# Medicinal Potential of Pine Trees: A Brief Review Focusing on Three Species

Qinsong Li, Qiyu Li, Anping Wang, and Wenxuan Quan *

*Pinus* trees are widely distributed worldwide, and pine needles, pine bark, pinecones, *etc.*, have potential medicinal value. This paper reviews the medicinal potential of extracts from different organs of three trees of the genus *Pinus* in East Asia. Studies have shown that pine trees are rich in bioactive compounds, and these compounds have a variety of pharmacological activities, including antioxidation, anti-inflammatory, antibacterial, antitumor, and hypolipidemic effects. The wide range of pharmacological activities of these bioactive components is helpful for the treatment of cardiovascular diseases, inflammatory diseases, tumors, and other diseases. These findings can help promote research on the medicinal potential of *Pinus* and its organs to realize the efficient utilization of byproducts of pine resources.

*DOI: 10.15376/biores.20.1.Li*

*Keywords: Masson pine; Pollen; Extracts; Biological activity*

*Contact information: Guizhou Key Laboratory for Information Systems of Mountainous Areas and Protection of Ecological Environment /Guizhou Key Laboratory of Forest Cultivation in Plateau Mountain, Guizhou Normal University, Guiyang, China, 550001; *Corresponding author: wenxuanq@gznu.edu.cn*

## INTRODUCTION

*Pinus* trees are widely distributed in the Northern Hemisphere and include various species and large biomasses. There are a variety of *Pinus* plants distributed in East Asia, among which Masson pine (*Pinus massoniana* Lamb.), red pine (*Pinus densiflora* Sieb. et Zucc.), and Korean pine (*Pinus koraiensis* Sieb. et Zucc.) are typical. These three pine species are important timber trees with slight differences in their physical properties. Overall, their woods exhibit good physical performance, and many studies have explored their primary applications as timber (Wang *et al*. 2018b; Peng *et al*. 2022; Zhang *et al*. 2022; Suri *et al*. 2022; Park *et al*. 2024). Many byproducts are produced in the process of forest management and protection, especially after harvesting wood, including branches, needles, bark, pinecones, *etc*. These materials all contain large amounts of active substances (Fig. 1). Masson pine is a 2-needle pine. It is native to central and southern China and northern Vietnam. It is the main tree species used for afforestation in southern China and one of the main industrial timber tree species in southern China (Feng *et al.* 2014; Zhang *et al.* 2015). Red pine, a type of 2-needle pine, is distributed mainly in northeastern China, southeastern Russia, Korea, and Japan (Jiang *et al.* 2012). Korean pine is a 5-needle pine that is widely distributed in Northeast China, the Korean Peninsula, and the Russian Far East. Korean pine has become a valuable economic tree species because of its excellent wood quality and delicious seeds (Li *et al.* 2020; Weng *et al.* 2020; Shitara *et al.* 2021).

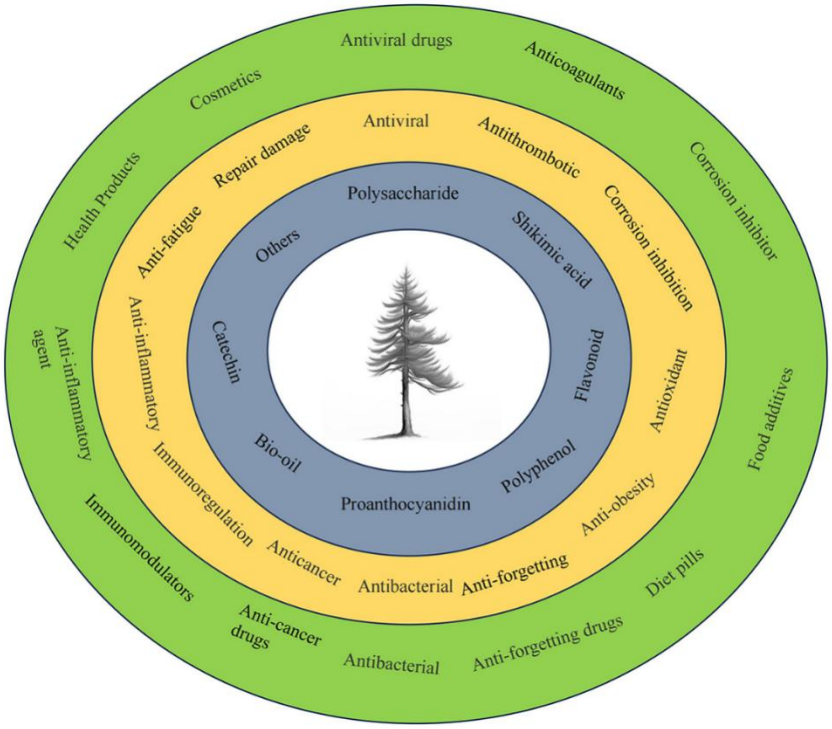


**Fig. 1.** Metabolites, functions, and applications of *Pinus* species

In East Asia, various parts of the pine tree, including pine needles, cones, bark, and pollen, have historically been used for their medicinal and dietary properties (Kim and Chung 2000). Masson pine natural products have sedative, analgesic, antipyretic, anti-inflammatory, and antibacterial effects. The active substances are derived mainly from plant bark, pine needles, pollen, *etc*. Polysaccharides constitute a significant class of bioactive compounds that is recognized for their diverse pharmacological properties, particularly their strong immunomodulatory functions (Wang *et al.* 2021). Biologically active polysaccharides represent a substantial resource for potential applications, particularly in the medical field. They have attracted considerable interest in vaccine development, emerging as a significant trend in the advancement of vaccine adjuvants (Li *et al.* 2015). In recent years, with increasing research, the polyphenols (Dziedziński *et al.* 2021) and flavonoids (Delgado-Alvarado *et al.* 2022) of *Pinus* trees have gradually become known and have attracted increasing attention (Fig. 2). Research on the activity of different organs of three kinds of *Pinus* trees is based mainly on the antioxidative, antiobesity, anticancer, antibacterial, and other aspects of the extract (Table S1).

## RESEARCH AND APPLICATION OF MASSON PINE

Polysaccharides are the most common structurally diverse macromolecules produced by organisms during their metabolism, and they are composed of repetitive structural features linked by glycosidic linkages. The normal operation of plants is beneficial for their growth and development. They have attracted much attention because of their significant biological activity, and they have developed rapidly in drug research

(Huang *et al.* 2019; Sivanesan *et al.* 2022). The polysaccharide structure forms an important part of the cell membranes of higher plants, animals, and microorganisms and is involved in major physiological functions. In recent years, due to the outstanding curative effects of natural products and extracts in the prevention and treatment of diseases, polysaccharides have been applied in the treatment of diseases (Yu *et al.* 2018; Santos *et al.* 2021). The biological activity of the Masson pine pollen polysaccharide is reflected mainly in its pharmacological application. Any dose of pollen polysaccharide can increase the general antibody level, blood lymphocyte ratio, lymphocyte proliferation rate, average daily intake, and average daily gain of rabbits (Wei *et al.* 2011). These findings indicate that pollen polysaccharides have potential as immune enhancers. More importantly, sulfated derivatives of pollen polysaccharides and pollen polysaccharides have been found to inhibit the proliferation of cancer cells (Chu *et al.* 2013; Shang *et al.* 2022). These findings indicate the potential of pollen polysaccharides as anticancer drugs.

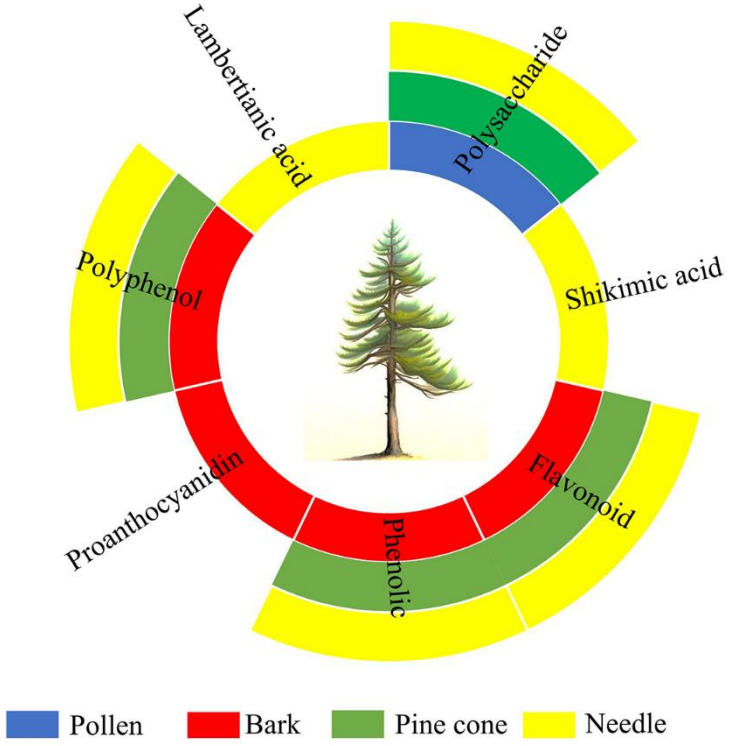


**Fig. 2.** Medicinal parts and extraction fractions of *Pinus* species

There are more in-depth studies on the application of polysaccharides from pollen in poultry. Researchers have reported that pollen polysaccharides have immune-enhancing, immune response-modulating, virus infection-inhibiting, and virus proliferation-inhibiting effects on *Proteus mirabilis*, subgroup B *avian leukosis* virus, *Bordetella avium*, H9N2 subtype avian influenza virus, Newcastle disease virus, and avian leukosis virus subgroup J (Cui *et al.* 2013; Guo *et al.* 2014; Zhu *et al.* 2016; Wang *et al.* 2019; Shang *et al.* 2020; Cui *et al.* 2021; Sha *et al.* 2021). There is further demonstration of the potential of pollen polysaccharides as immune enhancers. The differential expression of several proteins in pollen polysaccharide-treated chickens is associated with the host innate immune response, stress-induced immune response, or lipid synthesis-related pathways (Yang *et al.* 2018).

Moreover, studies in mice have shown that they are a new type of immune enhancer for livestock and regulate the intestinal microenvironment (Zhao *et al.* 2013; Niu *et al.* 2021). In addition, polysaccharides extracted from pollen have antioxidant and antiviral activities (Yang *et al.* 2015). Among them, pollen polysaccharides were found to have a significant protective effect against $CCl_4$-induced acute hepatotoxicity (Zhou *et al.* 2018). In addition, pollen polysaccharides were found to have an immune-enhancing effect on a porcine reproductive and respiratory syndrome virus subunit vaccine (Peng *et al.* 2016). In summary, the polysaccharides extracted from the pollen of Masson pine have antioxidant, antiviral, and immunomodulatory properties. Given the widespread distribution and significant resource availability of Masson pine, these findings indicate considerable potential for future applications and advancements in research and development.

An extract of Masson pine needles can improve the diversity and structure of the gut microbial composition, production performance, egg quality, and serum indicators in laying hens (Guo *et al.* 2022). The results indicated that the needles are efficient inhibitors with a corrosion inhibition efficiency of 95% (Wang *et al.* 2018a). Needle polysaccharides significantly improved serum lipid levels and reduced malondialdehyde levels in mice and had significant antioxidant capacity and the ability to reduce inflammation (Chu *et al.* 2019).

Some active substances are extracted from the needles of Masson pine *via* the supercritical $CO_2$ fluid extraction method, and studies have shown that the extracts have antioxidant activity (Yang *et al.* 2021). Several new compounds have been isolated and identified from the extracts of fresh needles of Masson pine, such as massonside A, massonside B, massonside C, massonianoside F, and 3,8-dimethyl-heracetin-7-O-*β*-D-glucopyranoside, and their biochemical activities need to be further investigated (Xiao *et al.* 2017, 2020).

Masson pine bark extract was shown to improve the viability and fertility potential of spermatozoa after cryo-resuscitation (Li *et al.* 2021). Both pinmassin D and abieta-8,11,13,15-tetraen-18-oic acid, obtained from the root bark of Masson pine, moderately inhibited phosphodiesterase type 4D (Fu *et al.* 2020). Studies have shown that dietary supplements with bark extract as the main ingredient can reduce oxidative stress in healthy elderly people (Ferguson *et al.* 2022). Additionally, the bark extract significantly inhibited the growth of lung cancer cells. Furthermore, bark extract inhibited the wound healing and migration of lung cancer cells and significantly inhibited the invasive ability of HeLa cells (Li *et al.* 2016; Mao *et al.* 2017). Proanthocyanidin from the pine bark of Masson pine significantly inhibited the growth of ovarian cancer cells and induced dose-dependent apoptosis (Liu *et al.* 2015). These results indicate that extracts related to Masson pine have great medicinal potential.

## RESEARCH AND APPLICATION OF RED PINE

Supercritical fluid extracts of red pine needles significantly inhibited the lipopolysaccharide-induced expression of monocyte macrophage (RAW264.7) macrophage proinflammatory mediators, inducible nitric oxide synthase, interleukin-6, and interleukin-1β in mouse leukemia cells (Venkatesan *et al.* 2017). Moreover, the 40% ethanolic extract of needles had stronger radical scavenging activity (Venkatesan *et al.* 2019a), and needles had a greater antioxidant capacity than did the bark (Venkatesan *et al.* 2019b, 2020). Protocatechuic and shikimic acids were isolated and identified from

fermented pine needle extract, which has fibrinolytic activity and aspirin-like inhibitory effects on fibrin formation (Park *et al.* 2016). Ethanolic pine needle extract modulates the stress response in mice, and the stress response in mice is significantly reduced after the administration of ethanolic pine needle extract (Lee *et al.* 2017a). Studies have shown that the water extract of red pine can be used as an herbal prescription or health functional food to prevent or treat osteoporotic bone diseases (Shim and Ma 2018).

Red pine needle extract promotes the expression of some mitogenic proteins during liver regeneration in rats (Lee *et al.* 2019). Mice treated with needle extract exhibited complete protection against high-risk human papillomavirus (Lee *et al.* 2021a). The addition of fermented needle extract to the diet increased the egg production percentage, egg mass, and feed intake throughout the experimental period. In addition, the addition of fermented needle extract to the diet improved egg shell color, yolk color, and shell breakage intensity and increased the antioxidant activity of egg yolk in laying hens (Kothari *et al.* 2021). Needle hexane extract inhibited the proliferation of gastric cancer cells (Kim *et al.* 2020d). A variety of peptides extracted from needles have good antibacterial activity, and the peptides show no detectable hemolytic activity or cytotoxicity at antimicrobial concentrations (Lee *et al.* 2021b). Researchers have also reported potential antiphotoaging properties of needle extracts on the skin (Huh *et al.* 2015), suggesting that needle extracts also have potential as skin care products.

PineXol is extracted from red pine bark and has beneficial effects, such as antioxidant, anti-inflammatory, and antiadipogenic activities, *in vitro*. The antiobesity effect of red pine bark extract (PBE) was also achieved by blocking hepatic lipogenesis via the inhibition of adipogenesis in adipocytes (Ahn *et al.* 2017a,b). Researchers have studied PBE and reported that it is rich in polyphenols, flavonoids, and proanthocyanidins, which exert neuroprotective effects against cerebral ischemic injury in gerbils and have antiamnesic effects (Kim *et al.* 2018a; Park *et al.* 2021c; Go *et al.* 2022). An increase in the phenolic content of bark extracts increases their antioxidant efficiency (Venkatesan *et al.* 2019).

The addition of bark extract to weaned piglet diets significantly increased the total antioxidant status, and the addition of PBE had no adverse effect on growth (Kim *et al.* 2022a), whereas the addition of the PBE-chitosan composite improved growth performance and reduced the diarrhea rate and diarrhea index in weaned piglets (Ro *et al.* 2023). These findings suggest the potential of PBE as a livestock food additive. PBE increased antioxidant indices (superoxide dismutase and catalase activities and malondialdehyde content) and decreased acetylcholinesterase activity in hippocampal lysates of scopolamine-induced amnesic Sprague–Dawley rats (Kim *et al.* 2022b). PBE also reduces inflammation (Lee *et al.* 2018a), lowers blood pressure (Kim *et al.* 2020a), and enhances the thermal stability of biobased antioxidant films (Han *et al.* 2018).

Researchers have synthesized silver nanoparticles from aqueous silver nitrate solutions *via* pine cone extract, a new material with moderate antibacterial activity that inhibits a variety of dermatological pathogens (Velmurugan *et al.* 2015). Red pine cone extracts also inhibited food poisoning microorganisms (Lee *et al.* 2018b). Bio-oil prepared by fast pyrolysis of pinewood chips was also found to have antibacterial activity against *Bacillus cereus* and *Listeria monocytogenes (*Patra *et al.* 2015b). Bio-oil was also found to have significant antioxidant capacity (Patra *et al.* 2015a). The results of cellular studies of extracellular vesicles isolated from the sap of *Pinus* cereus plants revealed that extracellular vesicles were cytotoxic to tumor cells but not to normal cells (Kim *et al.* 2020b). Methane emissions from cattle are significantly reduced when red pine extracts are added to their

diet (Lee *et al.* 2020). Among the various compounds from red pine needles, dehydroabietic and 4-*epi*-trans-communic acids have been isolated. Researchers confirmed that both compounds inhibited angiotensin-converting enzyme activity in human umbilical vein endothelial cells (Park *et al.* 2021d). In experiments in which a human keratinocyte cell line was used as the study material, it was confirmed that malonic acid isolated from red pine extracts retarded cellular aging (Park *et al.* 2021a). A substance was extracted from pine branches with ethanol, and the results of *in vitro* tests revealed that the extract inhibited cellular inflammation and reduced cellular damage (Kim *et al*. 2021).

## RESEARCH AND APPLICATION OF KOREAN PINE

Korean pine needle extract has antiobesity, cholesterol-lowering, hepatoprotective, and antidiabetic properties. Researchers have reported that an ethanolic extract of needles containing lambertianic acid has antiobesity and cholesterol-lowering effects (Lee *et al.* 2016b). The extract from needles is linked to a decrease in waist circumference and cholesterol levels while also increasing superoxide dismutase activity (Lee *et al.* 2016a). These findings suggest that needle extract ameliorates alcohol-induced fatty liver *via* the activation of phosphorylated liver kinase B1 (LKB1)–AMP-activated protein kinase and the modulation of proteins related to lipogenesis synthesis, cholesterol synthesis, and fatty acid oxidation (Hong *et al.* 2017; Park *et al.* 2021b). Through experiments in rats, the needle extract was also found to have anticancer, antiobesity, antidiabetic, and antihyperlipidemic biological activities (Lee *et al.* 2022a). Korean pine needles have fatigue resistance, as assessed by weight-loaded forced swimming and rotarod tests in mice (Lee *et al.* 2022b).

The polyphenols of Korean pine pinecones have been more intensively studied, and the phenolic compound of the ethanol eluent of polyphenols from the pinecone of Korean pine showed the strongest inhibitory effect on human colon cancer line cells (Yi *et al.* 2016; 2017a). Subsequently, it was found to significantly inhibit tumor growth (Yi *et al.* 2017b). Phytochemicals prepared from extracts of waste red pine cones also increased the contents of major functional fatty acids, conjugated linoleic acid, and eicosapentaenoic acid, but the ω6:ω3 fatty acid ratio was also reduced in the milk of Holstein cows (Kim *et al.* 2016). The addition of pinecone extract to the diet of hens increased egg production and the immune response during inflammation and improved the intestinal flora (Kim *et al.* 2018b). This study provides a basis for the utilization of pine cone extracts in animal husbandry and introduces the use of pinecones. Researchers have prepared novel chitosan microspheres encapsulated with pinecone polyphenols and pine polyphenol-loaded microspheres with protective effects against $^{60}$Co-γ radiation-induced damage in mice via the emulsion crosslinking technique (Shao *et al.* 2018). The biological activity of pinecone extracts has also been investigated, and the results revealed that pinecone extracts have anticancer activity (Lee *et al.* 2017b). These findings indicate the potential of pinecone extract as an anticancer drug.

Among the studies on pinecones, pine cone polysaccharides have been studied more frequently. The extraction of pinecone polysaccharides from pinecones *via* the hot water extraction method results in polysaccharide extraction rates of up to 10.25% (Zhao *et al.* 2019). Researchers have extracted various polysaccharide fractions. These polysaccharide fractions have significant scavenging effects on hydroxyl radicals, as well as a high reducing ability (Zhang *et al.* 2016, 2021a). Pine cone extracts have *in vitro* and

*in vivo* antibacterial effects (Kim *et al.* 2020c), and they inhibit cell proliferation through cell cycle arrest (Xin *et al.* 2021). The essential oil of a pinecone nanoemulsion was prepared from the essential oil of pinecones, and the prepared nanoemulsion has good stability and can effectively inhibit tumor growth, promote apoptosis, and inhibit the proliferation of cancer cells (Zhang *et al.* 2020).

Few studies have examined extracts of Korean pine bark, which have inhibitory effects on α-glucosidase activity and, at the same time, have the strongest inhibitory effect on nitric oxide production in activated macrophages (Shpatov *et al.* 2017). The extract of bark had a good radioprotective effect on rat splenocytes (Yun *et al.* 2017). Bark polyphenols have antioxidant capacity, inhibit cancer cell growth, induce cell cycle arrest and induce apoptosis (Huang *et al.* 2021). Polysaccharides obtained from purified pine nuts effectively protect cells from damage caused by $CCl_4$ (Qu *et al.* 2019). Pinecone scale polyphenols promote the proliferation of osteoblasts (Diao *et al.* 2018). Researchers have improved the extraction process of Korean pine nut-coated films and reported that Korean pine nut-coated films have a natural antioxidant capacity (Zhang *et al.* 2021b). A study of various substances extracted from Korean pine shoots revealed that the extracted compounds had an effect on C6 glioma cells *via* the induction of nerve growth factor secretion (Park *et al.* 2020). Researchers added Korean pine extract to the feed of pigs, which increased the average daily weight gain (Seok *et al.* 2021). The hot water extract of Korean pine bark has a low yield but a high content of phenolic compounds. However, its antioxidant activity is low (Ku *et al.* 2007). Korean pine waste extracts have great application value in both human health and the livestock industry, which helps promote the use of resources and the development of related industries.

## CONCLUSIONS AND FUTURE PERSPECTIVES

This paper has examined the medicinal potential of three pine species, with a particular emphasis on the polysaccharides found in Masson pine pollen, which have been extensively studied, particularly for their immunomodulatory effects, demonstrating significant application prospects. In contrast, research on needle and bark extracts is relatively limited; however, several bioactive compounds that exhibit anti-inflammatory and anticancer properties have nonetheless been identified. Research on red pine has focused primarily on needle and bark extracts, which have yielded notably positive results as livestock feed additives, although the efficacy of various extraction methods shows considerable variability. Similarly, investigations into Korean pine have focused predominantly on needle and bark extracts, with needle extracts primarily exhibiting antiobesity properties and bark extracts demonstrating anticancer effects, suggesting their potential utility as animal feed additives. Overall, Masson pine is distinct from the other two species because of its extensive distribution, substantial biostorage capacity, and greater application potential. In terms of medicinal capacity, all three pine species possess a significant array of active compounds, including polysaccharides, flavonoids, phenols, and bio-oils, with polysaccharides, flavonoids, and phenols constituting the principal components.

These pine species contain a diverse array of active compounds, including polysaccharides, flavonoids, phenols, and bio-oil. Polysaccharides, which are predominantly found in pine pollen, are known to enhance immune function and inhibit the proliferation of cancer cells, whereas flavonoids, which are concentrated in pine

needles and bark, exhibit antioxidant, antibacterial, antihypertensive, and antiobesity properties. Phenolic compounds display antioxidant, antiobesity, and anticancer activities, and bio-oils are recognized for their antibacterial and antioxidant effects. Although further research is necessary to comprehensively validate their therapeutic effects, existing studies underscore their significant medicinal potential. This paper also addresses the critical importance of employing appropriate extraction techniques to efficiently isolate these bioactive components while maintaining their biological activity. Research on *Pinus* not only provides a foundation for medical applications but also suggests that ongoing investigations will unveil new opportunities for drug development and advances in the nutraceutical industry.

## ACKNOWLEDGMENTS

The authors are grateful to the National Natural Science Foundation of (31960301), Projects of Guizhou Provincial Department of Education (QJJ[2024]324), and the Postdoctoral Research Foundation of China Project (2020M673583XB).

## REFERENCES CITED

Ahn, H., and Go, G. (2017a). "*Pinus densiflora* bark extract (PineXol) decreases adiposity in mice by down-regulation of hepatic de novo lipogenesis and adipogenesis in white adipose tissue," *Journal of Microbiology and Biotechnology* 27(4), 660-667. DOI: 10.4014/jmb.1612.12037

Ahn, H., Jeong, J., Moyo, K. M., Ryu, Y., Min, B., Yun, S. H., Kim, H. Y., Kim, W., and Go, G. (2017b). "Downregulation of hepatic de novo lipogenesis and adipogenesis in adipocytes by *Pinus densiflora* bark extract," *Journal of Microbiology and Biotechnology* 27(11), 1925-1931. DOI: 10.4014/jmb.1707.07030

Chu, H. L., Mao, H., Feng, W., Liu, J. W., and Geng, Y. (2013). "Effects of sulfated polysaccharide from Masson pine (*Pinus massoniana*) pollen on the proliferation and cell cycle of HepG2 cells," *International Journal of Biological Macromolecules* 55, 104-108. DOI: 10.1016/j.ijbiomac.2012.12.025

Chu, L., Yang, L., Lin, L., Wei, J., Wang, N., Xu, M., Qiao, G., and Zheng, G. (2019). "Chemical composition, antioxidant activities of polysaccharide from pine needle (*Pinus massoniana*) and hypolipidemic effect in high-fat diet-induced mice," *International Journal of Biological Macromolecules* 125, 445-452. DOI: 10.1016/j.ijbiomac.2018.12.082

Cui, G., Zhong, S., Yang, S., Zuo, X., Liang, M., Sun, J., Liu, J., and Zhu, R. (2013). "Effects of Taishan *Pinus massoniana* pollen polysaccharide on the subunit vaccine of *Proteus mirabilis* in birds," *International Journal of Biological Macromolecules* 56, 94-98. DOI: 10.1016/j.ijbiomac.2013.02.006

Cui, W., Huang, J., Niu, X., Shang, H., Sha, Z., Miao, Y., Wang, H., Chen, R., Wei, K., and Zhu, R. (2021). "Screening active fractions from *Pinus massoniana* pollen for inhibiting ALV-J replication and their structure activity relationship investigation," *Veterinary Microbiology* 252, article ID 108908. DOI: 10.1016/j.vetmic.2020.108908

Delgado-Alvarado, E. A., Almaraz-Abarca, N., Herrera-Arrieta, Y., Torres-Ricario, R., González-Valdez, L. S., Ávila-Reyes, J. A., and Naranjo-Jiménez, N. (2022).

"Phenolics content, antioxidant potential, α-glucosidase and α-amylase inhibitory activities of four foliar extracts from Pinus species," *Farmacia* 70(2), 214-221. DOI: 10.31925/farmacia.2022.2.5

Diao, Y., Chen, B., Wei, L., and Wang, Z. (2018). "Polyphenols (S3) isolated from cone scales of *Pinus koraiensis* alleviate decreased bone formation in rat under simulated microgravity," *Scientific Reports* 8(1), article ID 12719. DOI: 10.1038/s41598-018-30992-8

Dziedziński, M., Kobus-Cisowska, J., and Stachowiak, B. (2021). "*Pinus* species as prospective reserves of bioactive compounds with potential use in functional food—current state of knowledge," *Plants* 10(7), article 1306. DOI: 10.3390/plants10071306

Feng, Y. H., Yang, Z. Q., Wang, J., Luo, Q. F., and Li, H. G. (2014). "Development and characterization of SSR markers from *Pinus massoniana* and their transferability to *P. elliottii*, *P. caribaea*, and *P. yunnanensis*," *Genetics and Molecular Research* 13(1), 1508-1513. DOI: 10.4238/2014.March.12.2

Ferguson, J. J. A., Oldmeadow, C., Bentley, D., and Garg, M. L. (2022). "Antioxidant Effects of a polyphenol-rich dietary supplement incorporating *Pinus massoniana* bark extract in healthy older adults: A two-arm, parallel group, randomized placebo-controlled trial," *Antioxidants* 11(8), article 1560. DOI: 10.3390/antiox11081560

Fu, Y., Ding, X., Zhang, X., Shao, X., Zhao, J., Xu, Y., Luo, X., and Zhao, W. (2020). "Diterpenoids from the root bark of *Pinus massoniana* and evaluation of their phosphodiesterase type 4D inhibitory activity," *Journal of Natural Products* 83(4), 1229-1237. DOI: 10.1021/acs.jnatprod.9b01269

Go, M. J., Kim, J. M., Kang, J. Y., Park, S. K., Lee, C. J., Kim, M. J., Lee, H. R., Kim, T. Y., Joo, S. G., Kim, D. O., *et al.* (2022). "Korean red pine (*Pinus densiflora*) bark extract attenuates Aβ-induced cognitive impairment by regulating cholinergic dysfunction and neuroinflammation," *Journal of Microbiology and Biotechnology* 32(9), 1154-1167. DOI: 10.4014/jmb.2207.07015

Guo, F., Xue, C., Wu, C., Zhao, X., Qu, T., He, X., Guo, Z., and Zhu, R. (2014). "Immunoregulatory effects of Taishan *Pinus massoniana* pollen polysaccharide on chicks co-infected with avian leukosis virus and Bordetella avium early in *ovo*," *Research in Veterinary Science* 96(2), 260-266. DOI: 10.1016/j.rvsc.2013.11.010

Guo, Y., Huang, S., Zhao, L., Zhang, J., Ji, C., and Ma, Q. (2022). "Pine (*Pinus massoniana* Lamb.) needle extract supplementation improves performance, egg quality, serum parameters, and the gut microbiome in laying hens," *Frontiers in Nutrition* 9, article ID 810462. DOI: 10.3389/fnut.2022.810462

Han, Y., Yu, M., and Wang, L. (2018). "Bio-based films prepared with soybean by-products and pine (*Pinus densiflora*) bark extract," *Journal of Cleaner Production* 187, 1-8. DOI: 10.1016/j.jclepro.2018.03.115

Hong, S. H., Lee, H., Lee, H. J., Kim, B., Nam, M. H., Shim, B. S., and Kim, S. H. (2017). "Ethanol extract of *Pinus koraiensis* leaf ameliorates alcoholic fatty liver *via* the activation of LKB1-AMPK signaling *in vitro* and *in vivo*," *Phytotherapy Research* 31(5), 783-791. DOI: 10.1002/ptr.5801

Huang, L., Shen, M., Morris, G. A., and Xie, J. (2019). "Sulfated polysaccharides: immunomodulation and signaling mechanisms," *Trends in Food Science & Technology* 92, 1-11. DOI: 10.1016/j.tifs.2019.08.008

Huang, Y., Zhu, X., Zhu, Y., and Wang, Z. (2021). "*Pinus koraiensis* polyphenols: Structural identification, *in vitro* antioxidant activity, immune function and inhibition

of cancer cell proliferation," *Food Function* 12(9), 4176-4198. DOI: 10.1039/D0FO03347B

Huh, W. B., Kim, J. E., Kang, Y. J., Park, G., Lim, T., Kwon, J. Y., Song, D. S., Jeong, E. H., Lee, C. C., Son, J. E., *et al.* (2015). "Brown pine leaf extract and its active component trans-communic acid inhibit UVB-induced MMP-1 expression by targeting PI3K," *PloS ONE* 10(6), article ID e0128365. DOI: 10.1371/journal.pone.0128365

Jiang, Y., Han, W., Shen, T., and Wang, M. H. (2012). "Antioxidant activity and protection from DNA damage by water extract from pine (*Pinus densiflora*) bark," *Preventive Nutrition and Food Science* 17(2), 116-121. DOI: 10.3746/pnf.2012.17.2.116

Kim, K. Y., and Chung, H. J. (2000). "Flavor compounds of pine sprout tea and pine needle tea," *Journal of Agricultural and Food Chemistry* 48(4), 1269-1272. DOI: 10.1021/jf9900229

Kim, M. J., Jung, U. S., Jeon, S. W., Lee, J. S., Kim, W. S., Lee, S. B., Kim, Y. C., Kim, B. Y., Wang, T., and Lee, H. G. (2016). "Improvement of milk fatty acid composition for production of functional milk by dietary phytoncide oil extracted from discarded pine nut cones (*Pinus koraiensis*) in Holstein dairy cows," *Asian-australasian Journal of Animal Sciences* 29(12), 1734-1741. DOI: 10.5713/ajas.16.0281

Kim, J. W., Im, S., Jeong, H. R., Jung, Y. S., Lee, I., Kim, K. J., Park, S. K., and Kim, D. O. (2018a). "Neuroprotective effects of Korean red pine (*Pinus densiflora*) bark extract and its phenolics," *Journal of Microbiology and Biotechnology* 28(5), 679-687. DOI: 10.4014/jmb.1801.01053

Kim, M. J., Jung, U. S., Lee, J. S., Jeon, S. W., Kim, W. S., An, B. K., Kim, E. J., Wang, T. W., Kim, B. Y., Im, J. T., *et al.* (2018b). "Effects of dietary phytoncides extracted from Korean pine (*Pinus koraiensis*) cone on performance, egg quality, gut microflora, and immune response in laying hens," *Journal of Animal Physiology and Animal Nutrition* 102(5), 1220-1231. DOI: 10.1111/jpn.12934

Kim, K. J., Hwang, E. S., Kim, M. J., Park, J. H., and Kim, D. O. (2020a). "Antihypertensive effects of polyphenolic extract from Korean red pine (*Pinus densiflora* Sieb. et Zucc.) bark in spontaneously hypertensive rats," *Antioxidants* 9(4), article 333. DOI: 10.3390/antiox9040333

Kim, K., Yoo, H. J., Jung, J. H., Lee, R., Hyun, J. K., Park, J. H., Na, D., and Yeon, J. H. (2020b). "Cytotoxic effects of plant sap-derived extracellular vesicles on various tumor cell types," *Journal of Functional Biomaterials* 11(2), article 22. DOI: 10.3390/jfb11020022

Kim, S., Memon, A., Kim, B. Y., Jeon, H., Lee, W. K., and Kang, S. C. (2020c). "Gastroprotective effect of phytoncide extract from *Pinus koraiensis* pinecone in *Helicobacter pylori* infection," *Scientific Reports* 10(1), article 9547. DOI: 10.1038/s41598-020-66603-8

Kim, W., Park, C., Park, J., Cheong, H., and Kim, S. (2020d). "Pine needle hexane extract promote cell cycle arrest and premature senescence via p27KIP1 upregulation gastric cancer cells," *Food Science and Biotechnology* 29(6), 845-853. DOI: 10.1007/s10068-019-00730-5

Kim, S. A., Oh, J., Choi, S. R., Lee, C. H., Lee, B. H., Lee, M. N., Hossain, M. A., Kim, J., Lee, S., and Cho, J. Y. (2021). "Anti-gastritis and anti-lung injury effects of pine tree ethanol extract targeting both NF-κB and AP-1 pathways," *Molecules* 26(20), article 6275. DOI: 10.3390/molecules26206275

Kim, K. C., Sin, S. I., Ri, M. R., Jo, C. H., and Mun, S. H. (2022a). "Effect of dietary *Pinus densiflora* bark extract on activity and mRNA expression of antioxidant enzyme in weaning piglets," *Livestock Science* 260, article ID 104931. DOI: 10.1016/j.livsci.2022.104931

Kim, K. J., Hwang, E., Kim, M., Rha, C., Song, M. C., Maeng, S., Park, J., and Kim, D. O. (2022b). "Effects of phenolic-rich *Pinus densiflora* extract on learning, memory, and hippocampal long-term potentiation in scopolamine-induced amnesic rats," *Antioxidants* 11(12), article 2497. DOI: 10.3390/antiox11122497

Kothari, D., Oh, J. S., Kim, J. H., Lee, W. D., and Kim, S. K. (2021). "Effect of dietary supplementation of fermented pine needle extract on productive performance, egg quality, and serum lipid parameters in laying hens," *Animals* 11(5), article 1475. DOI: 10.3390/ani11051475

Ku, C. S., Jang, J. P., and Mun, S. P. (2007). "Exploitation of polyphenol-rich pine barks for potent antioxidant activity," *Journal of Wood Science* 53, 524-528. DOI: 10.1007/s10086-007-0896-6

Lee, G. S., Yang, H. G., Kim, J. H., Ahn, Y. M., Han, M. D., and Kim, W. J. (2019). "Pine (*Pinus densiflora*) needle extract could promote the expression of PCNA and Ki-67 after partial hepatectomy in rat," *Acta Cirurgica Brasileira* 34(6), article ID e201900606. DOI: 10.1590/s0102-865020190060000006

Lee, H., Kim, H., Choue, R., and Lim, H. (2016a). "Evaluation of the effects of *Pinus koraiensis* needle extracts on serum lipid and oxidative stress in adults with borderline dyslipidemia: A randomized, double-blind, and placebo-controlled clinical trial," *Evidence-Based Complementary and Alternative Medicine* 2016(1), 1-6. DOI: 10.1155/2016/9594251

Lee, M. S., Cho, S. M., Lee, M., Lee, E. O., Kim, S. H., and Lee, H. J. (2016b). "Ethanol extract of *Pinus koraiensis* leaves containing lambertianic acid exerts anti-obesity and hypolipidemic effects by activating adenosine monophosphate-activated protein kinase (AMPK)," *BMC Complementary Medicine and Therapies* 16, article 51. DOI: 10.1186/s12906-016-1031-2

Lee, J. S., Kim, H. G., Lee, H. W., Kim, W. Y., Ahn, Y. C., and Son, C. G. (2017a). "Pine needle extract prevents hippocampal memory impairment in acute restraint stress mouse model," *Journal of Ethnopharmacology* 207, 226-236. DOI: 10.1016/j.jep.2017.06.024

Lee, T. K., Roh, H. S., Yu, J. S., Baek, J., Lee, S., Ra, M., Kim, S. Y., Baek, K. H., and Kim, K. H. (2017b). "Pinecone of *Pinus koraiensis* inducing apoptosis in human lung cancer cells by activating caspase-3 and its chemical constituents," *Chemistry & Biodiversity* 14(4), article ID e1600412. DOI: 10.1002/cbdv.201600412

Lee, J. W., Wu, Q., Jang, Y. P., and Choung, S. Y. (2018a). "*Pinus densiflora* bark extract ameliorates 2,4-dinitrochlorobenzene-induced atopic dermatitis in NC/Nga mice by regulating Th1/Th2 balance and skin barrier function," *Phytotherapy Research* 32(6), 1135-1143. DOI: 10.1002/ptr.6061

Lee, S., Kim, W., Park, S. H., Kim, M., Kim, D., Park, J., Hwang, D. Y., and Lee, H. (2018b). "Biological properties of butanol extracts from green pine cone of *Pinus densiflora*," *Food Science and Biotechnology* 27, 1485-1492. DOI: 10.1007/s10068-018-0382-5

Lee, S. J., Lee, Y. J., Eom, J. S., Kim, H. S., Choi, Y. Y., Jo, S. U., Kang, S. N., Park, H. Y., Kim, D. H., and Lee, S. S. (2020). "Effects of the appropriate addition of antioxidants from *Pinus densiflora* and *Mentha canadensis* extracts on methane

emission and rumen fermentation," *Animals* 10(10), article 1888. DOI: 10.3390/ani10101888

Lee, H. J., Park, M., Choi, H., Nowakowska, A., Moon, C., Kwak, J. H., and Kim, Y. B. (2021a). "Pine needle extract applicable to topical treatment for the prevention of human papillomavirus infection," *Journal of Microbiology and Biotechnology* 31(1), 137-143. DOI: 10.4014/jmb.2010.10055

Lee, J., Kang, H. K., Cheong, H., and Park, Y. (2021b). "A novel antimicrobial peptide from pine needles of *Pinus densiflora* Sieb. et Zucc. against foodborne bacteria," *Frontiers in Microbiology* 12, article ID 662462. DOI: 10.3389/fmicb.2021.662462

Lee, M. H., Park, S., Xu, Y., Kim, J., Han, H., Lee, J. H., Paik, J. K., and Lee, H. J. (2022a). "Ethanol extract of *Pinus koraiensis* leaves mitigates high fructose-induced hepatic triglyceride accumulation and hypertriglyceridemia," *Applied Sciences* 12(13), article 6745. DOI: 10.3390/app12136745

Lee, S. M., Kim, Y. H., Kim, Y. R., Lee, B. R., Shin, S., Kim, J. Y., Jung, I. C., and Lee, M. Y. (2022b). "Anti-fatigue potential of *Pinus koraiensis* leaf extract in an acute exercise-treated mouse model," *Biomedicine & Pharmacotherapy* 153, article ID 113501. DOI: 10.1016/j.biopha.2022.113501

Li, Y. Y., Feng, J., Zhang, X. L., and Cui, Y. Y. (2015). "Pine bark extracts: Nutraceutical, pharmacological, and toxicological evaluation," *Journal of Pharmacology and Experimental Therapeutics* 353(1), 9-16. DOI: 10.1124/jpet.114.220277

Li, Y. Y., Feng, J., Zhang, X. L., Li, M. Q., and Cui, Y. Y. (2016). "Effects of *Pinus massoniana* bark extract on the invasion capability of HeLa cells," *Journal of Functional Foods* 24, 520-526. DOI: 10.1016/j.jff.2016.04.030

Li, X., Liu, X. T., Wei, J. T., Li, Y., Tigabu, M., and Zhao, X. Y. (2020). "Genetic improvement of *Pinus koraiensis* in China: Current situation and future prospects," *Forests* 11(2), article 148. DOI: 10.3390/f11020148

Li, Y., Zhang, T., Jia, Y., Yang, H., Liu, W., Pan, J., Wang, Y., Liang, S., and Li, K. (2021). "Supplementation of cryoprotectant with *Pinus massoniana* bark extract improves human sperm vitality and fertility potential," *Andrology* 9(2), 700-719. DOI: 10.1111/andr.12945

Liu, J., Bai, J., Jiang, G., Li, X., Wang, J., Wu, D., Owusu, L., Zhang, E., and Li, W. (2015). "Anti-tumor effect of *Pinus massoniana* bark proanthocyanidins on ovarian cancer through induction of cell apoptosis and inhibition of cell migration," *PloS ONE* 10(11), article ID e0142157. DOI: 10.1371/journal.pone.0142157

Mao, P., Zhang, E., Chen, Y., Liu, L., Rong, D., Liu, Q., and Li, W. (2017). "*Pinus massoniana* bark extract inhibits migration of the lung cancer A549 cell line," *Oncology Letters* 13(2), 1019-1023. DOI: 10.3892/ol.2016.5509

Niu, X., Shang, H., Chen, S., Chen, R., Huang, J., Miao, Y., Cui, W., Wang, H., Sha, Z., Peng, D., *et al.* (2021). "Effects of *Pinus massoniana* pollen polysaccharides on intestinal microenvironment and colitis in mice," *Food Function* 12(1), 252-266. DOI: 10.1039/D0FO02190C

Park, J., Lee, B., Choi, H., Kim, W., Kim, H. J., and Cheong, H. (2016). "Antithrombosis activity of protocatechuic and shikimic acids from functional plant *Pinus densiflora* Sieb. et Zucc needles," *Journal of Natural Medicines* 70, 492-501. DOI: 10.1007/s11418-015-0956-y

Park, C., Park, J., Kim, W. J., Kim, W., Cheong, H., and Kim, S. J. (2021a). "Malonic acid isolated from *Pinus densiflora* inhibits UVB-induced oxidative stress and inflammation in HaCaT keratinocytes," *Polymers* 13(5), article 816. DOI:

10.3390/polym13050816

Park, J. H., Bok, M. K., Kim, J., Maeng, S., Kim, S. H., Jung, J. H., Lee, H. J., and Lim, H. (2021b). "Effect of an extract of *Pinus koraiensis* leaves, *Lycium chinense* fruit, and *Saururus chinensis* (Lour.) Baill. leaves on liver function in excessive drinkers: A randomized, double-blind, placebo-controlled trial," *Journal of Functional Foods* 83, article ID 104535. DOI: 10.1016/j.jff.2021.104535

Park, J. H., Kim, J. D., Lee, T. K., Han, X., Sim, H., Kim, B., Lee, J. C., Ahn, J. H., Lee, C. H., Kim, D. W., *et al.* (2021c). "Neuroprotective and anti-inflammatory effects of *Pinus densiflora* bark extract in gerbil hippocampus following transient forebrain ischemia," *Molecules* 26(15), article 4592. DOI: 10.3390/molecules26154592

Park, J., Kim, W. J., Kim, W., Park, C., Choi, C. Y., Cho, J. H., Kim, S. J., and Cheong, H. (2021d). "Antihypertensive effects of dehydroabietic and 4-epi-trans-communic acid isolated from *Pinus densiflora*," *Journal of Medicinal Food* 24(1), 50-58. DOI: 10.1089/jmf.2020.4797

Park, K. J., Khan, Z., Subedi, L., Kim, S. Y., and Lee, K. R. (2020). "Antineurodegenerative labdane diterpenoid glycosides from the twigs of *Pinus koraiensis*," *Journal of Natural Products* 83(6), 1794-1803. DOI: 10.1021/acs.jnatprod.9b01158

Park, Y., Kim, C. K., Jeong, H., Lee, H. M., Kim, K. M., Lee, I. H., Kim, M. J., Kwon, G. B., Yoon, N., and Lee, N. (2024). "Evaluation of the basic properties for the Korean major domestic wood species: I. Korean red pine (*Pinus densiflora*) in Pyeongchang-gun, Gangwon-do," *Journal of the Korean Wood Science and Technology* 52(1), 87-100. DOI: 10.5658/WOOD.2024.52.1.87

Patra, J. K., Hwang, H., Choi, J. W., and Baek, K. H. (2015a). "Bactericidal mechanism of bio-oil obtained from fast pyrolysis of *Pinus densiflora* against two foodborne pathogens, *Bacillus cereus* and *Listeria monocytogenes*," *Foodborne Pathogens and Disease* 12(6), 529-535. DOI: 10.1089/fpd.2014.1914

Patra, J., Kim, S., Hwang, H., Choi, J., and Baek, K. H. (2015b). "Volatile compounds and antioxidant capacity of the bio-oil obtained by pyrolysis of Japanese red pine (*Pinus densiflora* Siebold and Zucc.)," *Molecules* 20(3), 3986-4006. DOI: 10.3390/molecules20033986

Peng, J., Yuan, Y., Du, Y., Wu, J., Li, B., Li, J., Yu, J., Hu, L., Shen, S., Wang, J., *et al.* (2016). "Potentiation of Taishan *Pinus massoniana* pollen polysaccharide on the immune response and protection elicited by a highly pathogenic porcine reproductive and respiratory syndrome virus glycoprotein 5 subunit in pigs," *Molecular and Cellular Probes* 30(2), 83-92. DOI: 10.1016/j.mcp.2016.01.008

Peng, Q., Ormondroyd, G., Spear, M., and Chang, W. S. (2022). "The effect of the changes in chemical composition due to thermal treatment on the mechanical properties of *Pinus densiflora*," *Construction and Building Materials* 358, article 129303. DOI: 10.1016/j.conbuildmat.2022.129303

Qu, H., Gao, X., Zhao, H. T., Wang, Z. Y., and Yi, J. J. (2019). "Structural characterization and *in vitro* hepatoprotective activity of polysaccharide from pine nut (*Pinus koraiensis* Sieb. et Zucc.)," *Carbohydrate Polymers* 223, article ID 115056. DOI: 10.1016/j.carbpol.2019.115056

Ro, K. S., Jong, S. I., Sin, J. I., Ryu, U. R., Jong, J., Kim, J. H., and Kim, K. C. (2023). "Supplementation of *Pinus densiflora* bark extract-chitosan composite improves growth performance, nutrient digestibility, intestinal health in weaned piglets," *Livestock Science* 267, article ID 105148. DOI: 10.1016/j.livsci.2022.105148

Santos, A. M., Carvalho, S. G., Meneguin, A. B., Sábio, R. M., Gremião, M. P. D., and Chorilli, M. (2021). "Oral delivery of micro/nanoparticulate systems based on natural polysaccharides for intestinal diseases therapy: Challenges, advances and future perspectives," *Journal of Controlled Release* 334, 353-366. DOI: 10.1016/j.jconrel.2021.04.026

Seok, W. J., Hoque, M. R., Serpunja, S., and Kim, I. H. (2021). "Performance of phytoncide (*Pinus koraiensis* extract) as an alternative to zinc oxide supplementation in weaning pig diet," *Canadian Journal of Animal Science* 101(4), 745-752. DOI: 10.1139/cjas-2021-0008

Sha, Z., Shang, H., Miao, Y., Huang, J., Niu, X., Chen, R., Peng, D., Wei, K., and Zhu, R. (2021). "Polysaccharides from *Pinus massoniana* pollen improve intestinal mucosal immunity in chickens," *Poultry Science* 100(2), 507-516. DOI: 10.1016/j.psj.2020.09.015

Shang, H., Niu, X., Cui, W., Sha, Z., Wang, C., Huang, T., Guo, P., Wang, X., Gao, P., Wang, X., *et al.* (2022). "Anti-tumor activity of polysaccharides extracted from *Pinus massoniana* pollen in colorectal cancer—*in vitro* and *in vivo* studies," *Food & Function* 13(11), 6350-6361. DOI: 10.1039/D1FO03908C

Shang, H., Sha, Z., Wang, H., Miao, Y., Niu, X., Chen, R., Huang, J., Huang, H., Wei, K., and Zhu, R. (2020). "Taishan *Pinus massoniana* pollen polysaccharide inhibits H9N2 subtype influenza virus infection both *in vitro* and *in vivo*," *Veterinary Microbiology* 248, article ID 108803. DOI: 10.1016/j.vetmic.2020.108803

Shao, S., Yi, J., Regenstein, J., Cheng, C., Zhang, H., Zhao, H., and Wang, Z. (2018). "Protective effects on 60Co-γ radiation damage of pine cone polyphenols from *Pinus koraiensis*-loaded chitosan microspheres *in vivo*," *Molecules* 23(6), article 1392. DOI: 10.3390/molecules23061392

Shim, K. S., and Ma, J. Y. (2018). "Pine needles attenuate receptor activator for nuclear factor-B ligand (RANKL)-induced trabecular bone loss by inhibiting osteoclast differentiation," *Integrative Medicine Research* 7(4), 374-380. DOI: 10.1016/j.imr.2018.06.006

Shitara, T., Fukui, S., Matsui, T., Momohara, A., Tsuyama, I., Ohashi, H., Tanaka, N., and Kamijo, T. (2021). "Climate change impacts on migration of *Pinus koraiensis* during the Quaternary using species distribution models," *Plant Ecology* 222(7), 843-859. DOI: 10.1007/s11258-021-01147-z

Shpatov, A. V., Popov, S. A., Salnikova, O. I., Kukina, T. P., Shmidt, E. N., and Um, B. H. (2017). "Composition and bioactivity of lipophilic metabolites from needles and twigs of Korean and Siberian pines (*Pinus koraiensis* Siebold & Zucc. and *Pinus sibirica* Du Tour)," *Chemistry & Biodiversity* 14(2), article ID e1600203. DOI: 10.1002/cbdv.201600203

Sivanesan, I., Muthu, M., Gopal, J., and Oh, J. W. (2022). "Mushroom polysaccharide-assisted anticarcinogenic mycotherapy: Reviewing its clinical trials," *Molecules* 27(13), article 4090. DOI: 10.3390/molecules27134090

Suri, I. F., Purusatama, B. D., Kim, J. H., Yang, G. U., Prasetia, D., Kwon, G. J., Hidayat, W., Lee, S. H., Febrianto, F. and Kim, N. H. (2022). "Comparison of physical and mechanical properties of Paulownia tomentosa and *Pinus koraiensis* wood heat-treated in oil and air," *European Journal of Wood and Wood Products* 80(6), 1389-1399. DOI:10.1007/s00107-022-01840-4

Velmurugan, P., Park, J. H., Lee, S. S., Jang, J. S., Lee, K. J., Han, S. S., Lee, H., Cho, M., and Oh, B. T. (2015). "Synthesis and characterization of nanosilver with

antibacterial properties using *Pinus densiflora* young cone extract," *Journal of Photochemistry and Photobiology B: Biology* 147, 63-68. DOI: 10.1016/j.jphotobiol.2015.03.008

Venkatesan, T., Choi, Y. W., and Kim, Y. K. (2019a). "Effect of an extraction solvent on the antioxidant quality of *Pinus densiflora* needle extract," *Journal of Pharmaceutical Analysis* 9(3), 193-200. DOI: 10.1016/j.jpha.2019.03.005

Venkatesan, T., Choi, Y. W., and Kim, Y. K. (2019b). "Impact of different extraction solvents on phenolic content and antioxidant potential of *Pinus densiflora* bark extract," *Biomedical Research International* 2019(1), 1-14. DOI: 10.1155/2019/3520675

Venkatesan, T., Choi, Y. W., and Kim, Y. K. (2020). "Comparative evaluation of the impact of extraction solvent and time on the yield and antioxidant potential of *Pinus densiflora* needle and bark extracts," *Wood Science and Technology* 54, 587-598. DOI: 10.1007/s00226-020-01173-6

Venkatesan, T., Choi, Y. W., Lee, J., and Kim, Y. K. (2017). "*Pinus densiflora* needle supercritical fluid extract suppresses the expression of pro-inflammatory mediators iNOS, IL-6 and IL-1β, and activation of inflammatory STAT1 and STAT3 signaling proteins in bacterial lipopolysaccharide-challenged murine macrophages," *DARU Journal of Pharmaceutical Sciences* 25, 1-10. DOI: 10.1186/s40199-017-0184-y

Wang, D., Liu, Y., and Zhao, W. (2021). "The Adjuvant effects on vaccine and the immunomodulatory mechanisms of polysaccharides from traditional Chinese medicine," *Frontiers in Molecular Biosciences* 8, article ID 655570. DOI: 10.3389/fmolb.2021.655570

Wang, X., Ren, S., Zhang, D., Jiang, H., and Gu, Y. (2018a). "Inhibitory effect of *Pinus massoniana* needle extract on corrosion of Q235 steel in hydrochloric acid medium," *International Journal of Electrochemical Science* 13(10), 9888-9904. DOI: 10.20964/2018.10.31

Wang, X., Chen, X., Xie, X., Wu, Y., Zhao, L., Li, Y., and Wang, S. (2018b). "Effects of thermal modification on the physical, chemical and micromechanical properties of Masson pine wood (*Pinus massoniana* Lamb.)," *Holzforschung* 72(12), 1063-1070.DOI: 10.1515/hf-2017-0205

Wang, Q., Miao, Y., Xu, Y., Meng, X., Cui, W., Wang, Y., Zhu, L., Sha, Z., Wei, K., and Zhu, R. (2019). "Taishan *Pinus massoniana* pollen polysaccharide inhibits the replication of acute tumorigenic ALV-J and its associated tumor growth," *Veterinary Microbiology* 236, article ID 108376. DOI: 10.1016/j.vetmic.2019.07.028

Wei, K., Sun, Z., Yan, Z., Tan, Y., Wang, H., Zhu, X., Wang, X., Sheng, P., and Zhu, R. (2011). "Effects of Taishan *Pinus massoniana* pollen polysaccharide on immune response of rabbit haemorrhagic disease tissue inactivated vaccine and on production performance of Rex rabbits," *Vaccine* 29(14), 2530-2536. DOI: 10.1016/j.vaccine.2011.01.068

Weng, Y. H., Liu, K. J., Chen, Y. B., Li, Y., Wang, J., and Meng, Q. F. (2020). "Variation in cone and seed traits in a clonal seed orchard of red pine (*Pinus koraiensis* Sieb. et Zucc.)," *Scandinavian Journal of Forest Research* 35(1-2), 1-9. DOI: 10.1080/02827581.2020.1725620

Xiao, Y. C., Ye, L., Zhao, M. X., Yan, C., Wang, W., Huang, Q. S., Liang, K., Meng, B. H., and Ke, X. (2017). "Two new sesquiterpene glycosides isolated from the fresh needles of *Pinus massoniana* Lamb," *Natural Product Research* 31(3), 341-346. DOI: 10.1080/14786419.2016.1239089

Xiao, Y. C., Shi, Z. F., Yan, C. Q., Tang, Q. X., Zhao, M. X., Liu, L. T., Huang, Q. S., Ye, L., Xu, K., and Xiao, K. (2020). "Isolation, X-ray crystal structure of the new diterpene and identification of others lignans and flavonoids from the fresh needles of *Pinus massoniana*," *Journal of Asian Natural Products Research* 22(8), 707-715. DOI: 10.1080/10286020.2019.1642331

Xin, C., Zhang, Y., Zhao, M., Wang, Z., and Cheng, C. (2021). "Polyditerpene acid from *Pinus koraiensis* pinecones inhibits the progression of hepatocarcinoma," *Arabian Journal of Chemistry* 14(4), article ID 103069. DOI: 10.1016/j.arabjc.2021.103069

Yang, S., Wei, K., Jia, F., Zhao, X., Cui, G., Guo, F., and Zhu, R. (2015). "Characterization and biological activity of Taishan *Pinus massoniana* pollen polysaccharide *in vitro*," *PloS ONE* 10(3), article ID e0115638. DOI: 10.1371/journal.pone.0115638

Yang, S., Zhao, Z., Zhang, A., Jia, F., Song, M., Huang, Z., Fu, J., Li, G., and Lin, S. (2018). "Proteomics analysis of chicken peripheral blood lymphocyte in Taishan *Pinus massoniana* pollen polysaccharide regulation," *PloS ONE* 13(11), article ID e0208314. DOI: 10.1371/journal.pone.0208314

Yang, L., Zhao, Z., Wang, G., Ruan, X., Wu, Q., Luo, C., Wu, Z., Wei, F., Zhao, Y., and Wang, Q. (2021). "Supercritical extraction and antioxidant activity of major ingredients in *Pueraria lobata* root, *Pinus massoniana* needle, *Citrus reticulata* peel and their mixture," *Journal of $CO_2$ Utilization* 48, article ID 101518. DOI: 10.1016/j.jcou.2021.101518

Yi, J., Cheng, C., Li, X., Zhao, H., Qu, H., Wang, Z., and Wang, L. (2017a). "Protective mechanisms of purified polyphenols from pinecones of *Pinus koraiensis* on spleen tissues in tumor-bearing S180 mice *in vivo*," *Food Function* 8(1), 151-166. DOI: 10.1039/C6FO01235C

Yi, J., Qu, H., Wu, Y., Wang, Z., and Wang, L. (2017b). "Study on antitumor, antioxidant and immunoregulatory activities of the purified polyphenols from pinecone of *Pinus koraiensis* on tumor-bearing S180 mice *in vivo*," *International Journal of Biological Macromolecules* 94, 735-744. DOI: 10.1016/j.ijbiomac.2016.10.071

Yi, J., Wang, Z., Bai, H., Li, L., Zhao, H., Cheng, C., Zhang, H., and Li, J. (2016). "Polyphenols from pinecones of *Pinus koraiensis* induce apoptosis in colon cancer cells through the activation of caspase *in vitro*," *RSC Advances* 6(7), 5278-5287. DOI: 10.1039/c5ra24913a

Yu, Y., Shen, M., Song, Q., and Xie, J. (2018). "Biological activities and pharmaceutical applications of polysaccharide from natural resources: A review," *Carbohydrate Polymers* 183, 91-101. DOI: 10.1016/j.carbpol.2017.12.009

Yun, K., Bai, J. H., and Wang, Z. (2017). "*In vitro* bioassay-guided isolation of radioprotective fractions from extracts of *Pinus koraiensis* bark," *Pharmacognosy Magazine* 13(2), 712-718. DOI: 10.1002/cbdv.201600203

Zhang, J. W., D'Rozario, A., Adams, J. M., Liang, X. Q., Jacques, F. M. B., Su, T., and Zhou, Z. K. (2015). "The occurrence of *Pinus massoniana* Lambert (Pinaceae) from the upper Miocene of Yunnan, SW China and its implications for paleogeography and paleoclimate," *Review of Palaeobotany and Palynology* 215, 57-67. DOI: 10.1016/j.revpalbo.2014.11.006

Zhang, H., Zhao, H., Zhou, X., Yang, X., Shen, S., Wang, J., Wang, Z., and Geng, L. (2016). "Isolation and characterization of antioxidant polysaccharides (PKCP-D 70 -2-a and PKCP-D 70 -2-b) from the *Pinus koraiensis* pinecone," *RSC Advances* 6(112), 110706-110721. DOI: 10.1039/c6ra23205a

Zhang, Y., Xin, C., Cheng, C., and Wang, Z. (2020). "Antitumor activity of nanoemulsion based on essential oil of *Pinus koraiensis* pinecones in MGC-803 tumor-bearing nude mice," *Arabian Journal of Chemistry* 13(11), 8226-8238. DOI: 10.1016/j.arabjc.2020.09.058

Zhang, H., Zou, P., Zhao, H., Qiu, J., Regenstein, J. M., and Yang, X. (2021a). "Isolation, purification, structure and antioxidant activity of polysaccharide from pinecones of *Pinus koraiensis*," *Carbohydrate Polymers* 251, article ID 117078. DOI: 10.1016/j.carbpol.2020.117078

Zhang, M., Ma, W., Wang, C., Yang, X., Lou, Y., Xia, X., and Xu, H. (2021b). "Optimization of enzyme-assisted extraction and purification of flavonoids from *Pinus koraiensis* nut-coated film and antioxidant activity evaluation," *Molecules* 26(7), article 1950. DOI: 10.3390/molecules26071950

Zhang, Q., Pei, X., Lu, X., Zhao, C., Dong, G., Shi, W., Wang, L., Li, Y., Zhao, X., and Tigabu, M. (2022). "Variations in growth traits and wood physicochemical properties among *Pinus koraiensis* families in Northeast China," *Journal of Forestry Research* 33(5), 1637-1648. DOI: 10.1007/s11676-022-01455-8

Zhao, Q., Qin, J., Wang, H., Wang, J., and Zhang, X. (2019). "Effects of different extraction methods on the properties of pine cone polysaccharides from *Pinus koraiensis*," *BioResources* 14(4), 9945-9956. DOI: 10.15376/biores.14.4.9945-9956

Zhao, X., Liang, M., Yang, P., Guo, F., Pan, D., Huang, X., Li, Y., Wu, C., Qu, T., and Zhu, R. (2013). "Taishan *Pinus massoniana* pollen polysaccharides promote immune responses of recombinant *Bordetella avium* ompA in BALB/c mice," *International Immunopharmacology* 17(3), 793-798. DOI: 10.1016/j.intimp.2013.09.008

Zhou, C., Yin, S., Yu, Z., Feng, Y., Wei, K., Ma, W., Ge, L., Yan, Z., and Zhu, R. (2018). "Preliminary characterization, antioxidant and hepatoprotective activities of polysaccharides from Taishan *Pinus massoniana* pollen," *Molecules* 23(2), article 281. DOI: 10.3390/molecules23020281

Zhu, F., Liu, X., Sun, Z., Yu, C., Liu, L., Yang, S., Li, B., Wei, K., and Zhu, R. (2016). "Immune-enhancing effects of Taishan *Pinus massoniana* pollen polysaccharides on DNA vaccine expressing Bordetella avium ompA," *Frontiers in Microbiology* 7, article 66. DOI: 10.3389/fmicb.2016.00066

Article submitted: October 11, 2024; Peer review completed: December 8, 2024; Revised version received and accepted: December 27, 2024; Published: January 10, 2025.
DOI: 10.15376/biores.20.1.Li

## APPENDIX

**Table S1.** Three *Pinus* Species Extract Sources, Compounds, Extraction Methods, Experimental Materials, Effect, Products or Possible Uses

| Compounds | Species | Studied Organ | Extract Method | Experimental Materials | Effect | Products or Possible Uses | Reference |
|---|---|---|---|---|---|---|---|
| – | Red pine | Needle | Supercritical fluid extraction | Mouse leukemia cells of monocyte-macrophage | Inhibition of the expression of pro-inflammatory mediators | Immunomodulatory drugs | Venkatesan *et al.* 2017 |
| – | Red pine | Needle | Ethanol extraction | HepG2 cells | Significant amelioration of nuclear damage and loss of cell viability | Antioxidant | Venkatesan *et al.* 2019a |
| – | Red pine | Needle | Ethanol extraction | Mice | Functions to modulate memory impairment | Anti-forgetting drugs | Lee *et al.* 2017a |
| – | Red pine | Needle | Water extraction | Mice | Inhibition of osteoclastogenesis | Traditional medicine and health functional food | Shim *et al.* 2018 |
| – | Red pine | Needle | Solvent extraction | Human papillomavirus | Human papillomavirus growth inhibited | Antiviral drugs | Lee *et al.* 2021a |
| – | Red pine | Needle | Solvent extraction | Gastric cancer cells | Inhibit gastric cancer cell proliferation | Anti-gastric cancer drugs | Kim *et al.* 2020d |
| – | Red pine | Needle | Ethanol extraction | HaCaT cells | Protective effect against skin aging | Anti-wrinkling agents and cosmetic ingredients | Huh *et al.* 2015 |

| Compounds | Species | Studied Organ | Extract Method | Experimental Materials | Effect | Products or Possible Uses | Reference |
|---|---|---|---|---|---|---|---|
| – | Red pine | Bark | Ethanol extraction | Pig | Increased antioxidant enzyme activity and gene expression | Antioxidant | Kim *et al.* 2022a |
| – | Red pine | Bark | Solvent extraction | Pig | Improve growth performance and intestinal function | Health functional food | Ro *et al.* 2023 |
| – | Red pine | Pinecone | Ethanol extraction | *Brevibacterium linens* | Demonstrates moderate antibacterial activity against bacteria causing skin infections | Anti-bacterial drugs | Velmurugan *et al*. 2015 |
| – | Korean pine | Needle | Solvent extraction | Human | Effectively improves superoxide dismutase levels | Antioxidant | Lee *et al.* 2016a |
| – | Korean pine | Needle | Ethanol extraction | HepG2 cells, rats, mice | Alcohol-induced fatty liver improved | Health functional food | Hong *et al.* 2017 |
| – | Korean pine | Needle | Ethanol extraction | Human | They show the potential to improve liver function in excessive drinkers | Health functional food | Park *et al.* 2021c |
| – | Korean pine | Needle | Ethanol extraction | Rat and HepG2 cells | They relieve hypertriglyceridemia and hepatic triglyceride accumulation | Anti-hyperlipidemic drugs, anti-obesity drugs and anti-diabetic properties drugs | Lee *et al.* 2022a |
| Anthocyanin series B | Masson pine | Bark | – | A549 cell line | Lung cancer cell growth is inhibited | Anti-lung cancer drugs | Mao *et al.* 2017 |

| Compounds | Species | Studied Organ | Extract Method | Experimental Materials | Effect | Products or Possible Uses | Reference |
|---|---|---|---|---|---|---|---|
| Arginine, shikimic acid, and caryophyllene | Masson pine | Needle | Soaking extraction | Q235 steel | The extract is an efficient corrosion inhibitor with 95% corrosion inhibition efficiency | Efficient corrosion inhibitor | Wang *et al.* 2018 |
| Bio-oil | Red pine | – | Fast pyrolysis | Bacillus cereus and Listeria monocytogenes | Suppression of the viability of pathogenic bacteria | Anti-bacterial drugs | Patra *et al.* 2015a |
| Bio-oil | Red pine | Sawdust | Fast pyrolysis | – | Significant antioxidant potential | Antioxidant | Patra *et al.* 2015b |
| Bornyl p-coumarate, et al | Korean pine | Needle | Solvent extraction | Activated macrophages | Inhibition of α-glucosidase activity and nitric oxide production in activated macrophages | Immunomodulatory drugs | Shpatov *et al.* 2017 |
| Catechin, gallic acid | Korean pine | Needle | Ethanol extraction | Mice | Improves motor performance and reduces fatigue | Health functional food | Lee *et al.* 2022b |
| Dehydroabietic acid and 4-epi-trans-communic acid | Red pine | – | – | Human umbilical vein endothelial cells, and rat | Inhibited angiotensin-converting enzyme. Significantly reduced vasoconstriction pressure in rats | Antihypertensive drugs | Park *et al.* 2021d |
| Dehydroabietic acid, et al | Korean pine | Pinecone | Water extraction | Human lung cancer cell lines | Inhibition of cancer cell growth and reproduction | Anti-lung cancer drugs | Lee *et al.* 2017b |

| Compounds | Species | Studied Organ | Extract Method | Experimental Materials | Effect | Products or Possible Uses | Reference |
|---|---|---|---|---|---|---|---|
| Diterpenoid | Masson pine | Root bark | – | – | Moderate inhibition of phosphodiesterase type 4D | PDE4 inhibitors | Fu *et al.* 2020 |
| Essential oil | Korean pine | Pine nut cone | Water-vapor | Cow | Increased the content of major functional fatty acids and reduced the proportion of fatty acids in milk | Animal feed additives | Kim *et al.* 2016 |
| Essential oil | Korean pine | Pinecone | Steam distillation | Hen | Improves egg production, immune response during inflammation, and intestinal flora of hens | Animal feed additives | Kim *et al.* 2018b |
| Essential oil | Korean pine | Pinecone | Distillation | Helicobacter pylori | Helicobacter pylori is killed in large numbers | Anti-bacterial drugs | Kim *et al.* 2020c |
| Essential oil | Korean pine | Pinecone | Hydrodistillation | Mice | Inhibit the proliferation of cells | Anti-cancer drugs | Zhang *et al.* 2020 |
| Flavonoid | Korean pine | Nut-coated film | Enzyme-assisted solvent | – | Antioxidant capacity | Antioxidant | Zhang *et al.* 2021b |
| Labdane-type diterpenoid glycoside | Korean pine | Twig | Solvent extraction | C6 glioma cells and BV2 Cells | Both extracts have a stimulating effect on nerve growth factor secretion | Neuroprotective drugs | Park *et al.* 2020 |

| Compounds | Species | Studied Organ | Extract Method | Experimental Materials | Effect | Products or Possible Uses | Reference |
|---|---|---|---|---|---|---|---|
| Malonic acid | Red pine | – | Solvent extraction | Human keratinocyte cell line | Inhibits skin inflammation and induces collagen biosynthesis | Anti-inflammatory drugs | Park *et al.* 2021a |
| Phenolic | Masson pine | Needle | Supercritical $CO_2$ fluid replacing | – | Antioxidant capacity | Antioxidant | Yang *et al.* 2021 |
| Phenolic | Red pine | Bark | Solvent extraction | – | High antioxidant capacity | Antioxidant | Venkatesan *et al.* 2019b |
| Phenolic | Red pine | Bark | – | PC-12 cells | They are an effective potent neuroprotective | Neuroprotective drugs | Kim *et al.* 2018a |
| Phenolic and flavonoid | Korean pine | Bark | Solvent extraction | Rat | Restoration of superoxide dismutase, catalase activity, reduction of DNA damage | Radioprotective drugs | Yun *et al.* 2017 |
| Phenolic | Red pine | Bark | Water extraction | Mice | They have an anti-forgetting effect | Anti-forgetting drugs | Go *et al.* 2022 |
| Phenolic | Red pine | Bark | Hot water extraction | Rat | Can be used as a cognitive enhancer | Cognitive enhancer | Kim *et al.* 2022b |
| Phenolic | Red pine | Bark | – | Soy protein isolate | Improved thermal stability of the film | Antioxidant | Han *et al*. 2018 |

| Compounds | Species | Studied Organ | Extract Method | Experimental Materials | Effect | Products or Possible Uses | Reference |
|---|---|---|---|---|---|---|---|
| Phenolic and flavonoid | Red pine | Bark | – | Mice | Inhibition of hepatic lipid synthesis and lipogenesis in white adipose tissue | Anti-hyperlipidemic drugs, anti-obesity drugs | Ahn *et al.* 2017a |
| Phenolic and flavonoid | Red pine | Bark | Water extraction | HepG2 cells, 3T3-L1 cells | Inhibits lipogenesis in adipocytes | Anti-hyperlipidemic drugs, anti-obesity drugs | Ahn *et al.* 2017b |
| Phenolic and flavonoid | Red pine | Pinecone | Butanol extraction | Hyaluronidase, Bacillus cereus, Staphylococcus aureus | Exhibits inhibitory activity against food poisoning microorganisms | Anti-bacterial drugs | Lee *et al.* 2018b |
| Phenolic, flavonoid and alkaloids | Masson pine | Needle | – | Hen | Improvement of intestinal microbiology and performance in laying hens | Animal feed additives | Guo *et al.* 2022 |
| Polyditerpene acid | Korean pine | Pinecone | Solvent extraction | HepG2 cells | Promotes apoptotic cell death | Anti-cancer drugs | Xin *et al.* 2021 |
| Polyphenol | Red pine | Bark | Ethanol extraction | Mice | Reducing the symptoms of atopic dermatitis | Anti-inflammatory drugs | Lee *et al.* 2018a |
| Polyphenol | Korean pine | Pinecone | Ethanol extraction | LOVO cells | The growth of LOVO cells is inhibited | Anti-cancer drugs | Yi *et al.* 2016 |
| Polyphenol | Korean pine | Pinecone | Ethanol extraction | Mice | Tumor cells are suppressed | Anti-cancer drugs | Yi *et al.* 2017b |

| Compounds | Species | Studied Organ | Extract Method | Experimental Materials | Effect | Products or Possible Uses | Reference |
|---|---|---|---|---|---|---|---|
| Polyphenol | Korean pine | Pinecone | Ethanol extraction | Mice | Significantly higher tumor suppression rate | Anti-cancer drugs | Yi *et al*. 2017a |
| Polyphenol | Korean pine | Pinecone | – | Mice | Protective effect on radiation damage in mice | Radioprotective drugs | Shao *et al.* 2018 |
| Polyphenol | Korean pine | Bark | Ethanol extraction | Human cancer cells, mice | Polyphenols inhibit cancer cell growth, cell cycle arrest, and induction of apoptosis | Anti-cancer drugs | Huang *et al.* 2021 |
| Polyphenol, flavonoid, proanthocyanidin | Red pine | Bark | Water extraction | Gerbils | They have a neuroprotective effect | Neuroprotective drugs | Park *et al.* 2021c |
| Polyphenol | Red pine | Bark | Water extraction | Rat | It has an antihypertensive effect and has an antioxidant effect. | Antioxidant | Kim *et al.* 2022a |
| Polyphenol | Korean pine | Pinecone scales | Ethanol extraction | Rat | They promote the proliferation of osteoblasts | Health functional food | Diao *et al.* 2018 |
| Polyphenol and flavonoid | Red pine | Needle | – | Hen | Improving egg production performance | Animal feed additives | Kothari *et al.* 2021 |
| Polysaccharide | Masson pine | Pollen | Ethanol precipitation | Rex rabbit | Enhanced antibody levels and average daily feed intake in rabbits. | Immunomodulatory drugs | Wei *et al.* 2011 |

| Compounds | Species | Studied Organ | Extract Method | Experimental Materials | Effect | Products or Possible Uses | Reference |
|---|---|---|---|---|---|---|---|
| Polysaccharide | Masson pine | Pollen | Hot water extraction | HepG2 cells | Inhibition of proliferation of liver cancer cells | Anti-cancer drugs | Chu *et al.* 2013 |
| Polysaccharide | Masson pine | Pollen | Water extraction and ethanol precipitation | Mice | Effectively inhibited colorectal cancer cell proliferation | Anti-cancer drugs | Shang *et al.* 2022 |
| Polysaccharide | Masson pine | Pollen | – | Chicks | Polysaccharides enhance the immune effect of vaccines | Immunomodulatory drugs | Cui *et al.* 2013 |
| Polysaccharide | Masson pine | Pollen | Hot water extraction and ethanol precipitation | Specific pathogen-free embryonated eggs | Improve chicken immune function | Animal feed additives | Guo *et al.* 2014 |
| Polysaccharide | Masson pine | Pollen | Water extraction and ethanol precipitation | Chickens | Vaccine with polysaccharide as adjuvant improves protection in chickens | Immunomodulatory drugs | Zhu *et al.* 2016 |
| Polysaccharide | Masson pine | Pollen | Water extraction and ethanol precipitation | MDCK cells | Inhibits H9N2 subtype influenza virus infection both in vitro and in vivo | Antiviral drugs | Shang *et al.* 2020 |

| Compounds | Species | Studied Organ | Extract Method | Experimental Materials | Effect | Products or Possible Uses | Reference |
|---|---|---|---|---|---|---|---|
| Polysaccharide | Masson pine | Pollen | Water extraction and ethanol precipitation | Chickens | Reduced histopathological damage and improved immune function in chicks | Animal feed additives | Sha *et al.* 2021 |
| Polysaccharide | Masson pine | Pollen | – | DF-1 cells | Inhibition of proliferation of subgroup B avian leukemia virus | Antiviral drugs | Wang *et al.* 2019 |
| Polysaccharide | Masson pine | Pollen | Petroleum ether extraction | DF-1 cells | Inhibition of replication of subpopulation J of acute oncogenic avian leukemia virus and its associated tumor growth | Antiviral drugs | Cui *et al.* 2021 |
| Polysaccharide | Masson pine | Pollen | Ethanol precipitation | Chickens | Multiple immune-related proteins are regulated in cells | Immunomodulatory drugs | Yang *et al.* 2018 |
| Polysaccharide | Masson pine | Pollen | Ethanol precipitation | Mice | Enhanced immunity in mice | Immunomodulatory drugs | Zhao *et al.* 2013 |
| Polysaccharide | Masson pine | Pollen | Ethanol precipitation | Mice | Modulation of systemic immunity and attenuation of colonic injury and colitis symptoms in mice | Immunomodulatory drugs | Niu *et al.* 2021 |

| Compounds | Species | Studied Organ | Extract Method | Experimental Materials | Effect | Products or Possible Uses | Reference |
|---|---|---|---|---|---|---|---|
| Polysaccharide | Masson pine | Pollen | Hot water extraction and ethanol precipitation | Rat | Significant protective effect against $CCl_4$-induced acute hepatotoxicity | Immunomodulatory drugs | Zhou *et al.* 2018 |
| Polysaccharide | Masson pine | Pollen | Hot water extraction and ethanol precipitation | Pig | Its immune-boosting effect | Animal feed additives | Peng *et al.* 2016 |
| Polysaccharide | Masson pine | Needle | Ethanol precipitation | Mice | Enhances antioxidant capacity and alleviates hyperlipidemia | Antioxidant | Chu *et al.* 2019 |
| Polysaccharide | Korean pine | Pinecone | Hot water extraction | *Escherichia coli* | Inhibitory effect on *Escherichia coli* | | Zhao *et al.* 2019 |
| Polysaccharide | Korean pine | Pinecone | Fractionated | – | Antioxidant capacity | Antioxidant | Zhang *et al.* 2016 |
| Polysaccharide | Korean pine | Pinecone | Water extraction | – | Antioxidant capacity | Antioxidant | Zhang *et al.* 2021a |
| Polysaccharide | Korean pine | Pine nut | Solvent extraction | Human hepatocyte cell line L02 | Protection of L02 cells from CCl4-induced damage | Immunomodulatory drugs | Qu *et al.* 2019 |
| Proanthocyanidin | Masson pine | Bark | – | HeLa cells | HeLa cell invasion was significantly inhibited | Anti-cancer drugs | Li *et al*. 2016 |

| Compounds | Species | Studied Organ | Extract Method | Experimental Materials | Effect | Products or Possible Uses | Reference |
|---|---|---|---|---|---|---|---|
| Proanthocyanidin | Masson pine | Bark | – | Ovarian cancer cells | Ovarian cancer cell growth was significantly inhibited and apoptosis was induced | Anti-cancer drugs | Liu *et al.* 2015 |
| Protein | Red pine | Needle | – | *Staphylococcus aureus* and *Escherichia coli* | They have good antimicrobial activity | Antithrombotic drugs | Lee *et al.* 2021b |
| Protein | Red pine | Extracellular vesicles | – | Human cancer cells | Cytotoxic to malignant skin tumor cells | Anti-cancer drugs | Kim *et al.* 2020b |
| Protocatechuic and shikimic acid | Red pine | Needle | Solvent extraction | Mice | They have antithrombotic activity | Antithrombotic drugs | Park *et al.* 2016 |
| Quinic acid, *etc.* | Red pine | Branche | Solvent extraction | Souse leukemia cells of monocyte-macrophage | Inhibits inflammation, thereby reducing cellular damage | Anti-inflammatory drugs | Kim *et al.* 2021 |
| Terpene, flavonoid, phenolic, alkaloid, tannin, saponin | Korean pine | – | Steam distillation | Pig | Increases average daily weight gain of pig | Animal feed additives | Seok *et al.* 2021 |