided into eight functional groups, including nucleic acid binding, binding activity, metabolic process, cellular process, developmental process, organelle, cell component, and cell (Aniya et al., 2022). Chi-square analysis revealed that three subcategories such as nucleic acid binding transcription factor activity, binding, and cellular process were the most prevalent, consistent with the established role of ERF transcription factors in gene regulation. The remaining five subcategories showed relatively lower or insignificant enrichment compared to the whole-genome background (Su et al., 2025). Expression profiling across multiple developmental stages and tissues demonstrated dynamic PgERF activity. Specifically, PgERF expression patterns were examined in the roots of 5-, 12-, 18-, and 25-year-old plants, across 14 different tissues from 4-year-old ginseng plants, and in the roots of 42 distinct genotypes. In all cases, the PgERF transcripts were classified into the same eight functional subcategories, suggesting that the functional roles of *PgERF* genes are conserved across developmental stages, tissues, and genotypes (Jiang et al., 2024). However, significant variations in transcript abundance were observed, indicating differential gene expression influenced by age, tissue type, or genetic background. Overall, 189 PgERF genes were classified into five subfamilies including DREB, ERF, AP2, RAV, and Soloist paralleling the organization seen in *Arabidopsis thaliana*. Conserved AP2/ERF domains were identified among these genes, supporting their classification within the broader AP2/ERF transcription factor superfamily. Despite functional divergence, most PgERF members appear to participate in coordinated regulatory networks, implying that the majority of these genes retain biological relevance (Chen et al., 2020). The comprehensive identification and characterization of PgERF genes provide valuable resources for understanding their roles in plant development, stress responses, and secondary metabolite biosynthesis particularly the regulation of ginsenoside production in *Panax ginseng* and related species (Jiang et al., 2024).

Health benefits

Ginseng has been used in traditional Chinese medicine for centuries due to its restorative and adaptogenic properties. This slow-growing perennial herb, characterized by its fleshy, forked roots, is classified according to age and processing method into three main types: fresh ginseng, harvested before four years; white ginseng, harvested between four and six years and air-dried; and red ginseng, harvested after six or more years and steamed before drying (Song et al., 2025).

Reduce inflammation

Ginseng exhibits notable anti-inflammatory properties, largely attributed to its bioactive compounds, including ginsenosides, which can modulate cellular inflammation and enhance antioxidant capacity. *In vitro* studies have shown that extracts of ginseng, such as Korean red ginseng, can reduce inflammatory responses and improve antioxidant activity in skin cells, including those from individuals with eczema (Ratan et al., 2021). Human studies also provide supporting evidence: in one trial, 18 young male athletes consumed 2 grams of Korean red ginseng extract three times daily for seven days, resulting in significantly lower markers of inflammation after exercise compared with a placebo group, with effects lasting up to 72 hours (Jung et al., 2011). However, the interpretation of these results is limited by differences in placebo treatments, highlighting the need for further research. In a larger study involving 71 postmenopausal women, daily supplementation with 3 grams of red ginseng for 12 weeks improved antioxidant activity and reduced markers of oxidative stress, suggesting that ginseng may help mitigate inflammation and oxidative damage by enhancing the body's natural antioxidant defenses (Seo et al., 2014).

Benefit brain function

Ginseng has been shown to support brain function, including improvements in memory, attention, mood, and cognitive performance. Laboratory and animal studies suggest that ginseng compounds, such as ginsenosides and gintonin, protect neurons from oxidative damage caused by free radicals (Lee et al., 2024). In human trials, supplementation with *Panax ginseng* has demonstrated measurable cognitive benefits. For instance, 30 healthy participants who consumed 200 mg of *Panax ginseng* daily for four weeks showed improvements in mental health, social functioning, and mood, although these effects diminished after eight weeks, suggesting that prolonged use may reduce efficacy (Reay et al., 2010). In another study, single doses of 200 or 400 mg of *Panax ginseng* were administered to 30 healthy adults before and after a brief cognitive test; the 200 mg dose improved mental performance and reduced fatigue more effectively than the higher dose, potentially by helping regulate blood glucose levels. A separate trial reported that 400 mg daily for eight days enhanced calmness and mathematical performance. Additionally, some studies indicate that ginseng may have beneficial effects on cognitive function and behavior in individuals with Alzheimer's disease, highlighting its potential as a supportive agent for both healthy and impaired brain function (Hwang et al., 2025).

Boost the immune system

Ginseng has been shown to enhance immune system function, particularly in individuals undergoing medical treatments such as surgery or chemotherapy (Chen et al., 2014). Studies have reported that ginseng supplementation can improve immune markers and reduce symptoms in patients recovering from cancer (Chen et al., 2014). For example, 39 patients who had undergone stomach cancer surgery and took 400 mg of ginseng daily for two years demonstrated significant improvements in immune function and overall health. Similarly, patients with advanced stomach cancer receiving chemotherapy showed enhanced immunity after three months of red ginseng supplementation compared with control or placebo groups (Kim et al., 2018c). Some studies have even suggested that ginseng use may increase five-year disease-free survival rates by approximately 35–38% following surgical treatment. Additionally, ginseng may boost resistance to infections such as influenza. While these findings highlight ginseng's potential to support immune function, most research has focused on individuals with compromised immunity, and further studies are needed to confirm its effectiveness in healthy populations (Ratan et al., 2020).

Potential benefits against cancer

Ginseng has demonstrated potential benefits in reducing the risk of certain cancers, largely due to its bioactive compounds, particularly ginsenosides, which exhibit anti-inflammatory and antioxidant properties. These compounds can influence the cell cycle, helping to prevent abnormal cell proliferation and the growth of malignant cells (Wee et al., 2011). A review of multiple studies suggests that regular ginseng consumption may be associated with an approximately 16% lower risk of developing cancer. Experimental evidence also indicates that ginseng intake may reduce the likelihood of developing specific cancers, including those of the lip, oral cavity, stomach, colon, liver, and lungs. Additionally, ginseng has been reported to support the health of chemotherapy patients, alleviating treatment-related side effects and potentially enhancing the efficacy of certain anticancer medications. However, despite these promising findings, the evidence remains inconsistent, and further well-controlled studies are needed to clarify ginseng's role in cancer prevention and adjunctive therapy (Jin et al., 2015).

Combat fatigue and boost energy levels

Research indicates that certain compounds in ginseng, such as polysaccharides and oligopeptides, may help reduce oxidative stress and enhance cellular energy production, which can contribute to fighting fatigue (Bach et al., 2016; Yu et al., 2022). In one four-week study, 90 individuals with chronic fatigue were given either 1 or 2 grams of *Panax ginseng* or a placebo. Participants who received *Panax ginseng* reported less physical and mental fatigue and showed lower markers of oxidative stress compared with the placebo group (Arring et al., 2018). Another study involving 364 cancer survivors experiencing fatigue administered 2,000 mg of American ginseng or a placebo. After eight weeks, the ginseng group reported significantly reduced fatigue levels compared with those taking the placebo. Overall, a review of more than 155 studies concluded that ginseng supplementation can help alleviate fatigue and enhance physical performance (Lu et al., 2021).

Lower blood sugar

Both American and Asian ginseng have been found to support pancreatic function, enhance insulin production, and help regulate blood sugar levels (Chen et al., 2019). Studies report an average 11% reduction in blood sugar, a 38% decrease in fasting insulin, and a 33% improvement in insulin sensitivity. In one small study, American ginseng improved blood sugar response in ten healthy participants after a sugary beverage challenge. Boiled red ginseng, in particular, appears to be effective in managing blood sugar. Research indicates that taking 2.7 grams of boiled red ginseng daily can lower blood sugar and increase insulin levels after a test diet, compared with a placebo (Luo & Luo, 2008).

Although *Panax ginseng* is generally considered safe when consumed in recommended doses, it may cause mild side effects such as insomnia, headaches, gastrointestinal discomfort, or nervousness in some individuals (Frazer et al., 2025). Caution is advised for people taking anticoagulants, antiplatelet drugs, or medications that affect blood sugar, as ginseng can interact with these treatments and potentially alter their efficacy. Long-term or high-dose consumption may also lead to hormonal effects, including changes in blood pressure or menstrual cycles. Pregnant or breastfeeding women are typically advised to avoid ginseng due to limited safety data. Therefore, while ginseng offers numerous health benefits, awareness of potential adverse effects and drug interactions is essential for safe use (Thompson-Coon & Ernst, 2002).

Conclusion

Ginseng has long been recognized for its biological activity, and recent research has provided more detailed insights into its effects at both the cellular and molecular levels. A common challenge in many studies has been the use of unspecified or variable ginseng sources, which has made it difficult to fully validate findings or assess the efficacy and safety of different preparations. This issue is particularly relevant given the notable differences between ginseng species, such as *Panax ginseng* and *Panax quinquefolium*, which contain diverse profiles of potentially bioactive compounds. Commercial ginseng products also show significant variability. One study of 50 products from 11 countries found that over 90% differed in total ginsenoside content by 2–9%, and some contained no detectable ginsenosides at all. The development of standardized, certified ginseng from Asia and North America will be crucial for conducting reliable, double-blind human studies to evaluate its therapeutic potential. The focus of this review has been on identifying high-quality Korean and Chinese *P. ginseng* varieties, particularly those with favorable physical traits, disease resistance, high yield, and elevated saponin contents. Such varieties are designed to overcome common cultivation challenges, including root diseases and environmental stress, while maximizing bioactive compounds. This information can guide individuals in selecting ginseng types that support a healthy lifestyle. Furthermore, the potential for inter- and intraspecific hybridization of *Panax species* offers opportunities for developing new varieties with enhanced properties and health benefits. The findings of this study can inform the development of standardized, high-quality *Panax ginseng* products with consistent ginsenoside content, ensuring safety and efficacy for therapeutic use. Such products can support controlled, double-blind clinical trials to determine optimal dosing and health benefits. Inter- and intraspecific hybridization and selective breeding offer opportunities to create new ginseng varieties with enhanced bioactive compounds, improved disease resistance, and greater environmental adaptability.

Declarations

i. Ethics approval and consent to participate

Ethical approval and informed consent were not required for this study as it did not involve human participants, human data, or animals.

ii. Consent for publication

Consent for publication is not applicable.

iii. Data availability

All data generated or analyzed during this study are included in this article.

iv. Competing interests

Authors have declared that no competing interests exist.

v. Authors' contributions

H.B. developed the original idea and research scope for the review. He collected and analyzed literature on chemical composition and functional properties of *Panax ginseng*; F.A. provided overall guidance, critical information, and scientific oversight throughout the project. He prepared the initial draft of the manuscript. A.M. revised and refined the manuscript, strengthened the discussion, and ensured coherence across sections.

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Not applicable.

viii. SDGs addressed

Good Health and Well-Being (SDG 3); Industry, Innovation and Infrastructure (SDG 9)

References

Aniya, Q., Nomura, Y., Appiah, K. S., Fuerdeng, F., Suzuki, Y., Fujii, Y., & Xia, Q. (2022). Relationship between the antioxidant activity and allelopathic activities of 55 Chinese pharmaceutical plants. *Plants, 11*(19), 2481; https://doi.org/10.3390/plants11192481

Arring, N. M., Millstine, D., Marks, L. A., & Nail, L. M. (2018). Ginseng as a treatment for fatigue: A systematic review. *Journal of Alternative and Complementary Medicine, 24*(7), 624–633. https://doi.org/10.1089/acm.2017.0361

Attele, A. S., Zhou, Y.-P., Xie, J.-T., Wu, J. A., Zhang, L., Dey, L., Pugh, W., Rue, P. A., Polonsky, K. S., & Yuan, C.-S. (2002). Antidiabetic effects of *Panax ginseng* berry extract and the identification of an effective component. *Diabetes, 51*(6), 1851–1858. https://doi.org/10.2337/diabetes.51.6.1851

Azike, C. G., Charpentier, P. A., Hou, J., Pei, H., & Lui, E. M. K. (2011). The Yin and Yang actions of North American ginseng root in modulating the immune function of macrophages. *Chinese Medicine, 6*, 21; https://doi.org/10.1186/1749-8546-6-21

Aziz, M. A., & Masmoudi, K. (2025). Molecular breakthroughs in modern plant breeding techniques. *Horticultural Plant Journal, 11*(1), 15–41. https://doi.org/10.1016/j.hpj.2024.01.004

Bach, H. V., Kim, J., Myung, S.-K., & Cho, Y. A. (2016). Efficacy of ginseng supplements on fatigue and physical performance: A meta-analysis. *Journal of Korean Medical Science, 31*(12), 1879–1886. https://doi.org/10.3346/jkms.2016.31.12.1879

Bohar, R., Chitkineni, A., & Varshney, R. K. (2020). Genetic molecular markers to accelerate genetic gains in crops. *BioTechniques, 69*, 158–160. https://doi.org/10.2144/btn-2020-0066

Bohra, A., Kilian, B., Sivasankar, S., Caccamo, M., Mba, C., McCouch, S. R., & Varshney, R. K. (2022). Reap the crop wild relatives for breeding future crops. *Trends in Biotechnology, 40*(4), 412–431. https://doi.org/10.1016/j.tibtech.2021.08.009

Chen, J., Zhou, Y., Zhang, Q., Liu, Q., Li, L., Sun, C., Wang, K., Wang, Y., Zhao, M., Li, H., Han, Y., Chen, P., Li, R., Lei, J., Zhang, M., & Wang, Y. (2020). Structural variation, functional differentiation and expression characteristics of the AP2/ERF gene family and its response to cold stress and methyl jasmonate in *Panax ginseng* C.A. Meyer. *PLoS ONE, 15*(3), e0226055; https://doi.org/10.1371/journal.pone.0226055

Chen, S., Wang, Z., Huang, Y., O'Barr, S. A., Wong, R. A., Yeung, S., & Chow, M. S. S. (2014). Ginseng and anticancer drug combination to improve cancer chemotherapy: A critical review. *Evidence-Based Complementary and Alternative Medicine, 2014*, 168940; https://doi.org/10.1155/2014/168940

Chen, W., Balan, P., & Popovich, D. G. (2019). Review of ginseng anti-diabetic studies. *Molecules, 24*(24), 4501; https://doi.org/10.3390/molecules24244501

Chen, W., Balan, P., & Popovich, D. G. (2020). Comparison of ginsenoside components of various tissues of New Zealand forest-grown Asian ginseng (*Panax ginseng*) and American ginseng (*Panax quinquefolium* L.). *Biomolecules, 10*(3), 372; https://doi.org/10.3390/biom10030372

Choi, H. S., Kim, S., Kim, M. J., Kim, M.-S., Kim, J., Park, C.-W., Seo, D., Shin, S. S., & Oh, S. W. (2017). Efficacy and safety of Panax ginseng berry extract on glycemic control: A 12-wk randomized, double-blind, and placebo-controlled clinical trial. *Journal of Ginseng Research, 42*(1), 90–97. https://doi.org/10.1016/j.jgr.2017.01.003

Choi, H. S., Koo, H. B., Jeon, S. W., Han, J. Y., Kim, J. S., Jun, K. M., & Choi, Y. E. (2022). Modification of ginsenoside saponin composition via the CRISPR/Cas9-mediated knockout of protopanaxadiol 6-hydroxylase gene in *Panax ginseng*. *Journal of Ginseng Research, 46*(4), 505–514. https://doi.org/10.1016/j.jgr.2021.06.004

Collard, B. C. Y., & Mackill, D. J. (2007). Marker-assisted selection: An approach for precision plant breeding in the twenty-first century. *Philosophical Transactions of the Royal Society B: Biological Sciences, 363*, 557–572. https://doi.org/10.1098/rstb.2007.2170

Ding, R., Qu, Y., Wu, C. H., & Vijay-Shanker, K. (2018). Automatic gene annotation using GO terms from cellular component domain. *BMC Medical Informatics and Decision Making, 18*, 119; https://doi.org/10.1186/s12911-018-0694-7

Ekor, M. (2014). The growing use of herbal medicines: Issues relating to adverse reactions and challenges in monitoring safety. *Frontiers in Pharmacology, 4*, 177; https://doi.org/10.3389/fphar.2013.00177

Fatoki, T. H. (2021). Bioinformatics exploration of ginseng: A review. In C. F. E. Hano & J.-T. Chen (Eds.), *Ginseng – Modern aspects of the famed traditional medicine*. IntechOpen. https://doi.org/10.5772/intechopen.96167

Foster, S. (2016). Toward an understanding of ginseng adulteration: The tangled web of names, history, trade, and perception. *HerbalGram: The Journal of the American Botanical Council, 111*, 36–57.

Frazer, E., Zhao, C., Lee, J., Shaw, J., Lai, C., Bota, P., & Allee, T. (2025). A review of the mechanisms and risks of *Panax ginseng* in the treatment of alcohol use disorder. *Diseases, 13*(9), 285; https://doi.org/10.3390/diseases13090285

Gwak, Y. S., Han, J. Y., & Choi, Y. E. (2019). Production of ginsenoside aglycone (protopanaxatriol) and male sterility of transgenic tobacco co-overexpressing three *Panax ginseng* genes: PgDDS, CYP716A47, and CYP716A53v2. *Journal of Ginseng Research, 43*(2), 261–271. https://doi.org/10.1016/j.jgr.2018.02.005

Han, M., & Fang, X.-L. (2006). Difference in oral absorption of ginsenoside Rg1 between *in vitro* and *in vivo* models. *Acta Pharmacologica Sinica, 27*(4), 499–505. https://doi.org/10.1111/j.1745-7254.2006.00303.x

Hasan, N., Choudhary, S., Naaz, N., Sharma, N., & Laskar, R. A. (2021). Recent advancements in molecular marker-assisted selection and applications in plant breeding programmes. *Journal of Genetic Engineering and Biotechnology, 19*(1), 128; https://doi.org/10.1186/s43141-021-00231-1

Hou, M., Wang, R., Zhao, S., & Wang, Z. (2021). Ginsenosides in *Panax genus* and their biosynthesis. *Acta Pharmaceutica Sinica B, 11*(7), 1813–1834. https://doi.org/10.1016/j.apsb.2020.12.017

Hwang, J., Keum, M., Choe, Y. M., Suh, G.-H., Choi, H. J., Lee, B. C., Kim, S. G., Kim, H. S., Yi, D., & Kim, J. W. (2025). Panax ginseng: A modulator of amyloid, tau pathology, and cognitive function in Alzheimer's disease. *Journal of Ginseng Research, 49*(4), 348–355. https://doi.org/10.1016/j.jgr.2025.03.011

Hyun, S. H., Kim, S. W., Seo, H. W., Youn, S. H., Kyung, J. S., Lee, Y. Y., In, G., Park, C.-K., & Han, C.-K. (2020). Physiological and pharmacological features of the non-saponin components in Korean Red Ginseng. *Journal of Ginseng Research, 44*(4), 527–537. https://doi.org/10.1016/j.jgr.2020.01.005

Hyun, T. K., & Jang, K.-I. (2017). Are berries useless by-products of ginseng? Recent research on the potential health benefits of ginseng berry. *EXCLI Journal, 16*, 780–784. https://doi.org/10.17179/excli2017-376

Ichim, M. C., & de Boer, H. J. (2020). A review of authenticity and authentication of commercial ginseng herbal medicines and food supplements. *Frontiers in Pharmacology, 11*, 612071; https://doi.org/10.3389/fphar.2020.612071

Ichim, M. C., & de Boer, H. J. (2021). A review of authenticity and authentication of commercial ginseng herbal medicines and food supplements. *Frontiers in Pharmacology, 11*, 612071. https://doi.org/10.3389/fphar.2020.612071

Jarallah, M. H., Mouhsan, Z. M., & Alamry, A. T. S. (2025). Integration of genetic tools: Strategies for combining traditional and modern breeding to combat plant diseases. *European Journal of Ecology, Biology and Agriculture, 2*(4), 79–91. https://doi.org/10.59324/ejeba.2025.2(4).07

Jiang, Y., Zhang, Q., Zeng, Z., Wang, Y., Zhao, M., Wang, K., & Zhang, M. (2024). The AP2/ERF transcription factor PgERF120 regulates ginsenoside biosynthesis in ginseng. *Biomolecules, 14*(3), 345; https://doi.org/10.3390/biom14030345

Jin, X., Che, D.-b., Zhang, Z.-h., Yan, H.-m., Jia, Z.-y., & Jia, X.-b. (2015). Ginseng consumption and risk of cancer: A meta-analysis. *Journal of Ginseng Research, 40*(3), 269–277. https://doi.org/10.1016/j.jgr.2015.08.007

Jing, H. (2024). Advances in ginseng tissue culture research. *Transactions on Materials, Biotechnology and Life Sciences, 6*, 58–64.

Jung, H. L., Kwak, H. E., Kim, S. S., & Kim, Y. C. (2011). Effects of *Panax ginseng* supplementation on muscle damage and inflammation after uphill treadmill running in humans. *The American Journal of Chinese*

Medicine, *39*(3), 441–450. https://doi.org/10.1142/S0192415X11008944

Kang, O.-J., & Kim, J.-S. (2016). Comparison of ginsenoside contents in different parts of Korean ginseng (*Panax ginseng* C.A. Meyer). *Preventive Nutrition and Food Science, 21*(4), 389–392. https://doi.org/10.3746/pnf.2016.21.4.389

Khan, Z. U., Khan, N., & Hussain, Z. (2020). Evaluation of secondary metabolites profile and antioxidant potential of *Terminalia chebula* and *Glycyrrhiza glabra*. *Advances in Agriculture and Biology, 3*(1), 1-7. https://doi.org/10.63072/aab.20001

Kim, E. J., Kwon, K. A., Lee, Y. E., Kim, J. H., & Kim, S. H. (2018a). Korean Red Ginseng extract reduces hypoxia-induced epithelial-mesenchymal transition by repressing NF-kappaB and ERK1/2 pathways in colon cancer. *Journal of Ginseng Research, 42*, 288–297. https://doi.org/10.1016/j.jgr.2017.03.008

Kim, H. S., Lim, J. M., Kim, J. Y., Kim, Y., Park, S., & Sohn, J. (2016). Panaxydol, a component of *Panax ginseng*, induces apoptosis in cancer cells through EGFR activation and ER stress and inhibits tumor growth in mouse models. *International Journal of Cancer*, *138*, 1432–1441. https://doi.org/10.1002/ijc.29879

Kim, K. H., Lee, D., Lee, H. L., Kim, C.-E., Jung, K., & Kang, K. S. (2018b). Beneficial effects of *Panax ginseng* for the treatment and prevention of neurodegenerative diseases: Past findings and future directions. *Journal of Ginseng Research, 42*(3), 239–247. https://doi.org/10.1016/j.jgr.2017.03.011

Kim, S.-J., Choi, S., Kim, M., Park, C., Kim, G.-L., Lee, S.-O., Kang, W., & Rhee, D.-K. (2018c). Effect of Korean Red Ginseng extracts on drug-drug interactions. *Journal of Ginseng Research, 42*(3), 370–378. https://doi.org/10.1016/j.jgr.2017.08.008

Kim, Y.-R., & Yang, C.-S. (2018). Protective roles of ginseng against bacterial infection. *Microbial Cell, 5*(11), 472–481. https://doi.org/10.15698/mic2018.11.654

Lee, J. H., Jeong, S. M., Kim, J. H., Lee, B. H., Yoon, I. S., Choi, S. H., Lee, S. M., Park, Y. S., Lee, J. H., & Kim, S. S. (2006). Effects of ginsenosides and their metabolites on voltage-dependent Ca^{2+} channel subtypes. *Molecules and Cells*, *21*, 52–62.

Lee, J.-W., Kim, J.-U., Bang, K.-H., Kim, D.-H., Jo, I.-H., & Park, Y.-D. (2023). Efficient micropropagation of genetically stable *Panax ginseng* Meyer by somatic embryogenesis. *Agronomy*, *13*(4), 1139; https://doi.org/10.3390/agronomy13041139

Lee, R., Kim, J.-H., Kim, W.-W., Hwang, S.-H., Choi, S.-H., Kim, J.-H., Cho, I.-H., Kim, M., & Nah, S.-Y. (2024). Emerging evidence that ginseng components improve cognition in subjective memory impairment, mild cognitive impairment, and early Alzheimer's disease dementia. *Journal of Ginseng Research, 48*(3), 245–252. https://doi.org/10.1016/j.jgr.2024.02.002

Lee, S. Y., Kim, Y. K., Park, N. I., Kim, C. S., Lee, C. Y., & Park, S. U. (2010). Chemical constituents and biological activities of the berry of *Panax ginseng*. *Journal of Medicinal Plants Research*, *4*(5), 349–353. http://www.academicjournals.org/JMPR

Leung, K. W., & Wong, A. S. T. (2010). Pharmacology of ginsenosides: A literature review. *Chinese Medicine, 5*, 20; https://doi.org/10.1186/1749-8546-5-20

Li, J., Zhao, J., Wang, X., Lin, Z., Lin, H., & Lin, Z. (2024). Ginsenoside – a promising natural active ingredient with steroidal hormone activity. *Food & Function*, *15*(4), 1825–1839. https://doi.org/10.1039/D3FO05484E

Li, X., Cao, D., Sun, S., & Wang, Y. (2023). Anticancer therapeutic effect of ginsenosides through mediating reactive oxygen species. *Frontiers in Pharmacology, 14*, 1215020; https://doi.org/10.3389/fphar.2023.1215020

Li, Y., Yang, B., Guo, W., Zhang, P., Zhang, J., Zhao, J., Wang, Q., Zhang, W., Zhang, X., & Kong, D. (2022). Classification of three types of ginseng samples based on ginsenoside profiles: Appropriate data normalization improves the efficiency of multivariate analysis. *Heliyon*, *8*(12), e12044; https://doi.org/10.1016/j.heliyon.2022.e12044

Lu, G., Liu, Z., Wang, X., & Wang, C. (2021). Recent advances in *Panax ginseng* C.A. Meyer as a herb for anti-fatigue: An effects and mechanisms review. *Foods*, *10*(5), 1030; https://doi.org/10.3390/foods10051030

Lü, J.-M., Yao, Q., & Chen, C. (2009). Ginseng compounds: An update on their molecular mechanisms and medical applications. *Current Vascular Pharmacology*, *7*(3), 293–302. https://doi.org/10.2174/157016109788340767

Luo, J. Z., & Luo, L. (2008). Ginseng on hyperglycemia: Effects and mechanisms. *Evidence-Based Complementary and Alternative Medicine*, *6*(4), 423–427. https://doi.org/10.1093/ecam/nem178

Mandal, A. (2023, June 14). *What is ginseng? News-Medical Life Sciences*. Retrieved from https://www.news-medical.net/health/What-is-Ginseng.aspx

Mohanan, P., Subramaniyam, S., Mathiyalagan, R., & Yang, D.-C. (2018). Molecular signaling of ginsenosides Rb1, Rg1, and Rg3 and their mode of actions. *Journal of Ginseng Research*, *42*(2), 123–132. https://doi.org/10.1016/j.jgr.2017.01.008

Mohanan, P., Yang, T.-J., & Song, Y. H. (2023). Genes and regulatory mechanisms for ginsenoside biosynthesis. *Journal of Plant Biology*, *66*(1), 87–97. https://doi.org/10.1007/s12374-023-09384-7

Nag, S. A., Qin, J.-J., Wang, W., Wang, M.-H., Wang, H., & Zhang, R. (2012). Ginsenosides as anticancer agents: *In vitro* and *in vivo* activities, structure–activity relationships, and molecular mechanisms of action. *Frontiers in Pharmacology*, *3*, 25; https://doi.org/10.3389/fphar.2012.00025

Nair, R. J., & Pandey, M. K. (2021). Role of molecular markers in crop breeding: A review. *Agricultural Reviews*, *1*, 1–8. https://doi.org/10.18805/ag.R-2322

Park, J.-E., Kim, H., Kim, J., Choi, S.-J., Ham, J., Nho, C. W., & Yoo, G. (2019). A comparative study of ginseng berry production in a vertical farm and an open field. *Industrial Crops and Products*, *140*, 111612; https://doi.org/10.1016/j.indcrop.2019.111612

Park, S.-Y., Park, J.-H., Kim, H.-S., Lee, C.-Y., Lee, H.-J., Kang, K. S., & Kim, C.-E. (2017). Systems-level mechanisms of action of Panax ginseng: A network pharmacological approach. *Journal of Ginseng Research, 42*(1), 98–106. https://doi.org/10.1016/j.jgr.2017.09.001

Piao, X. M., Huo, Y., Kang, J. P., Mathiyalagan, R., Zhang, H., Yang, D. U., Kim, M., Yang, D. C., Kang, S. C., & Wang, Y. P. (2020). Diversity of ginsenoside profiles produced by various processing technologies. *Molecules, 25*(19), 4390; https://doi.org/10.3390/molecules25194390

Potenza, M. A., Montagnani, M., Santacroce, L., Charitos, I. A., & Bottalico, L. (2022). Ancient herbal therapy: A brief history of Panax ginseng. *Journal of Ginseng Research, 47*(3), 359–365. https://doi.org/10.1016/j.jgr.2022.03.004

Ramadevi, S., Tejasree, P., Eshwar Sai Prasad, C., & Praisy, T. (2024). Conventional breeding approaches. In U. G. Reddy, S. K. Deshpande, P. K., & S. Jahagirdar (Eds.), *Advances in crop breeding* (pp. 27–43). Puducherry, India: Cornous Publications LLP. https://doi.org/10.37446/edibook072024/27-43

Ratan, Z. A., Haidere, M. F., Hong, Y. H., Park, S. H., Lee, J.-O., Lee, J., & Cho, J. Y. (2021). Pharmacological potential of ginseng and its major component ginsenosides. *Journal of Ginseng Research, 45*(2), 199–210. https://doi.org/10.1016/j.jgr.2020.02.004

Reay, J. L., Scholey, A. B., & Kennedy, D. O. (2010). Panax ginseng (G115) improves aspects of working memory performance and subjective ratings of calmness in healthy young adults. *Human Psychopharmacology, 25*(6), 462–471. https://doi.org/10.1002/hup.1138

Seo, S. K., Hong, Y., Yun, B. H., Chon, S. J., Jung, Y. S., Park, J. H., Cho, S., Choi, Y. S., & Lee, B. S. (2014). Antioxidative effects of Korean red ginseng in postmenopausal women: A double-blind randomized controlled trial. *Journal of Ethnopharmacology, 154*(3), 753–757. https://doi.org/10.1016/j.jep.2014.04.051

Shahiba, A. M., Jayalekshmy, V. G., & Chacko, A. (2023). Traditional plant breeding techniques – Exploring crossbreeding and selection methods. In *Modern approaches in plant breeding: Enhancing crop genetics* (pp. 1–14). New Delhi, India: Elite Publishing House. https://doi.org/10.5281/zenodo.8406082

Shi, Z.-Y., Zeng, J.-Z., & Wong, A. S. T. (2019). Chemical structures and pharmacological profiles of ginseng saponins. *Molecules, 24*(13), 2443; https://doi.org/10.3390/molecules24132443

Song, X.-X., Liu, E.-L., & Du, X.-W. (2025). Ginseng: A traditional medicine and food homologous plant. *Journal of Asian Natural Products Research*. Advance online publication. https://doi.org/10.1080/10286020.2025.2514689

Su, Z.-L., Li, A.-M., Wang, M., Qin, C.-X., Pan, Y.-Q., Liao, F., Chen, Z.-L., Zhang, B.-Q., Cai, W.-G., & Huang, D.-L. (2025). The role of AP2/ERF transcription factors in plant responses to biotic stress. *International Journal of Molecular Sciences, 26*(10), 4921; https://doi.org/10.3390/ijms26104921

Sun, G. Z., Liu, Z., Li, X. G., & Zheng, Y. N. (2005). Isolation and identification of two malonyl-ginsenosides from the fresh root of *Panax ginseng*. *Chinese Journal of Analytical Chemistry, 33*(12), 1783–1786.

Thompson-Coon, J., & Ernst, E. (2002). Panax ginseng: A systematic review of adverse effects and drug interactions. *Drug Safety, 25*(5), 323–344. https://doi.org/10.1111/j.2042-7166.2002.tb03399.x

Tong, Y., Song, X., Zhang, Y., Xu, Y., & Liu, Q. (2022). Insight on structural modification, biological activity, structure–activity relationship of PPD-type ginsenoside derivatives. *Fitoterapia, 158*, 105135; https://doi.org/10.1016/j.fitote.2022.105135

Tsutsumi, Y. M., Tsutsumi, R., Mawatari, K., Nakaya, Y., Kinoshita, M., Tanaka, K., & Oshita, S. (2011). Compound K, a metabolite of ginsenosides, induces cardiac protection mediated by nitric oxide via Akt/PI3K pathway. *Life Sciences, 88*, 725–729. https://doi.org/10.1016/j.lfs.2011.02.011

Valdés-González, J. A., Sánchez, M., Moratilla-Rivera, I., Iglesias, I., & Gómez-Serranillos, M. P. (2023). Immunomodulatory, anti-inflammatory, and anti-cancer properties of ginseng: A pharmacological update. *Molecules, 28*(9), 3863; https://doi.org/10.3390/molecules28093863

Valdés-González, J. A., Sánchez, M., Moratilla-Rivera, I., Iglesias, I., & Gómez-Serranillos, M. P. (2023). Immunomodulatory, anti-inflammatory, and anti-cancer properties of ginseng: A pharmacological update. *Molecules, 28*(9), 3863; https://doi.org/10.3390/molecules28093863

Wang, H.-P., Wang, Z.-J., Du, J., Lin, Z.-Z., Zhao, C., Zhang, R., Yin, Q., Fan, C.-L., Peng, P., & Wang, Z.-B. (2023). Comprehensive identification of ginsenosides in the roots and rhizomes of *Panax ginseng* based on their molecular features-oriented precursor ions selection and targeted MS/MS analysis. *Molecules, 28*(3), 941; https://doi.org/10.3390/molecules28030941

Wang, N., Wang, X., He, M., Zheng, W., Qi, D., Zhang, Y., & Han, C.-C. (2021). Ginseng polysaccharides: A potential neuroprotective agent. *Journal of Ginseng Research, 45*(2), 211–217. https://doi.org/10.1016/j.jgr.2020.09.002

Wang, W., Rayburn, E. R., Zhao, Y., Wang, H., & Zhang, R. (2009). Novel ginsenosides 25-OH-PPD and 25-OCH_3-PPD as experimental therapy for pancreatic cancer: Anticancer activity and mechanisms of action. *Cancer Letters, 278*(2), 241–248. https://doi.org/10.1016/j.canlet.2009.01.005

Wee, J. J., Park, K. M., & Chung, A. S. (2011). Biological activities of ginseng and its application to human health. In I. F. F. Benzie & S. Wachtel-Galor (Eds.), *Herbal medicine: Biomolecular and clinical aspects* (2nd ed., Chapter 8). CRC Press. https://doi.org/10.1201/b10787-9

Xu, F., Valappil, A. K., Mathiyalagan, R., Tran, T. N. A., Ramadhania, Z. M., Awais, M., & Yang, D. C.

(2023). *In vitro* cultivation and ginsenosides accumulation in *Panax ginseng*: A review. *Plants (Basel)*, *12*(17), 3165; https://doi.org/10.3390/plants12173165

Xu, X.-F., Gao, Y., Xu, S.-Y., Liu, H., Xue, X., Zhang, Y., Zhang, H., Liu, M.-N., Xiong, H., Lin, R.-C., & Li, X.-R. (2018). Remarkable impact of steam temperature on ginsenosides transformation from fresh ginseng to red ginseng. *Journal of Ginseng Research*, *42*(3), 277–287. https://doi.org/10.1016/j.jgr.2017.02.003

Yao, C. J., Chow, J. M., Chuang, S. E., Chang, C. L., Yan, M. D., Lee, H. L., Lai, I. C., Lin, P. C., & Lai, G. M. (2017). Induction of Forkhead Class box O3a and apoptosis by a standardized ginsenoside formulation, KG-135, is potentiated by autophagy blockade in A549 human lung cancer cells. *Journal of Ginseng Research*, *41*, 247–256. https://doi.org/10.1016/j.jgr.2016.04.003

Ye, X.-W., Li, C.-S., Zhang, H.-X., Li, Q., Cheng, S.-Q., Wen, J., Wang, X., Ren, H.-M., Xia, L.-J., Wang, X.-X., Xu, X.-F., & Li, X.-R. (2023). Saponins of ginseng products: A review of their transformation in processing. *Frontiers in Pharmacology*, *14*, 1177819. https://doi.org/10.3389/fphar.2023.1177819

Yu, S. E., Mwesige, B., Yi, Y.-S., & Yoo, B. C. (2019). Ginsenosides: The need to move forward from bench to clinical trials. *Journal of Ginseng Research*, *43*(3), 361–367. https://doi.org/10.1016/j.jgr.2018.09.001

Yu, X., Lu, Y., Chen, J., Deng, Y., & Liu, H. (2025). Unlocking ginsenosides' therapeutic power with polymer-based delivery systems: Current applications and future perspectives. *Frontiers in Pharmacology*, *16*, 1629803; https://doi.org/10.3389/fphar.2025.1629803

Yu, Y., Liu, H., Nie, J., Tan, J., Lv, C., & Lu, J. (2022). Acidic polysaccharides of Mountain Cultivated Ginseng: The potential source of anti-fatigue nutrients. *Journal of Functional Foods*, *95*, 105198. https://doi.org/10.1016/j.jff.2022.105198

Yuan, H.-D., Kim, J. T., Kim, S. H., & Chung, S. H. (2012). Ginseng and diabetes: The evidences from *in vitro*, animal and human studies. *Journal of Ginseng Research*, *36*(1), 27–39. https://doi.org/10.5142/jgr.2012.36.1.27

Yue, P. Y. K., Mak, N. K., Cheng, Y. K., Leung, K. W., Ng, T. B., Fan, D. T. P., Yeung, H. W., & Wong, R. N. S. (2007). Pharmacogenomics and the Yin/Yang actions of ginseng: Anti-tumor, angiomodulating and steroid-like activities of ginsenosides. *Chinese Medicine*, *2*, 6; https://doi.org/10.1186/1749-8546-2-6

Zhang, H., Abid, S., Ahn, J. C., Mathiyalagan, R., Kim, Y.-J., Yang, D.-C., & Wang, Y. (2020). Characteristics of Panax ginseng cultivars in Korea and China. *Molecules*, *25*(11), 2635; https://doi.org/10.3390/molecules25112635

Zhang, Z.-B., Yu, C.-Y., Wang, H.-Y., Jia, X.-B., Wu, W., Pang, S.-T., Li, W., Zahoor, S., Khan, W., Liu, Y.-C., Yang, B., & Feng, L. (2025). The history, beneficial ingredients, mechanism, processing, and products of *Panax ginseng* for medicinal and edible value. *Food & Medicine Homology*, *2*(4), 9420059; https://doi.org/10.26599/FMH.2025.9420059

Zheng, Y., Awais, M., Akter, R., Xu, F., Baik, S., Jung, D., Yang, D.-C., Kwak, G.-Y., & You, W. (2022). Discrimination of *Panax ginseng* from counterfeits using single nucleotide polymorphism: A focused review. *Frontiers in Plant Science*, *13*, 903306; https://doi.org/10.3389/fpls.2022.903306