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Apocynum venetum, a medicinal, economical and ecological plant: a review update

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ABSTRACT

Apocynum venetum L. is an important medicinal perennial rhizome plant with good ecological and economic value. Its leaves have many pharmacological effects such as anti-inflammatory, anti-depression, anti-anxiolytic, etc., while its fibers have the title of "king of wild fibers". Furthermore, it was suitable for the restoration of degraded saline soil in arid areas. An increasing studies have been published in the past years. A scientometric analysis was used to analyze the publications of *Apocynum venetum* L. to clearly review the pharmacology, fiber application of *Apocynum venetum* L. and the potential value with its similar species (*Apocynum pictum Schrenk*) to the environment.

Subjects Plant Science, Global Health, Nutrition
Keywords *Apocynum venetum* L, Medicinal plant, Fibrous plant, CiteSpace

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INTRODUCTION

Apocynum venetum L. (*A. venetum*), commonly known as "Luobuma" in Chinese and "Rafuma" in Japanese is a perennial herbaceous shrub (Fig. 1) widely distributed in the temperate regions of Asia, Europe and North America, especially in saline-alkali land, river-banks, fluvial plains and sandy soils (*Grundmann et al., 2007*; *Jiang et al., 2021b*; *Xie et al., 2012*). The species *Apocynum venetum* L. (Apocynaceae) currently includes 9 subspecies documented on World Flora Plant List (Table S1) (*World Flora Online, 2022*) *A. venetum* can adapt to extreme conditions where the surface salinity is up to 20% and the annual average precipitation is more than 250 mm, making the plant of high ecological value for the transformation of coastal saline and barren lands (*Thevs et al., 2012*; *Yuan, Li & Jia, 2020a*). *A. venetum* leaves has been used to produce herbal drugs and tea (*Chinese Pharmacopoeia, 2020*). Furthermore, since 2002 luobuma tea has been included in the list of health-care food in China (*National Health Commission of the People's Republic China, 2002*). *Lau et al. (2012)* confirmed that *A.venetum* leaf extract could stimulate vascular receptor (alpha-adrenergic and angiotensin II receptors) and inhibit vasoconstriction,

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Figure 1 ***Apocynum venetum*** **ssp.** ***Tauricum*****.** Image credit: Roman, https://www.inaturalist.org/photos/21168806.

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suggesting antihypertensive properties of the plant. Modern pharmacological investigations confirmed that *A. venetum* has, among other effects, anti-inflammatory, anti-depression, anti-anxiolytic, anti-ageing, antioxidants, cardiotonic and hepatoprotective effects (*Du et al., 2020*; *Grundmann et al., 2007*; *Xie et al., 2015*; *Xie et al., 2012*). *A. venetum* fiber, known as the "king of wild fibers", is receiving increasing attentions in the apparel industry owing to its additional advantage of possessing antibacterial properties (*Han et al., 2008*; *Wang, Han & Zhang, 2007*; *Xu et al., 2020a*).

Alongside the rapid increase in *A. venetum*-related studies, systematic and comprehensive analyses on *A. venetum* publications is essential. We have previously reviewed the traditional uses, phytochemistry and pharmacology of *A. venetum* (*Xie et al., 2012*). As a timely update, this article aims to respond to the rapidly increasing literature on *A. venetum* studies by: (i) conducting scientometric analysis of the publications on *A. venetum* and (ii) reviewing the progress recorded on the exploration of the medicinal, economical and ecological benefits of the plant from 2012 to date. For the scientometric analysis, we used Citespace, which is a specifically designed to facilitate the detection of emerging trends and mutations in the scientific literature (*Chen et al., 2012*). Web of Science Core Collection (WoSCC; Clarivate Analytics, London, UYK) is the premier resource on the Web of Science platform. It is considered as the most trusted citation index on many research topics (*Wu, Yakhkeshi & Zhang, 2022*). This work can provide researchers and readers with a comprehensive information on *A. venetum*, covering the areas of phytopharmacy and pharmacology, functional food, ecology, and applications in textile and fiber industry.

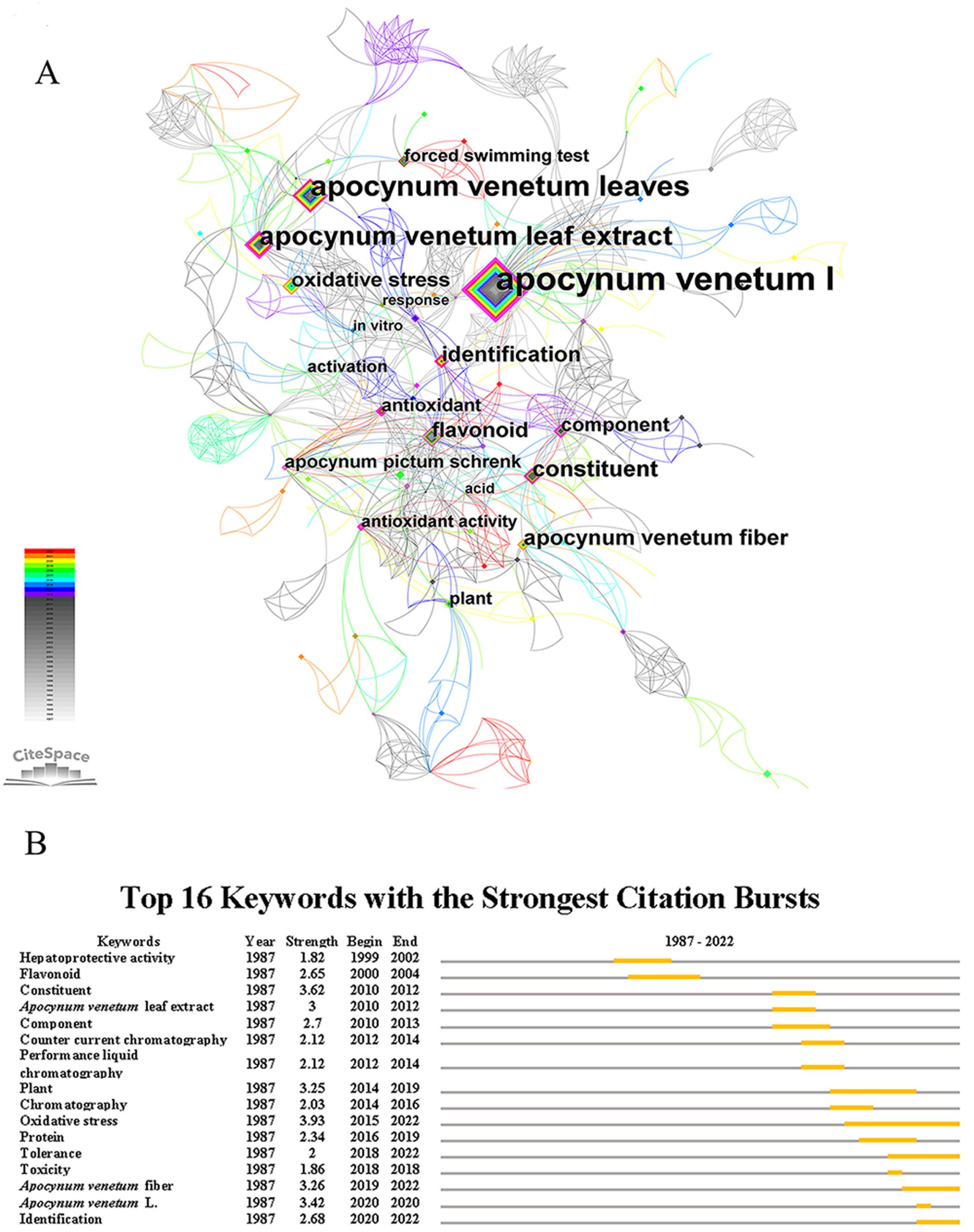
SURVEY METHODOLOGY

Data were collected from WoSCC with the following search strategy: Topical Subject = ("*Apocynum venetum*" OR "Luobuma") OR Title = ("*Apocynum venetum*" OR "Luobuma") OR Abstract = ("*Apocynum venetum*" OR "Luobuma"). The searched time spans 1987–2022, the type of literature was article and review, and the language was English. Our search strategy did not limit the impact factor of journals and the affiliation of authors. A total of 200 publications were obtained, including 190 articles and 10 reviews, and their full record with the cited references was exported in plain text format. CiteSpace 6.1.3 was used to analyze keywords of the literatures, with the time partition set to 1987–2022, the time slice set to 1, the node types set to keyword, G-index set to 25, and the pathfinder, pruning sliced networks and pruning the merged network were used to trim the atlas. Based on the result of keywords analysis of CiteSpace, the chapter topics were divided into the pharmacological effects and related components of *A. venetum*, *A. venetum* fiber, other *Apocynum* species similar to *A. venetum*: *Apocynum pictum Schrenk*, and the ecological value of *A. venetum* and *A. pictum*, and the topics were discussed. The discussion on the bioactive components cover the period 2012–2022.

Keywords analysis of CiteSpace

Keywords represent the core content of an article and provide information on the topic or the important category to which an article belongs. The keywords with high frequency and highly mediated centrality were analyzed and presented in the form of a visual mapping through the Citespace software (Fig. 2). The most frequent keywords from 1987–2022 were *Apocynum venetum* L. (111), *Apocynum venetum* leaves (52), *Apocynum venetum* leaf extract (31). The keywords with the highest centrality before 2018 include *Apocynum venetum* L. (0.49), component (0.28), hepatoprotective activity (0.27), identification (0.25) and antioxidant (0.23) (Fig. 2A, Table 1). However, after 2018, among the top ten keywords showing the highest centrality, two words that are poorly correlated with *Apocynum venetum* leaves appeared: *Apocynum venetum* fiber (0.28) and *Apocynum pictum* schrenk (0.27). These results implied that the studies before 2018 mainly focused on the components and the pharmacological effects of *Apocynum venetum* leaves while *Apocynum venetum* fiber and *Apocynum pictum Schrenk* have also attracted the attention of researchers in recent years.

Based on the keyword co-linear graph (Fig. 2A), the parameter of "burstiness" was set to $\gamma = 0.5$, minimum duration = 1. Sixteen burst entries were generated. Among them, the words that have kept the outbreak status were oxidative stress (3.93), *Apocynum venetum* fiber (3.26), identification (2.68) and tolerance (2.0) (Fig. 2B). These data confirmed that apart from the further in-depth pharmacological investigations, the fiber of this plant has recieved attention in recent years. In addition, the ecological value of *Apocynum venetum* L and *Apocynum pictum* Schrenk L has attracted increasing attentions.



Keywords	Year	Strength	Begin	End
Hepatoprotective activity	1987	1.82	1999	2002
Flavonoid	1987	2.65	2000	2004
Constituent	1987	3.62	2010	2012
Apocynum venetum leaf extract	1987	3	2010	2012
Component	1987	2.7	2010	2013
Counter current chromatography	1987	2.12	2012	2014
Performance liquid chromatography	1987	2.12	2012	2014
Plant	1987	3.25	2014	2019
Chromatography	1987	2.03	2014	2016
Oxidative stress	1987	3.93	2015	2022
Protein	1987	2.34	2016	2019
Tolerance	1987	2	2018	2022
Toxicity	1987	1.86	2018	2018
Apocynum venetum fiber	1987	3.26	2019	2022
Apocynum venetum L.	1987	3.42	2020	2020
Identification	1987	2.68	2020	2022

Figure 2 **Keywords analysis of *A. venetum*.** (A) Nodes in the network represent keywords. Node size represents the number of keyword occurrences. Node color: average time to appear, color from white to red, time from 1987 to 2022. (B) Top 16 keywords with the strongest citation bursts. The grey line represents time interval, the yellow line indicates time period in which a keyword was found to have a burst.

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Table 1 **The top ten co-cited keywords with highest centrality.**

Rank	Key words (1987–2018)	Counts	Centrality	Key words (2019–2022)	Counts	Centrality
1	*Apocynum venetum* l.	75	0.49	Antioxidant activity	4	0.77
2	Component	10	0.28	Acid	5	0.58
3	Hepatoprotective activity	3	0.27	Constituent	7	0.56
4	Identification	9	0.25	*Apocynum venetum* leaves	20	0.50
5	Antioxidant	6	0.23	Structural characterization	2	0.46
6	*Apocynum venetum* leaf extract	22	0.20	Oxidative stress	6	0.45
7	Mass spectrometry	2	0.20	Identification	9	0.30
8	*Apocynum venetum* leaves	37	0.18	*Apocynum venetum* l.	43	0.29
9	Apoptosis	3	0.18	*Apocynum venetum* fiber	10	0.28
10	Antioxidant activity	4	0.17	*Apocynum pictum* schrenk	3	0.27

The bioactive components of *A.venetum*

Flavonoids

With the deepening of research and the technological improvement in high performance liquid chromatography, mass spectrometry *etc*., many phytochemicals of *A.venetum* have been identified and isolated. Some of these phytochemicals were flavonoids such as hyperoside and isoquercetin, which bioactivities have been comprehensively reviewed previously (*Xie et al., 2016a*; *Xie et al., 2016b*; *Xie et al., 2012*). Since then, more studies have reported on the isolation and bioactivities of known and novel flavonoids from *A.venetum*. The flavonoids isolated from *A. venetum* since 2012 are listed in Table 2 and their structures shown in Fig. 3. Kaempferol, quercetin, isoquercitrin (quercetin-3-O-β-D-glucose) and astragalin (kaempferol-3-O-β-D-glucose) isolated from *A. venetum* leaves have significant anti-depressant activities in mice (*Yan et al., 2016*). Hyperoside isolated from the leaves of *A. venetum* showed antidepressant-like effect in P12 cell lines which could improve neuronal viability by protecting neurons from corticosterone damage (*Zheng et al., 2012*). Hyperoside had protective effect on H_2O_2-induced apoptosis of human umbilical vein endothelial cells (*Hao et al., 2016*). For acetaminophen-induced liver injury, both hyperoside and isoquercetin exerted hepatoprotective effect by upregulating the expression and activity of detoxifying enzymes such as sulfotransferases (hyperoside could also increase activities of UDP-glucuronosyltransferase) in liver microsomes and inhibited the activity of cytochrome P450 2E1, accelerating the harmless metabolism of acetaminophen. Additionally, isoquercetin could significantly inhibit acetaminophen induced oxidative stress and nitrosative stress (*Xie et al., 2016a*; *Xie et al., 2016b*). Isoquercitrin, isolated from the *A. venetum* leaf aqueous extract exerted anti-obesity effect in high fat diet induced obese mice by inhibiting adenosine 5′-monophosphate-activated protein kinase (AMPK)/sterol regulatory-element binding protein (SREBP-1c) signaling pathway, glucose uptake, and glycolysis flux. C-1-tetrahydrofolate synthase, carbonyl reductase, and glutathione S-transferase P are potential target proteins of isoquercitrin (*Manzoor et al., 2022*). 8-*O*-methylretusin (Fig. 3) isolated from *A venetum* leaves showed antifouling activity (*Kong et al., 2014*). On the other hand, 4′,7-dihydroxy-8-formyl-6-methoxyflavone isolated from *A venetum* leaves showed high anti-inflammatory activity *via* significant inhibitory effect on the production of nitric oxide (NO) and tumor necrosis factor-α (TNF-α) (IC_{50} values were 9.0 ± 0.7 and 42.1 ± 0.8 μM, respectively) in lipopolysaccharide-induced mouse peritoneal macrophages (RAW 264.7) (*Fu et al., 2022*).

Wang et al. (2020) investigated the absorption and metabolism of quercetin-3-*O*-sophoroside, isolated from the leaves of *A. venetum,* in rats. The results indicated that quercetin-3-*O*-sophoroside was completely absorbed in the small intestine and metabolized in the jejunum to sulfated quercetin-3-*O*-sophoroside, methylated quercetin-3-*O*-sophoroside, and methylated quercetin-3-*O*-sophoroside sulfate. Quercetin-3-*O*-sophoroside was deglycosylated to aglycones by the cecal microbiota to form derivatives of benzoic, phenylacetic and phenylpropionic acids (*Wang et al., 2020*).

To obtain larger amounts of flavonoids, *A. venetum* hairy roots were induced with *Agrobacterium rhizogenes* strain Ar.1193, and 117 kinds of flavonoids were detected in the roots. The flavonoid content and antioxidant activity of the roots were significantly increased as compared to field-planted roots, therefore, this technique could be used for large-scale production of flavonoids from *A. venetum* (*Zhang et al., 2021*).

Polysaccharides

Natural polysaccharides have been proved to possess, among other effects, immune regulatory, anti-oxidative and anti-inflammatory activities, as well as having the advantages of being safe and non-cytotoxic (*Liu et al., 2022*). *Zhou et al. (2019)* used different concentrations and kinds of solvents (HCl, H_2O, NaOH) to extract polysaccharides from *A. venetum* leaves. The results showed that the polysaccharide yield was the highest with 21.32% (w/w), 0.5 M NaOH at 90 °C, and the bioactivity of the alkaline extracted polysaccharides was the strongest, which was reflected in the antioxidant capacity (DPPH and ABTS radical scavenging activities) and α-glucosidase and lipase inhibitory activities. The 0.5 M NaOH extracted polysaccharides showed a strong inhibitory activity on α-glucosidase (IC50 value of 16.75 μg/mL), which was better than the positive control, acarbose (IC50 value of 1,400 μg/mL). In addition, the alkaline polysaccharide-rich extracts were proved to possess hypoglycemic and hypolipidemic effects on mice with high fat diet induced and streptozotocin-induced type 2 diabetes. Moreover, the extract reversed intestinal dysbiosis by increasing the abundance of *Odoribacter*, *Anaeroplasma*, *Muribaculum*, *Parasutterella* and decreasing the abundance of *Enterococcus*, *Klebsiella*, *Aerococcus* in diabetic mice (*Yuan et al., 2020b*).

Some polysaccharides were also isolated from various parts of *A. venetum* and validated for bioactivity. These are summarized in Table 3. ALRPN-1 and ALRPN-2 exerted a significant anti-inflammatory activity in lipopolysaccharide-induced macrophages by regulating the levels of pro-inflammatory mediators (NO) and cytokines (TNF-α, interleukin-6, interleukin-1 β) and the mechanism may involve, in part, extracellular signal-related kinase (ERK)/mitogen-activated protein kinases (MAPKs) signaling pathway (*Liu et al., 2022*). Vp2a-II and Vp3 obtained from the flowers of *A. venetum* showed anticoagulant activity and immunoregulation. The anticoagulant activities of Vp2a-II and Vp3 were assayed *in vitro* by plasma coagulation parameters (activated partial thromboplastin time (APTT), thrombin time (TT), prothrombin time (PT), fibrinogen). The results showed

Table 2 **Flavonoids isolated from *A. venetum* between 2012 to 2022.**

Class	Compound identified	Bioactivity	Plant part isolated from	Reference
Flavonols	Tamarixetin		70% methanol extract in *A. venetum* leaves	*Gao et al. (2019)*, *Yan et al. (2016)*
	Isorhamnetin		95% ethanol extract in *A. venetum* leaves	*Huang et al. (2017)*
	4′-hydroxy-7-*O*-(4-hydroxybenzyl)-3-methoxy-6-prenylflavone	anti-inflammatory	The ethyl acetate -soluble extract of the leaves of *A. venetum*	*Fu et al. (2022)*
	Myricetin		75% ethanol extract in *A. venetum* leaves	*Zhang et al. (2022)*
Flavones	Luteolin	antidepressant	70% methanol extract in *A. venetum* leaves	*Gao et al. (2019)*
	Isoorientin			*Gao et al. (2019)*
	Apigenin			*Gao et al. (2019)*
	Acacetin			*Gao et al. (2019)*
	Acacetin-7-*O*-rutinoside			*Gao et al. (2019)*
	Chrysoeriol-7-*O*-glucoside			*Gao et al. (2019)*
	Chrysoeriol	anti-inflammatory	The ethyl acetate -soluble extract of the leaves of *A. venetum.*	*Fu et al. (2022)*
	6,7-dimethoxy-4′-hydroxy-8-formylflavone	anti-inflammatory		*Fu et al. (2022)*
	4′,7-dihydroxy-8-formyl-6-methoxyflavone	anti-inflammatory		*Fu et al. (2022)*
Flavonones	Hesperidin		70% methanol extract in *A. venetum* leaves	*Gao et al. (2019)*
	Neocarthamin			*Gao et al. (2019)*
	Bavachin	anti-inflammatory	The ethyl acetate -soluble extract of the leaves of *A. venetum.*	*Fu et al. (2022)*
Flavonol glycosides	Kaempferol-3-*O*-(6″-*O*-malonyl)- galactoside		70% ethanol extract in *A. venetum* leaves	*An et al. (2013)*
	Kaempferol-3-*O*-(6″-*O*-malonyl)- glucoside			*An et al. (2013)*
	Eriodictyol-7-*O*-glucoside		70% ethanol extract in *A. venetum* leaves	*Zhao et al. (2014)*
	Quercetin-3-*O*-sophoroside		83% methanol extract in *A. venetum* leaves	*Wang et al. (2020)*
Flavan-3-ols	Plumbocatechin A	radical-scavenging activity	The ethyl acetate fraction of the methanol extract	*Kong et al. (2014)*
Isoflavones	8-*O*-methylretusin	antifouling activities		*Kong et al. (2014)*
Anthocyanidins	Delphinidin		70% methanol extract in *A. venetum* leaves	*Gao et al. (2019)*
	Pelargonidin			*Gao et al. (2019)*
	Malvidin			*Gao et al. (2019)*
	Peonidin			*Gao et al. (2019)*
	Cyanidin			*Gao et al. (2019)*
Proanthocyanidins	Procyanidin c1			*Gao et al. (2019)*
	Procyanidin			*Gao et al. (2019)*
Chalcones	Carthamin			*Gao et al. (2019)*

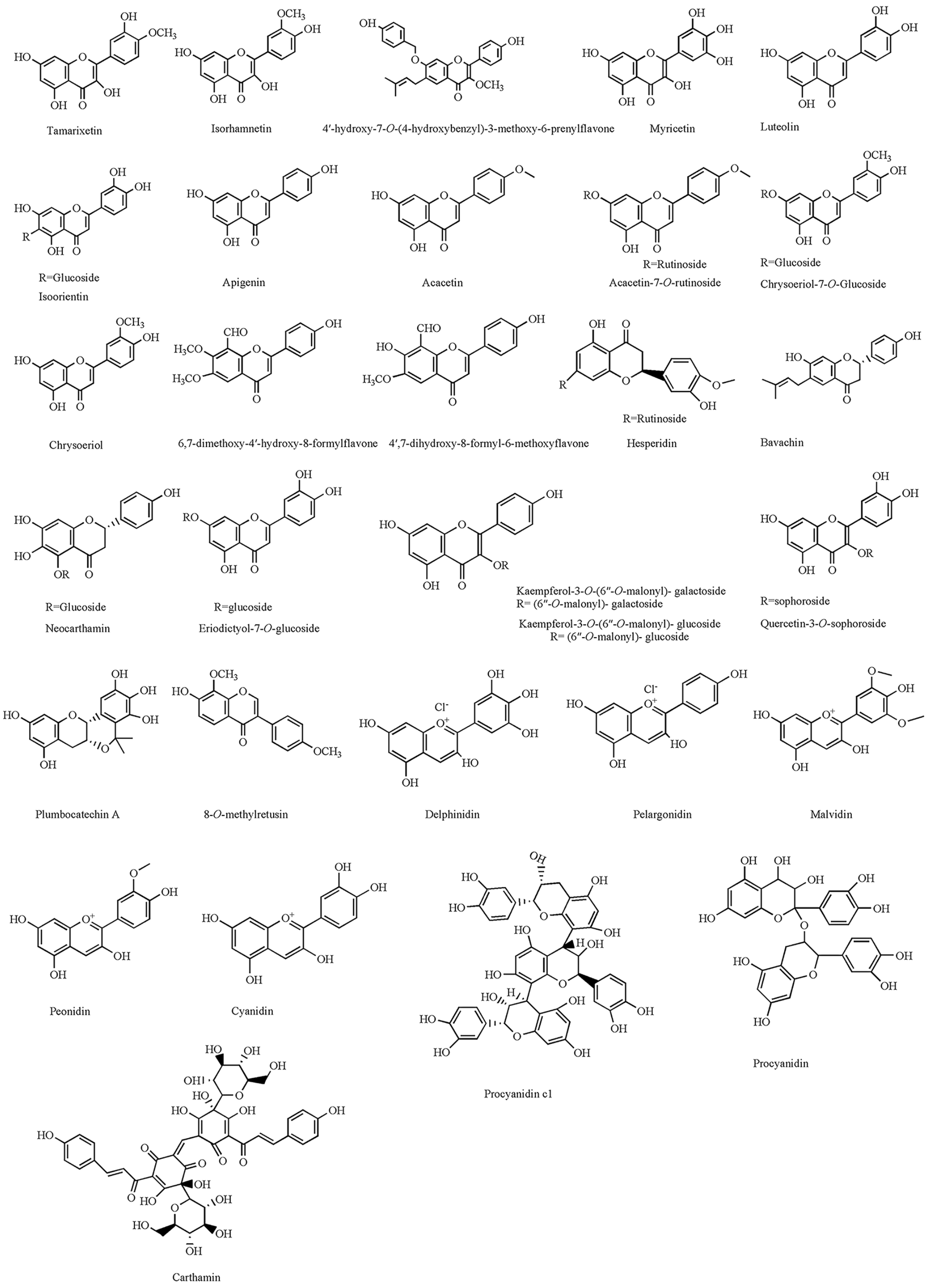

Figure 3 **Chemical structures of the flavonoids isolated from *A. venetum* between 2012 to 2022.**
Full-size DOI: 10.7717/peerj.14966/fig-3

that Vp3 significantly prolonged TT and PT, while Vp2a-II significantly prolonged APTT and TT, indicating that the two polysaccharides could inhibit blood coagulation (*Wang et al., 2019b*). In addition, the polysaccharides could exert immunomodulatory effects by promoting phagocytic activity, enhancing NO secretion and mRNA expression of inducible nitric oxide (iNO) synthase, interleukin-6 and TNF-α which activate RAW264.7 cells. Vp2a-II might activate the MAPK signaling pathway, which then induce the nuclear translocation of NF-κB p65 (*Wang et al., 2022*).

In addition to the pharmacological effects of *A. venetum* polysaccharides, researchers have also began exploring their other properties. The polysaccharide conjugates (ATPC-A) extracted from *A. venetum* tea residues with an alkaline solution (0.10 M NaOH) had emulsifying properties and stabilized the emulsion which comprised of amphipathic polysaccharides covalently bound to proteins. The stability of the neat ATPC-A emulsions with a concentration equal to or greater than 1.00 weight % was higher than 5.00 weight % gum arabic during storage at different temperatures and pH values (*Chen et al., 2022b*).

Other phytochemical components of *A. venetum*

Many studies have reported other phytochemicals from *A. venetum* leaf extracts and their pharmacological effects. The ethanol extract of *A. venetum* leaf possesses anti-cancer activity. A fraction separated from the extract could inhibit the proliferation of Human PCa cells tumor cells. Lupeol accounted for approximately one-fifth (19.3% w/w) of the components of the fraction and was implicated for the induced cytotoxicity against PCa cells. The fraction and lupeol elicited similar anti-proliferative mechanisms, involving: regulating apoptosis signal molecules (P53, cytochrome c, Bcl-2, and caspase 3 and 8), promoting G2/M arrest through impairing the DNA repair system *via* downregulating the expression of uracil-DNA glycosylase, as well as downregulating the expression of β-catenin (*Huang et al., 2017*). In preventing D-galactose-induced oxidative damage in mice, the polyphenol extract of *A. venetum* was superior to the antioxidant vitamin C (*Guo et al., 2020*). Within its safe concentration range (0–100 μg/ml), the polyphenol extract of *A. venetum* inhibited U87 glioma cell proliferation and caused cell apoptosis by affecting NF- κB and genes of other relevant pathways (*Zeng et al., 2019*). Additionally, *A. venetum* leaf extract inhibited doxorubicin induced cardiotoxicity through (protein kinase B) Akt/(B-cell lymphoma-2) Bcl-2 signaling pathway (*Zhang et al., 2022*). The efficacy and mechanism of action of individual chemical components, as well as their possible synergistic effects, of *A. venetum* leaf extract need to be further investigated.

In addition to flavonoids, polysaccharides and polyphenols, sterols (β-sitosterol, sitgmasterol), triterpenoids (lupeol, uvaol), glycolipids (apocynoside I), natural lignan glycoside (alloside of benzyl alcohol) and amino acids have been isolated from *A. venetum* (*Huang et al., 2017*; *Sun et al., 2022*). *A. venetum* flowers are rich in free amino acids, accounting for about 3% of the total dried weight, including leucine (13.71 μg/mg), isoleucine (7.86 μg/mg), lysine (2.22 μg/mg), tryptophan (1.67 μg/mg) and valine (1.20 μg/mg) (*Jin et al., 2019*). Uvaol from *A. venetum* leaves had potent anti-inflammatory

Table 3 Polysaccharides from different parts of *A. venetum*.

Name	Average molecular weight	Monosaccharide	Bioactivity	Mechanism	Plant part	Reference
ALRPN-1	1. 542$\times 10^{4}$ Da	Glucose Galactose Arabinose	Anti-inflammatory	ALRPN-1 and ALRPN-2 exert significant anti-inflammatory activity in LPS-induced macrophages by regulating the levels of pro-inflammatory mediators (NO) and cytokines (TNF- α, IL-6, IL-1 β) and activating the ERK/MAPKs signaling pathway.	A. *venetum* root	*Liu et al. (2022)*
ALRPN-2	5.105 $\times 10^{3}$ Da	Glucose Galactose Mannose				
Vp2a-II	7 $\times 10^{3}$ Da	–	Anticoagulant activity Immunoregulatory	Vp2a-II could inhibit blood coagulation through exogenous pathways and endogenous coagulation pathways. Vp2a-II and Vp3 could activate RAW264.7 cells by promoting cell viability phagocytosis, and enhancing the NO secretion and mRNA expression of iNOS, IL-6 and TNF- α. Moreover, Vp2a-II and Vp3 could trigger the MAPK signaling pathway and then induce the nuclear translocation of NF- κB p65.	A. *venetum* flower	*Wang et al. (2022)*; *Wang et al. (2019a)*; *Wang et al. (2019b)*
Vp3	9 $\times 10^{3}$ Da	–	Anticoagulant activity	Vp3 could inhibit blood coagulation mainly through exogenous pathways and coagulation pathways.		
ATPC-A mixture (the polysaccharide conjugates contained three components)	5.50 $\times 10^{4}$ Da 5.38 $\times 10^{4}$ Da 5.67 $\times 10^{3}$ Da	Mannose	Emulsifying properties	–	A. *venetum* tea (made of A.*venetum* leaves) residues	*Chen et al. (2022a)*, *Chen et al. (2022b)*

effects on dextran sulfate sodium-induced experimental colitis and lipopolysaccharide-stimulated RAW264 cells (*Du et al., 2020*). Validation of the activities of other components in *A. venetum* should be the focus of future studies.

A. venetum fiber

The fiber of *A. venetum* has been used in textile and paper industries with superior properties compared to other commonly used fibers. Fiber from *Apocynum* species has a higher average length to diameter ratio (up to 1219) compared to kenaf (209), another natural plant fiber (*Liu et al., 2020*; *Wang, Han & Zhang, 2007*; *Xie et al., 2012*). Another reason for the popularity of *A. venetum* fabric is the antibacterial effect that *A. venetum* fiber naturally possesses (*Li et al., 2012*; *Song et al., 2019*). Such antibacterial activity might be because: (i) *A. venetum* fiber has small openings between microstructures, which improve the breathability of the *A. venetum* fabric, which subsequently destroy the environment for bacterial growth (*Han et al., 2008*); (ii) the *A. venetum* stem cells contain tanning agents, which is resistant to microbial decomposition (*Thevs et al., 2012*); (iii) the presence of water-insoluble polyphenol derivatives confers antimicrobial properties to the fabric (*Xu et al., 2020a*).

A. venetum is rich in cellulose, but impurities such as pectin, lignin, and waxes must be removed to produce clean fibers (*Lou et al., 2019*). In the direction of environmental safety and high efficiency, various degumming methods have been proposed, including chemical degumming, biological degumming and microwave-assisted ultrasonic degumming. A study revealed that microwave-assisted ultrasonic degumming showed the advantages of requiring less chemical reagents during degumming (1 kg raw *A. venetum* bast needed 0.6 kg of reagents while the chemical degumming treatment required 1.34 kg) and shorter time, as well as higher quality (low residual gum content of 5.15%; lignin content less than 3%; whiteness more than 80% in the refined *A. venetum* fibers) (*Li et al., 2020*). Degumming methods and the fiber quality of *A. venetum* reported from 2012 to 2022 are listed in Table 4.

In addition to the textile industry, *A. venetum* fiber also has many potential applications in medicine as well as in the construction industry. Microcrystalline cellulose (MCC-N) from *A. venetum* fibers was shown to have a rougher structure and less macrostructure than commercially available microcrystalline cellulose (MCC-C). MCC-N had a crystallinity of up to 78.63% and a thermal stability comparable to that of MCC-C, which made it suitable as a load-bearing material for composite structures, and could be used in polymer composites with high temperature resistance (*Halim, 2021*). Furthermore, cellulose nanofibers (CNFs) from *A. venetum* straw were added into poly lactic acid (PLA), and the prepared PLA/CNFs film did not only improve the wettability and permeability of PLA, but also had superior antibacterial properties (the antibacterial growth inhibition rate on *Escherichia coli* and *Staphylococcus aureus* were 96.31% and 92.83% at PLA/6% (w/w) CNFs film, respectively). Then, polyvinyl pyrrolidone was added to this film to form a sustained-release nanofiber membrane (PLA/drug-loaded PVP nanofiber membranes), and a purified sea buckthorn was embedded in the drug-loaded film to evaluate its performance. The nanofiber membrane extended and sustained the release of purified

Table 4 Degumming methods and the quality of fiber obtained from *A. venetum* (studies between 2012 to 2022).

Degumming type	Processing method	Fiber quality	Impact on the environment	Reference
Bio-chemical combined degumming process	*Apocynum* fibers >> Boiling (12 g/L pectinase, Material: Liquor (M: L)-1:30, time: 2 h, temperature: 50 °C, PH8-10) >> washing >> boiling (12 g/L NaOH, M: L-1:30, time: 1.5 h) >> washing >> bleaching (20 g/L H_2O_2, M: L-1:30, time: 1.5 h, temperature: 95 °C) >> washing >> oven-dried (temperature: 80 °C)	Fiber breaking strength: 22.84 cN/dtex; Whiteness: 73.9; Fineness:4.97 dtex; Crystallinity: 74.5%; Moisture regain: 7.7380%.	This method could reduce the pollution caused by chemicals.	*Chen et al. (2022a)*, *Chen et al. (2022b)*
Biodegumming (Bacterial strain *Pectobacterium wasabiae*)	Oscillating fermentation (fermentation time: 12 h, inoculum size: 2%, M: L -1:10, temperature: 33 °C, shaking rate:180 rpm) >> boiling (temperature: 100 °C, time: 20 min) >> washing by machine	Residual gum content: 12.57%; Percentage of raw material weight loss: 30.05%; The fiber counts:1,002 m/g	Chemical Oxygen Demand: 3,119 mg/L	*Duan et al. (2021)*
Microwave-assisted ultrasonic degumming	Sample >> Microwave pretreatment (10 g/L NaOH, M: L-1:20, time: 20 min, temperature:120 °C, power: 600W) >> rinsing >> drying >> ultrasonic degumming >> soaking (10 g/L NaOH and 1 g/L H_2O_2, M: L-1:20, time: 60 min, temperature:50 °C, power: 800W, frequency: 28 Hz	Residual gum content: 5.15%; Fiber breaking strength: 7.67 cN/dtex; Fiber length:32.5mm; Whiteness: 83%; Fineness: 4.05 dtex;	For degumming 1 kg of raw AV bast needed 0.6 kg of chemical reagents	*Li et al. (2020)*
Chemical degumming	Stripped bast by machine >> pretreatment (0.2%$Al_2(SO_4)_3$, room temperature, M: L- 1:15, time: 7h) >> fiber washing >> cooking (1%NaOH, 0.25% thiourea, M: L- 1:15, temperature:95 °C, time intervals:2, 3, 5 h) >> washing >> acid soaking (2% CH_3COOH, room temperature, M: L- 1:15, time: 2 min) >> washing >> bleaching (2% H_2O_2, 0.1% tween-80 surfactant, temperature: 94 °C, M: L- 1:15, time: 1 h) >> washing >> drying (oven-dried at 105 °C).	Moisture regain: 7.0%; The cooking processes of three different time intervals: Residual gum content: 3.64, 3.03, 2.70%, respectively; Crystallinity: 81.14, 78.80 73.75%, respectively; Tenacity: 8.63, 7.00, 6.93 cN/dtex, respectively; Fiber diameter: 2.52, 2.37, 2.14 dtex, respectively.	The method uses metal salts of aluminum for pretreatment, which is more sustainable.	*Halim et al. (2020)*
Deep eutectic solvents (DES) with the assistance of microwave	DES Configuring (choline chloride and car bamide-1:2 molar ratio (w/w) >> oil bathing (temperature: 80 °C, M: L- 1:20, time: 1 h) >> immersing with microwave oven (temperature:110 °C, M: L-1:20, time: 1 h) >> washing >> cooking (1%NaOH, time: 1 h) >> washing >> oven-dried	Residual gum content: 6.54%; Fiber breaking strength:14.14 cN/dtex; Crystallinity: 77.92%. Average fiber fineness: 4.05 dtex.	DES reagent selected for this method is biodegradable	*Song et al. (2019)*
Degumming with Ionic Liquid (IL:1-butyl-3-methylimidazolium acetate-water mixtures.) Pretreatment	*A.venetum* fibers >> pretreatment >> water boiling (temperature: 70 °C, M: L- 1:20, time: 3 h) >> rinsing with hot water (60 °C) >> rinsing with tap water >> degumming with IL-water mixtures (80% IL-water mixtures, temperature: 90 °C M: L- 1:20, time: 4 h) >>chemical degumming (10 g/L NaOH and 2% $Na_3P_3O_{10}$, M: L- 1:20 temperature: 95 °C, time: 2 h) >> acid rinsing (1.5 g/LH_2SO_4, room temperature, M: L- 1:20, time: 5 min) >> washing with tap water >> drying	Residual gum content: 3.90%; Fiber breaking strength: 452.7 cN/dtex; Fineness: 0.7 um Crystallinity:76.62%	Mild conditions and low toxicity.	*Yang et al. (2019)*
Chemical degumming	Pre-acid treatment (2% H_2SO_4, temperature: 60 °C, M: L- 1:15, time: 1 h) >> washing >> first-cooking (5% NaOH, 3% Na_2SiO_3, 2.5% Na_2SO_3, temperature: 100 °C, M: L- 1:10, time: 2.5 h) >> washing >> second-cooking (15% NaOH, 3% Na_2SiO_3, 2% sodium tripolyphosphate, temperature: 100 °C, M: L- 1:10, time: 2.5 h) >> washing >> acid rinsing (1 g/L H_2SO_4) >> washing >> dewatering >> shaking >> drying	Fiber breaking strength:401.56 cN/dtex; The average length:29.68 mm; Fineness:4673.25 nm; Color: reddish yellow; Moisture regain: 8.70%; Crystallinity:70.36%;	–	*Lou et al. (2019)*
Bio-degumming (*Pectobacterium* sp. DCE-01)	Machine rolling preprocessing >> bacteria culture (Pectobacterium sp. DCE-01, temperature: 34 °C, time: 6 h, speed: 180rpm, culture medium: 1.0% glucose, 0.5% NaCl, 0.5% beef extract, 0.5% peptone, and 100 mL water, pH 6.5–7.0.) >> Bacterial liquid preparation (water containing: 0.05% $NH_4H_2PO_4$ and 0.05% K_2HPO_4, pH 6.5–7.0) >> fermentation and degumming (temperature: 33 °C, M: L- 1:15, bacterial solution: fermentation water-2:100, time: 16 h, speed: 180 rpm) >> boiling (temperature: 33 °C, time: 20 min) >> washing by a fiber washer >> drying	Residual gum content: 12.22%; Fiber breaking strength: 5.47 cN/dtex;	Chemical Oxygen Demand: 3,245 mg/L	*Duan et al. (2017)*
A novel ionic liquid degumming	Boiling (1 g/L H_2SO_4, temperature: 50 °C, M: L- 1:20, time: 2 h) >> washing (until the washings were neutral) >> degumming (80% 1-butyl-3-methylimidazolium acetate, temperature: 130 °C, M: L- 1:20, time: 3 h) >> washing >> drying	Residual gum content: 9.80%; Fiber breaking strength: 4.64 cN/dtex; Length:24.44 mm Fineness: 4.10 dtex; Crystallinity:78.66%	The degumming process was mild compared to the traditional chemical process.	*Yang et al. (2015)*

sea buckthorn, and the cumulative release reached a maximum of 75.41%. It showed the advantage of a profile with a high initial release followed by a slow diffusion phase (*Wang et al., 2021b*; *Wang et al., 2019a*). In addition, when the hydrogel was prepared with chitosan as the matrix, the addition of CNFs improved the mechanical properties and swelling rate of the chitosan-based hydrogel. As the CNFs was 1.5%, the compressive strength of the hydrogel increased by nearly 20%, the swelling capacity reached 140%. In this form, the antibacterial efficacy against *Escherichia coli* and *Staphylococcus aureus* were 98.54% and 96.15%, respectively (*Wang et al., 2021a*). See *Abubakar, Gao & Zhu (2021)* for further details on the composition, properties and degumming methods of *A. venetum* fiber.

Other *Apocynum* species similar to *A. venetum*: *Apocynum pictum* Schrenk

Due to excessive exploitation, wild *A. venetum* has declined in recent years. A similar species, *Apocynum pictum* Schrenk (*Apocynum hendersonii* Hook) is often used in the market as a substitute for *A. venetum* due to their similarity in morphological characteristics and geographical distribution. The incorporation of *A. pictum* may affect the safety and effectiveness of *A. venetum* (*An et al., 2013*; *Chan et al., 2015*; *Zheng et al., 2022*). Although *A. pictum* has not been included in the Chinese Pharmacopoeia (*Chinese Pharmacopoeia, 2020*), some studies have reported that it is an important medicinal plant (*Gao et al., 2021*; *Jiang et al., 2021a*). For the quality control of *A. venetum* and to explore the potential application of *A. pictum*, some studies compared the similarities and differences between the two species in terms of genome size, flavonoid content, chemical composition and biological activity. The whole genomes of the two species were both small and similar, with 232.80 megabase (*A. venetum*) and 233.74 megabase (*A.pictum*). The contents of quercetin, hyperoside and total anthocyanin in *A. venetum* were much higher than those of *A. pictum*, which was considered to be the reason for the difference in color between the two species (*Gao et al., 2019*). Hyperoside could be a suitable chemical marker to distinguish between the two species (*Gao et al., 2019*). In addition, *A. venetum* has a better antioxidant activity than *A. pictum* (*Chan et al., 2015*). However, recent studies have shown that the flavonoids from *A. pictum* (quercetin-3-sophoroside, isoquercetin, quercetin-3-*O*-(6-*O*-malonyl)-galactoside) and *A. venetum* (hyperoside, isoquercetin, quercetin-3-*O*-(6-*O*-malonyl)-galactoside, quercetin-3-*O*-(6-*O*-malonyl)-glucoside, and quercetin-3-*O*-(6-*O*-acetyl)-galactoside) both exhibited significant antimicrobial activity against methicillin-resistant *Staphylococcus aureus*, *Pseudomonas aeruginosa* and the fungus, *Aspergillus flavus*, but *A. pictum* was superior to *A. venetum* in terms of antimicrobial capacity (*Gao et al., 2021*). Apart from the pharmacological value, in recent years, *A. pictum* is often studied together with *A. venetum* because of its high ecological value.

The ecological value of *A. venetum* and *A. pictum*

Phytoremediation is one of the appropriate ways to deal with land problems such as drought, salinity and metal pollution (*Pilon-Smits, 2005*). *Apocynum* spp. were selected to stabilize sands and restore the degraded saline lands due to their advantages of easy propagation, resistance to harsh environment, and high economic value (*Jiang et al., 2021a*; *Jiang et al.,*

Table 5 **Tolerance value of *Apocynum* spp. under Simulated Drought (PEG) and Salt (NaCl, LiCl) conditions.**

Tolerance value	*A. venetum*	*A. pictum*	Reference
Simulated critical value (PEG concentration)	29.56%	26.58%	*Jiang et al. (2021a)*; *Jiang et al. (2021b)*
Simulated limit value (PEG concentration)	40.16%	39.81%	
Simulated critical value (NaCl concentration)	431 mM	456 mM	
Simulated limit value (NaCl concentration)	653 mM	631 mM	
Simulated critical value (LiCl concentration)	196 mM	235 mM	*Jiang, Wang & Tian (2018a)*; *Jiang et al. (2018b)*
Simulated limit value (LiCl concentration)	428 mM	406 mM	

2021b). The matured seeds of *A. venetum* appeared to possess higher drought tolerance than seeds of *A. pictum*. The simulation of the critical values of *Apocynum* spp. seeds under PEG-6000 simulated drought conditions are summarized in Table 5. Different PEG-6000 concentrations (0%–35%) was used to simulate natural drought conditions to study the effect of drought stress on the germination of *Apocynum* spp. seeds. The results showed that low concentrations PEG (0–20%) had no significant impact on the germination rate of *Apocynum* spp. seeds. However, when the concentration was more than 20%, the germination rates of the seeds were reduced, and the negative impact on *A. pictum* seeds was higher than that on *A.venetum*. In addition, after the drought stress was alleviated, the seeds were able to germinate under appropriate conditions (*Han et al., 2021*; *Jiang et al., 2021a*). Moreover, the membership function (A mathematical tool for representing fuzzy sets) was used to comprehensively evaluate the drought resistance of *A. venetum* and another desert economic plant, *Lycium ruthenicum,* by analyzing the physiological and biochemical indices (the content of chlorophyll a, chlorophyll b, proline and soluble sugar, antioxidant enzyme activity, *etc.*). The results showed that when the soil moisture content was 9.70%, 6.89% and 5.54%, the drought resistance of *A. venetum* was stronger than that of *Lycium ruthenicum* (*Wang, 2017*).

Low concentration of salt solution (0–200 mM NaCl) had no significant effect on the germination rate of current season mature seeds the two species (*Jiang et al., 2021a*; *Shi et al., 2014*). However, another study showed that under 200 mM NaCl stress, the growth and development of *A. venetum* seedlings were inhibited, the phenotypic characteristics (plant height, root length, leaf length, leaf width) were damaged, and the total flavonoid content decreased. However, salt stress increased the content of quercetin and kaempferol in seedlings (*Xu et al., 2020b*). In addition, the seeds of *Apocynum* spp. both exhibited high tolerance to lithium salts during germination, particularly LiCl (Table 5) (*Gao et al., 2020*; *Jiang, Wang & Tian, 2018a*; *Jiang et al., 2018b*). The simulated critical value of *A. venetum* was as high as 196 mM (*Jiang, Wang & Tian, 2018a*). To put the salt tolerance of *A. venetum* into perspective, *Brassica carinata*, another heavy metal tolerant plant with phytoremediation potential, has a germination rate of less than 50% at LiCl concentration above 120 mM (*Li et al., 2009*). Notably, the addition of lithium in soil did not reduce the concentrations and antioxidant capacity of total flavonoids, rutin and hyperoside in *A. venetum* leaves (*Jiang et al., 2019*). Therefore, *Apocynum* spp. are suitable for the restoration of degraded saline soil in arid areas, and are promising species in the remediation of lithium pollution in the environment (*Jiang et al., 2021a*; *Jiang et al., 2021b*; *Rouzi et al., 2018*).

CONCLUSIONS

Looking back on the research history of *A. venetum*, the research focuses mainly on the components and pharmacological effects of *A. venetum* leaves. At present, many of the pharmacological effects are attributable to flavonoids, however these active components and their synergistic mechanism need to be further studied. In addition to flavonoids, some polysaccharides (Vp2a-II, Vp3) and triterpenoid (uvaol) from *A. venetum* have also shown pharmacological effects. However, the current research in this area is still lacking. In recent trends, the fiber of *A. venetum* have attracted attention. Apart from its textile value, the potential application of the fiber in other industries needs further exploration in future studies. The ecological value of *Apocynum* spp. is gradually being revealed by multiple research.

This study provided rich and rigorous CiteSpace analysis on *A. venetum*. However, as a limitation, we analyzed only the papers written in English, and within the WoS database, therefore it may not be comprehensive enough to reflect the entire research status. For example, we searched a major Chinese scientific literature database, the China National Knowledge Infrastructure (CNKI), and more than 2,000 *Apocynum* related publications were retrieved, although these were not within the analysis scope of the current study. This further attests to the interest *Apocynum* species have received from the scientific community over the past decades.

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Competing Interests

The authors declare there are no competing interests.

Author Contributions

- Tian Xiang performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the article, and approved the final draft.
- Longjiang Wu performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the article, and approved the final draft.
- Murtala Bindawa Isah analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the article, and approved the final draft.
- Chen Chen conceived and designed the experiments, analyzed the data, authored or reviewed drafts of the article, and approved the final draft.
- Xiaoying Zhang conceived and designed the experiments, analyzed the data, authored or reviewed drafts of the article, and approved the final draft.

Data Availability

The following information was supplied regarding data availability:

The datasets analyzed are available in the Supplementary File and at the Web of Science Core Collection: https://wfoplantlist.org/plant-list/taxon/wfo-0000245931-2022-12.

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