

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

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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.

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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).

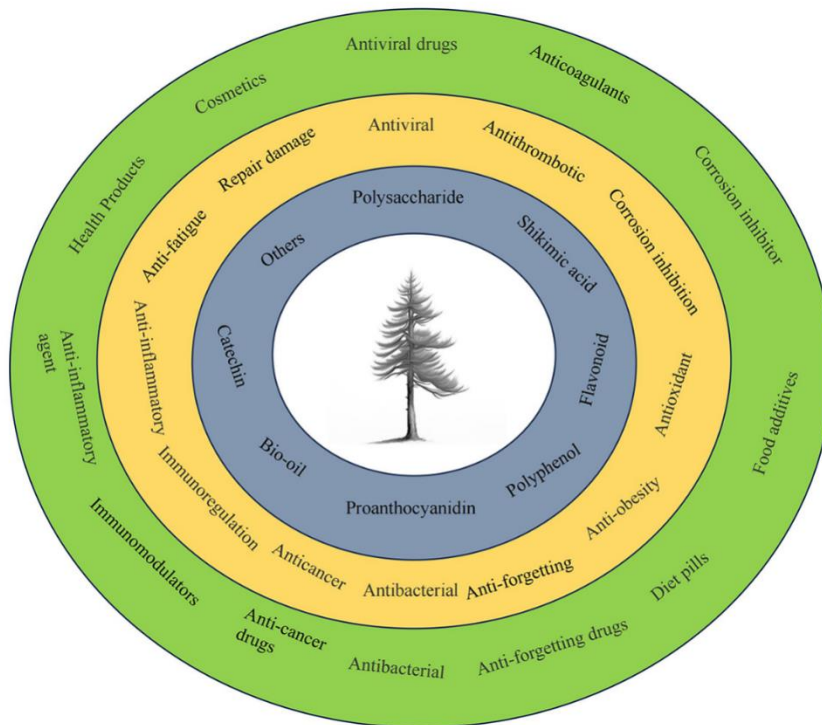


Fig. 1. Metabolites, functions, and applications of *Pinus* species

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.

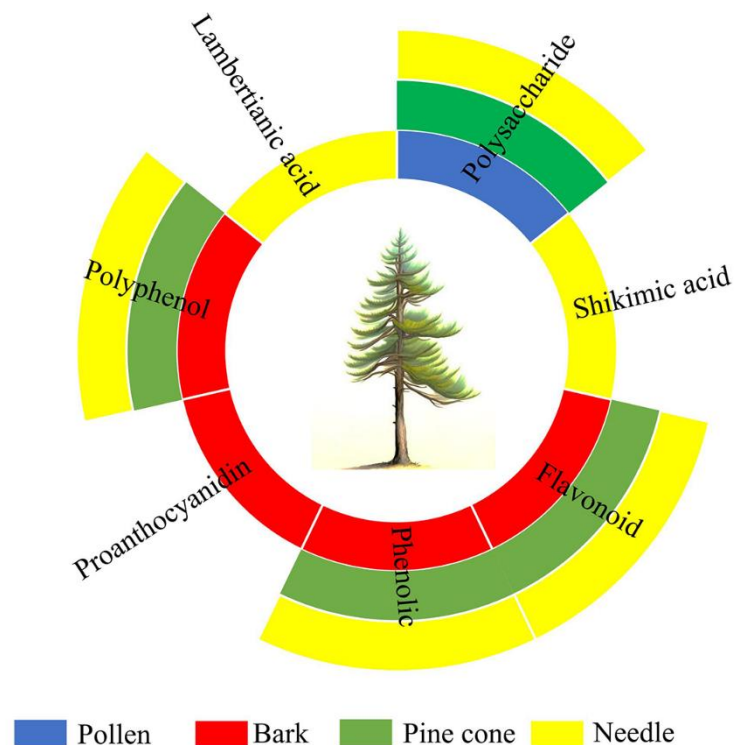


Fig. 2. Medicinal parts and extraction fractions of *Pinus* species

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 CCl₄-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 CO₂ 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, massonioside 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-1 β 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 antiphotaging 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 anti-amnesic 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 $\omega 6:\omega 3$ 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.

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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 <i>et al.</i> 2017
–	Red pine	Needle	Ethanol extraction	HepG2 cells	Significant amelioration of nuclear damage and loss of cell viability	Antioxidant	Venkatesan <i>et al.</i> 2019a
–	Red pine	Needle	Ethanol extraction	Mice	Functions to modulate memory impairment	Anti-forgetting drugs	Lee <i>et al.</i> 2017a
–	Red pine	Needle	Water extraction	Mice	Inhibition of osteoclastogenesis	Traditional medicine and health functional food	Shim <i>et al.</i> 2018
–	Red pine	Needle	Solvent extraction	Human papillomavirus	Human papillomavirus growth inhibited	Antiviral drugs	Lee <i>et al.</i> 2021a
–	Red pine	Needle	Solvent extraction	Gastric cancer cells	Inhibit gastric cancer cell proliferation	Anti-gastric cancer drugs	Kim <i>et al.</i> 2020d
–	Red pine	Needle	Ethanol extraction	HaCaT cells	Protective effect against skin aging	Anti-wrinkling agents and cosmetic ingredients	Huh <i>et al.</i> 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 <i>et al.</i> 2022a
–	Red pine	Bark	Solvent extraction	Pig	Improve growth performance and intestinal function	Health functional food	Ro <i>et al.</i> 2023
–	Red pine	Pinecone	Ethanol extraction	<i>Brevibacterium linens</i>	Demonstrates moderate antibacterial activity against bacteria causing skin infections	Anti-bacterial drugs	Velmurugan <i>et al.</i> 2015
–	Korean pine	Needle	Solvent extraction	Human	Effectively improves superoxide dismutase levels	Antioxidant	Lee <i>et al.</i> 2016a
–	Korean pine	Needle	Ethanol extraction	HepG2 cells, rats, mice	Alcohol-induced fatty liver improved	Health functional food	Hong <i>et al.</i> 2017
–	Korean pine	Needle	Ethanol extraction	Human	They show the potential to improve liver function in excessive drinkers	Health functional food	Park <i>et al.</i> 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 <i>et al.</i> 2022a
Anthocyanin series B	Masson pine	Bark	–	A549 cell line	Lung cancer cell growth is inhibited	Anti-lung cancer drugs	Mao <i>et al.</i> 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 <i>et al.</i> 2018
Bio-oil	Red pine	–	Fast pyrolysis	Bacillus cereus and Listeria monocytogenes	Suppression of the viability of pathogenic bacteria	Anti-bacterial drugs	Patra <i>et al.</i> 2015a
Bio-oil	Red pine	Sawdust	Fast pyrolysis	–	Significant antioxidant potential	Antioxidant	Patra <i>et al.</i> 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 <i>et al.</i> 2017
Catechin, gallic acid	Korean pine	Needle	Ethanol extraction	Mice	Improves motor performance and reduces fatigue	Health functional food	Lee <i>et al.</i> 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 <i>et al.</i> 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 <i>et al.</i> 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 <i>et al.</i> 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 <i>et al.</i> 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 <i>et al.</i> 2018b
Essential oil	Korean pine	Pinecone	Distillation	Helicobacter pylori	Helicobacter pylori is killed in large numbers	Anti-bacterial drugs	Kim <i>et al.</i> 2020c
Essential oil	Korean pine	Pinecone	Hydrodistillation	Mice	Inhibit the proliferation of cells	Anti-cancer drugs	Zhang <i>et al.</i> 2020
Flavonoid	Korean pine	Nut-coated film	Enzyme-assisted solvent	–	Antioxidant capacity	Antioxidant	Zhang <i>et al.</i> 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 <i>et al.</i> 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 <i>et al.</i> 2021a
Phenolic	Masson pine	Needle	Supercritical CO ₂ fluid replacing	–	Antioxidant capacity	Antioxidant	Yang <i>et al.</i> 2021
Phenolic	Red pine	Bark	Solvent extraction	–	High antioxidant capacity	Antioxidant	Venkatesan <i>et al.</i> 2019b
Phenolic	Red pine	Bark	–	PC-12 cells	They are an effective potent neuroprotective	Neuroprotective drugs	Kim <i>et al.</i> 2018a
Phenolic and flavonoid	Korean pine	Bark	Solvent extraction	Rat	Restoration of superoxide dismutase, catalase activity, reduction of DNA damage	Radioprotective drugs	Yun <i>et al.</i> 2017
Phenolic	Red pine	Bark	Water extraction	Mice	They have an anti-forgetting effect	Anti-forgetting drugs	Go <i>et al.</i> 2022
Phenolic	Red pine	Bark	Hot water extraction	Rat	Can be used as a cognitive enhancer	Cognitive enhancer	Kim <i>et al.</i> 2022b
Phenolic	Red pine	Bark	–	Soy protein isolate	Improved thermal stability of the film	Antioxidant	Han <i>et al.</i> 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 <i>et al.</i> 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 <i>et al.</i> 2017b
Phenolic and flavonoid	Red pine	Pinecone	Butanol extraction	Hyaluronidase, <i>Bacillus cereus</i> , <i>Staphylococcus aureus</i>	Exhibits inhibitory activity against food poisoning microorganisms	Anti-bacterial drugs	Lee <i>et al.</i> 2018b
Phenolic, flavonoid and alkaloids	Masson pine	Needle	–	Hen	Improvement of intestinal microbiology and performance in laying hens	Animal feed additives	Guo <i>et al.</i> 2022
Polyditerpene acid	Korean pine	Pinecone	Solvent extraction	HepG2 cells	Promotes apoptotic cell death	Anti-cancer drugs	Xin <i>et al.</i> 2021
Polyphenol	Red pine	Bark	Ethanol extraction	Mice	Reducing the symptoms of atopic dermatitis	Anti-inflammatory drugs	Lee <i>et al.</i> 2018a
Polyphenol	Korean pine	Pinecone	Ethanol extraction	LOVO cells	The growth of LOVO cells is inhibited	Anti-cancer drugs	Yi <i>et al.</i> 2016
Polyphenol	Korean pine	Pinecone	Ethanol extraction	Mice	Tumor cells are suppressed	Anti-cancer drugs	Yi <i>et al.</i> 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 <i>et al.</i> 2017a
Polyphenol	Korean pine	Pinecone	–	Mice	Protective effect on radiation damage in mice	Radioprotective drugs	Shao <i>et al.</i> 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 <i>et al.</i> 2021
Polyphenol, flavonoid, proanthocyanidin	Red pine	Bark	Water extraction	Gerbils	They have a neuroprotective effect	Neuroprotective drugs	Park <i>et al.</i> 2021c
Polyphenol	Red pine	Bark	Water extraction	Rat	It has an antihypertensive effect and has an antioxidant effect.	Antioxidant	Kim <i>et al.</i> 2022a
Polyphenol	Korean pine	Pinecone scales	Ethanol extraction	Rat	They promote the proliferation of osteoblasts	Health functional food	Diao <i>et al.</i> 2018
Polyphenol and flavonoid	Red pine	Needle	–	Hen	Improving egg production performance	Animal feed additives	Kothari <i>et al.</i> 2021
Polysaccharide	Masson pine	Pollen	Ethanol precipitation	Rex rabbit	Enhanced antibody levels and average daily feed intake in rabbits.	Immunomodulatory drugs	Wei <i>et al.</i> 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 <i>et al.</i> 2013
Polysaccharide	Masson pine	Pollen	Water extraction and ethanol precipitation	Mice	Effectively inhibited colorectal cancer cell proliferation	Anti-cancer drugs	Shang <i>et al.</i> 2022
Polysaccharide	Masson pine	Pollen	–	Chicks	Polysaccharides enhance the immune effect of vaccines	Immunomodulatory drugs	Cui <i>et al.</i> 2013
Polysaccharide	Masson pine	Pollen	Hot water extraction and ethanol precipitation	Specific pathogen-free embryonated eggs	Improve chicken immune function	Animal feed additives	Guo <i>et al.</i> 2014
Polysaccharide	Masson pine	Pollen	Water extraction and ethanol precipitation	Chickens	Vaccine with polysaccharide as adjuvant improves protection in chickens	Immunomodulatory drugs	Zhu <i>et al.</i> 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 <i>et al.</i> 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 <i>et al.</i> 2021
Polysaccharide	Masson pine	Pollen	–	DF-1 cells	Inhibition of proliferation of subgroup B avian leukemia virus	Antiviral drugs	Wang <i>et al.</i> 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 <i>et al.</i> 2021
Polysaccharide	Masson pine	Pollen	Ethanol precipitation	Chickens	Multiple immune-related proteins are regulated in cells	Immunomodulatory drugs	Yang <i>et al.</i> 2018
Polysaccharide	Masson pine	Pollen	Ethanol precipitation	Mice	Enhanced immunity in mice	Immunomodulatory drugs	Zhao <i>et al.</i> 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 <i>et al.</i> 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 <i>et al.</i> 2018
Polysaccharide	Masson pine	Pollen	Hot water extraction and ethanol precipitation	Pig	Its immune-boosting effect	Animal feed additives	Peng <i>et al.</i> 2016
Polysaccharide	Masson pine	Needle	Ethanol precipitation	Mice	Enhances antioxidant capacity and alleviates hyperlipidemia	Antioxidant	Chu <i>et al.</i> 2019
Polysaccharide	Korean pine	Pinecone	Hot water extraction	<i>Escherichia coli</i>	Inhibitory effect on <i>Escherichia coli</i>		Zhao <i>et al.</i> 2019
Polysaccharide	Korean pine	Pinecone	Fractionated	–	Antioxidant capacity	Antioxidant	Zhang <i>et al.</i> 2016
Polysaccharide	Korean pine	Pinecone	Water extraction	–	Antioxidant capacity	Antioxidant	Zhang <i>et al.</i> 2021a
Polysaccharide	Korean pine	Pine nut	Solvent extraction	Human hepatocyte cell line L02	Protection of L02 cells from CCl ₄ -induced damage	Immunomodulatory drugs	Qu <i>et al.</i> 2019
Proanthocyanidin	Masson pine	Bark	–	HeLa cells	HeLa cell invasion was significantly inhibited	Anti-cancer drugs	Li <i>et al.</i> 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 <i>et al.</i> 2015
Protein	Red pine	Needle	–	<i>Staphylococcus aureus</i> and <i>Escherichia coli</i>	They have good antimicrobial activity	Antithrombotic drugs	Lee <i>et al.</i> 2021b
Protein	Red pine	Extracellular vesicles	–	Human cancer cells	Cytotoxic to malignant skin tumor cells	Anti-cancer drugs	Kim <i>et al.</i> 2020b
Protocatechuic and shikimic acid	Red pine	Needle	Solvent extraction	Mice	They have antithrombotic activity	Antithrombotic drugs	Park <i>et al.</i> 2016
Quinic acid, <i>etc.</i>	Red pine	Branche	Solvent extraction	Souse leukemia cells of monocyte-macrophage	Inhibits inflammation, thereby reducing cellular damage	Anti-inflammatory drugs	Kim <i>et al.</i> 2021
Terpene, flavonoid, phenolic, alkaloid, tannin, saponin	Korean pine	–	Steam distillation	Pig	Increases average daily weight gain of pig	Animal feed additives	Seok <i>et al.</i> 2021