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Antimicrobial properties of *Sonchus* species: A review

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ABSTRACT

As a rich source of bioactive compounds, plant-derived natural products hold immense promise for pharmaceutical research and development, offering a path to discovering new drug targets and innovative treatments. *Sonchus* species, commonly known as sow thistles, are widely distributed across various geographical regions. Several common species within this plant group have a long history of use in traditional medicine, which can be attributed to their diverse therapeutic benefits. Recently, these plants have gained attention for their potential in antimicrobial therapy, owing to their rich phytochemical profile, including sesquiterpene, flavonoids, and phenolic acids with known antimicrobial activities. Currently, available pharmacological studies demonstrate that *Sonchus* species extracts possess antimicrobial properties, highlighting their potential as sources for new therapeutic agents. This review provides an overview of the current knowledge on the antibacterial, antifungal, antiparasitic, and antiviral activities of the *Sonchus* species, along with its possible mechanisms of action. The review aims to provide directions for future research and promote the exploration of these plants as viable sources of natural antimicrobial agents, potentially contributing to the development of alternative therapeutic strategies in the face of rising antibiotic resistance.

KEYWORDS: *Sonchus*; Antimicrobial; Antibacterial; Antiviral; Antifungal; Antiparasitic

1. Introduction

Infectious diseases pose a significant threat to global health in humans, animals, and plants, mostly due to the diversity and high infectivity of microbial pathogens, especially as the emergence

of antibiotic-resistant bacteria heightens the demand for novel treatments[1]. Plant-derived natural compounds present a promising option due to their diverse pharmacological qualities capable of addressing persistent health challenges. Recent studies increasingly demonstrate that plant-derived natural products possess significant biological activities, functioning as natural antibiotics with crucial roles in disease prevention, treatment, and the reduction of infectious

Summary

Question: Can *Sonchus* species be utilized as alternative plant-derived antimicrobial agents and what are their mechanisms of action?

Findings: *Sonchus* species exhibit antibacterial, antifungal, antiviral, and antiparasitic activities, which can be attributed to bioactive compounds such as sesquiterpenes, flavonoids, and phenolic acids. Recent studies confirm their pharmacological potential and suggest their antimicrobial mechanisms involve disruption of bacterial membranes, inhibition of efflux pumps, interference with biofilm formation, and induction of apoptosis-like death in bacteria.

Meaning: *Sonchus* species is a potential natural antimicrobial agent, offering promising alternatives to synthetic antibiotics in addressing rising antimicrobial resistance and supporting the development of new therapeutic strategies.

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disease prevalence[2–4]. One example is the *Sonchus* species, which has shown tremendous potential in terms of medicinal properties and phytoconstituents.

Sonchus species, commonly known as sow thistle, belong to the family Asteraceae and consist of approximately 95 species. The genus name originates from the Greek word for “hollow,” referencing the hollow stems characteristic of these plants[5,6]. Originally native to Europe, Asia, and Africa, these species have adapted to various climates, spreading to regions such as North and South America[7]. Characterized by rapid growth, quick flowering, and abundant seed production, these species thrive in temperate, tropical, and subtropical regions, with notable species such as *Sonchus asper* (*S. asper*), *Sonchus oleraceus* (*S. oleraceus*) and *Sonchus arvensis* (*S. arvensis*)[8,9]. *Sonchus* species exhibit diverse growth forms—annual, biennial, or perennial[10] and are characterized by milky latex, bright yellow flowers resembling dandelions, and hollow stems[7]. Depending on the species and environmental conditions, these plants grow between 0.3 and 1.8 meters in height[11,12].

Sonchus species, often dismissed as noxious weeds, hold significant traditional medicinal and culinary value. Across various cultures and geographic regions, *S. oleraceus* has been employed to treat gastrointestinal disorders, tumors, and inflammation, while *S. arvensis* is traditionally used for fever and inflammation relief[13–15]. Additionally, in the Mediterranean diet, *Sonchus* species are consumed in salads or utilized as fodder[13]. Beyond traditional uses, research has further highlighted the antimicrobial potential of the *Sonchus* species, with extracts demonstrating significant antibacterial, antifungal, antiparasitic, and antiviral activities[6,16–20]. Furthermore, *Sonchus* species exhibit a variety of biological activities, which are attributed to the diverse naturally occurring bioactive compounds, including flavonoids, phenolic acids, glycosides, carotenoids, and sesquiterpene lactones[21–24]. These compounds confer several health benefits: anti-inflammatory effects are provided by eudesmanolide sesquiterpene lactones, ferulic acid, β -sitosterol, ursolic acid, and rutin[8,25]; antioxidant properties are attributed to *trans*-caryophyllene and *cis*-cadina-1,4-dien[26]; antihyperglycemic effects are linked to hesperidin, vanillin, and quercetin[27]; antitumor activity is associated with luteolin and apigenin[14] as well as cardioprotective and hepatoprotective effects are contributed by chlorogenic and caffeic acids[21].

Although *Sonchus* species have been regarded as a traditional medicine and there are some review articles discussing their phytochemistry and pharmacological properties, understanding their effectiveness as an antimicrobial agent is insufficient. Hence, this review provides a comprehensive overview of the *Sonchus* species, covering its botanical characterization, geographical distribution, and ethnomedicinal uses while also exploring their current biological and medicinal activities. The primary focus is on the antimicrobial potential of *Sonchus* species, with an in-depth discussion of their antibacterial, antifungal, antiviral, and antiparasitic properties, as well as their likely mechanisms of antimicrobial action. This review

highlights the potential of *Sonchus* species as valuable medicinal plants with diverse therapeutic applications, including their promise as natural antimicrobial agents.

2. Botanical characterization and distribution of *Sonchus* species

Sonchus species exhibit notable distinctions based on various botanical characteristics such as life form, lamina shape, stem morphology, and the quantity and color of flowers in inflorescences among other distinguishing features[28]. Furthermore, Mejías *et al.*[29] highlighted variations within the *Sonchus* species concerning flower size, stamen dimensions, and chromosomal morphology. Additionally, Sidhu *et al.*[30] documented differences in *Sonchus* species based on pollen analysis. These studies collectively underscore the diverse botanical traits that contribute to the taxonomic characterization of the *Sonchus* species.

S. oleraceus, also known as common sow thistle or annual sow thistle, is one of the most prevalent species and has been extensively studied for its traditional uses and pharmacological properties. This plant belongs to the subtribe Hyoseridinae (synonym Sonchinae) within the tribe Cichorieae, subfamily Cichorioideae, in the family Asteraceae[31]. Characterized as both a winter and summer weed, *S. oleraceus* exhibits germination in fall or spring. The leaves of *S. oleraceus* are distinctive for their waxy texture, soft-thin flesh, variably serrated margins, and the absence of prickles on the mid-vein, unlike wild lettuce (*Lactuca* species). Furthermore, the main stem of the plant is hairless, pale green to reddish-purple with a branching form in the lower part of the plant. Under warm conditions, *S. oleraceus* can reach a height of 0.3 to 1.5 meters, producing bright yellow flowers and a seed head that resembles a smaller version of a dandelion. Originally native to Asia and Europe, *S. oleraceus* has since naturalized across various regions worldwide, including North America, South America, Australia, and the Middle East[32,33].

Meanwhile, *S. arvensis* is easily recognized by its erect, round stem that can reach heights of 0.65 to 1.50 meters. Its leaves are spear-shaped to lanceolate, with serrated margins and soft-thin flesh. The plant is anchored by a taproot with a root rosette[34]. The resulting fruits and seeds of *S. arvensis* are hard, brown, and wrinkled. Additionally, small clusters of flower heads develop at the end of its upper stems and branches. Indigenous to Europe, Iceland, and western Asia, *S. arvensis* has spread widely across America and Northern Canada[35]. This species is also known by various names across different cultures, including “niu she tou” in China, “laitron des champs” in France, and “sow thistle” in the United Kingdom[36].

S. asper, commonly known as prickly sow thistle, shares similarities with *S. arvensis* in its flower, pollen, fruit, and seed characteristics, as well as its branching pattern. However, it is distinguished by its smaller size, reaching heights of 0.1 to 0.7 meters. Its leaves are

auriculate-shaped with serrated, spiny margins and fleshy, thick flesh. Native to Europe, West Asia and North Africa, *S. asper* has established its populations in North America, South America, East Asia, South Africa, Australia, and New Zealand[37].

3. Ethnomedicinal properties of *Sonchus* species

Sonchus species have historically been integral to both human and animal diets. Known commonly as “hare thistle” or “hare lettuce”, these plants have been a crucial forage source for livestock. Among the most widely consumed are *S. oleraceus*, *S. asper*, *Sonchus tenerrimus*, and *S. arvensis*, particularly valued as edible leafy vegetables in Mediterranean countries such as Italy, Greece, and Portugal[13]. The basal leaves and tender raw stems of these plants are versatile in culinary applications, being used in salads, stews, or cooked similarly to asparagus[38]. These plants continue to hold significant cultural and dietary importance, particularly in urban areas, where they offer an affordable and nutritious vegetable option[39].

Moreover, members of the genus *Sonchus* have long been utilized in folk medicines in various parts of the world. In Chinese folk medicine, *Sonchus brachyotus* has long been used for its cooling properties, as documented in early texts like *the Shennong Threshes the Hundred Grasses* and *the Compendium of Materia Medica*. It is believed to clear heat, eliminate toxins, reduce swelling and pus, promote blood circulation, remove blood stasis, relieve cough, invigorate the liver, promote diuresis, and aid digestion. It is also valued as a wild vegetable due to its high nutritional content, including protein, essential amino acids, carotene, and a variety of trace elements[40].

In India, different *Sonchus* species are traditionally employed to

treat various ailments. For instance, *S. arvensis*, known locally as Dudh Kandij in Kashmir and Sochal in Jammu, is applied topically to manage boils and wounds[41], while its roots are utilized for respiratory conditions like asthma, bronchitis, and whooping cough[42]. Similarly, in Indonesia, *S. arvensis* or tempuyung plant is traditionally employed to treat ailments such as gout, kidney stones, high blood pressure, and inflammation[36,43].

S. asper, referred to as Dodli, is utilized for its anti-inflammatory properties[44]. *S. oleraceus* serves multiple traditional medical purposes, including treating skin diseases, eye and ear problems, indigestion, and kidney conditions[9,45]. In Uttarakhand, the leaves, roots, and stem of *S. oleraceus* have long been utilized in traditional medicine for a variety of purposes, including stimulating milk production, treating liver disorders and fever, and expelling intestinal worms. Additionally, leaves of *Sonchus wightianus* DC, or Dudhli, are applied topically to treat earaches[46], abscesses, and boils[47]. *Sonchus cornutus*, locally known as molieta, is used in Sudan to manage diabetes, hypertension, and malaria[21]. The diverse ethnomedicinal applications of *Sonchus* species, as depicted in Table 1, highlight their broad relevance in traditional practices across different cultures.

4. Antimicrobial activity of *Sonchus* species

Sonchus species have been extensively studied for their antimicrobial properties. Several researched species, including *S. arvensis*, *S. oleraceus*, and *S. asper*, have demonstrated broad-spectrum antimicrobial activity, such as antibacterial, antifungal, antiparasitic, and antiviral activities, as listed in Table 2. The antimicrobial potential of plants from this genus is largely attributed to its rich phytochemical profile, which includes bioactive compounds like

Table 1. Ethnomedicinal uses of *Sonchus* species.

Species	Country	Part used	Traditional uses	Ref
<i>Sonchus oleraceus</i>	New Zealand, China, India, Greece, Italy and Portugal	Young leaves and peeled stems	Edible plant, treatment of bronchitis, pertussis, ophthalmia, inflammation, tumor, urolithiasis, depurative diuretic, in contusions and burns	[8,13,14,38]
<i>Sonchus asper</i>	Britain, Ireland, Russia, Kazakhstan, Uzbekistan, Japan, China, India, Greece, Italy, and Portugal	Flowers, young leaves, and peeled stems	Edible plant, treatment of fever, inflammation, tonic, diuretic, jaundice, wound healing, and vermicide	[8,13,44]
<i>Sonchus brachyotus</i>	China	-	Edible plant, detoxification, reduces swelling and pus, promotes blood circulation, removes blood stasis, relieves cough, and aids digestion	[40]
<i>Sonchus arvensis</i>	China, Indonesia, Greece, Italy and Portugal	Whole plant, young leaves, root, and peeled stems	Edible plant, inflammation, detoxification, heat-clearing, treatment of asthma, coughs, swelling, gout, chronic fever, bronchitis, diuresis, urinary tract stones, gallstones, appendicitis, mastitis, dysentery, hemorrhoids, high blood pressure, and bruises	[13,36,41–43]
<i>Sonchus wightianus</i>	India and Algeria	Leaves	Earaches, treatment of cough, bronchitis, and bruise	[19,20]
<i>Sonchus cornutus</i>	Sudan	-	Treatment of diabetes, malaria, and hypertension	[21]
<i>Sonchus palustris</i>	Russia, Kazakhstan, Uzbekistan and China	Young leaves and stem	Edible plants	[8]

Table 2. Antibacterial, antifungal, antiparasitic, and antiviral activities of *Sonchus* species.

<i>Sonchus</i> plant	Part used	Type of extract	Bioactive compounds	Microorganism(s)	Findings	Used method	Ref
Antibacterial							
<i>Sonchus oleraceus</i>	Root	Methanol	Benzofuran, terpenoid	<i>Bacillus subtilis</i>	ZOI: 8 to 16 mm	Disc diffusion method	[54]
				<i>Staphylococcus aureus</i>	ZOI: 8 to 15 mm		
				<i>Escherichia coli</i>	ZOI: 7 to 16 mm		
				<i>Neisseria gonorrhoea</i>	ZOI: 7 to 15 mm		
	Leaves	Acetone	Phenolic acid, flavonoid, saponin, and alkaloid	<i>Bacillus cereus</i>	MIC: 2.5 mg/mL	Agar dilution method	[5]
				<i>Staphylococcus epidermidis</i>	MIC: 5.0 mg/mL		
				<i>Staphylococcus aureus</i>	MIC: 2.5 mg/mL		
				<i>Micrococcus kristinae</i>	MIC: 2.5 mg/mL		
				<i>Escherichia coli</i>	MIC: 1.0 mg/mL		
				<i>Serratia marcescens</i>	MIC: 2.5 mg/mL		
				<i>Pseudomonas aeruginosa</i>	MIC: 2.5 mg/mL		
				<i>Salmonella pooni</i>	NA		
				<i>Klebsiella pneumoniae</i>	NA		
	Aerial part	Methanol	Phenolic acid and flavonoid	<i>Staphylococcus aureus</i>	ZOI: 14.5 mm; MIC: 0.02 mg/mL	Disc diffusion method	[52]
				<i>Escherichia coli</i>	ZOI: 17.5 mm; MIC: 0.04 mg/mL		
				<i>Salmonella enterica</i>	ZOI: 16 mm; MIC: 0.05 mg/mL		
				<i>Vibrio parahaemolyticus</i>	ZOI: 10.5 mm; MIC: 0.05 mg/mL		
	Whole plant	Water	-	<i>Staphylococcus aureus</i>	ZOI: 7.9 mm; MIC: 5 mg/mL	Agar well diffusion method	[53]
				<i>Escherichia coli</i>	ZOI: 7.3 mm; MIC: 5 mg/mL		
	Leaves	Aqueous methanol	Phenolic acid, flavonol, glycoside, flavone, and glycoside	<i>Salmonella typhimurium</i>	MIC: 0.30 mg/mL	Microdilution method	[55]
				<i>Bacillus cereus</i>	MIC: 0.15 mg/mL		
<i>Sonchus asper</i>	Leaves	Acetone	Phenolic acid, flavonoid, saponin, and alkaloid	<i>Bacillus cereus</i>	MIC: 5.0 mg/mL	Agar dilution method	[5]
				<i>Staphylococcus aureus</i>	MIC: 2.0 mg/mL		
				<i>Micrococcus kristinae</i>	MIC: 5.0 mg/mL		
				<i>Klebsiella pneumoniae</i>	NA		
				<i>Streptococcus pyrogens</i>	NA		
				<i>Staphylococcus epidermidis</i>	NA		
				<i>Salmonella pooni</i>	NA		
				<i>Escherichia coli</i>	NA		
				<i>Serratia marcescens</i>	NA		
				<i>Pseudomonas aeruginosa</i>	NA		
	Whole plant	Methanol, <i>n</i> -hexane, chloroform, butanol, ethyl acetate, and water	Flavonoid, saponin, and phenolic acid	<i>Staphylococcus aureus</i>	ZOI: 12 mm; MIC: 2.5 µg/mL	Agar well diffusion method	[56]
				<i>Escherichia coli</i>	ZOI: 14 mm; MIC: 5.0 µg/mL		
				<i>Bacillus subtilis</i>	ZOI: 12 mm; MIC: 1.0 µg/mL		
				<i>Micrococcus luteus</i>	ZOI: 10 mm; MIC: 2.5 µg/mL		
				<i>Klebsiella pneumoniae</i>	ZOI: 12 mm; MIC: 1.0 µg/mL		
				<i>Pseudomonas aeruginosa</i>	ZOI: 12 mm; MIC: 2.5 µg/mL	Disc diffusion method	[52]
	Aerial part	Methanol	Phenolic acid and flavonoid	<i>Staphylococcus aureus</i>	ZOI: 11.5 mm; MIC: 0.04 mg/mL		
				<i>Escherichia coli</i>	ZOI: 14.0 mm; MIC: 0.05 mg/mL		
				<i>Salmonella enterica</i>	ZOI: 13.5 mm; MIC: 0.08 mg/mL		
				<i>Vibrio parahaemolyticus</i>	ZOI: 8.0 mm; MIC: 0.10 mg/mL		
	Leaves	Methanol, ethanol, and water	-	<i>Staphylococcus aureus</i>	ZOI: 24 mm	Agar well diffusion method	[17]
				<i>Bacillus subtilis</i>	ZOI: 17 mm		
				<i>Escherichia coli</i>	ZOI: 19 mm		
				<i>Pseudomonas aeruginosa</i>	ZOI: 15 mm		

Table 2. Antibacterial, antifungal, antiparasitic, and antiviral activities of *Sonchus* species (continued).

<i>Sonchus</i> plant	Part used	Type of extract	Bioactive compounds	Microorganism(s)	Findings	Used method	Ref
<i>Sonchus arvensis</i>	Whole plant	Ethanol	Sesquiterpene lactones	<i>Streptococcus mutans</i>	Compound 1 MIC: 15.60 µg/mL; Compound 2 MIC: 62.50 µg/mL	Broth microdilution method	[57]
	Aerial part	Methanol	Phenolic acid and flavonoid	<i>Staphylococcus aureus</i>	ZOI: 13.5 mm; MIC: 0.04 mg/mL	Disc diffusion method	[52]
				<i>Escherichia coli</i>	ZOI: 16.0 mm; MIC: 0.05 mg/mL		
				<i>Salmonella enterica</i>	ZOI: 15.0 mm; MIC: 0.06 mg/mL		
				<i>Vibrio parahaemolyticus</i>	ZOI: 9.5 mm; MIC: 0.06 mg/mL		
<i>Sonchus erzincanicus</i>	Aerial part	Methanol and water	Phenolic compounds	<i>Escherichia coli</i>	ZOI: 10 to 12 mm; MIC: 0.625 to 1.25 mg/mL	Disc diffusion method	[58]
				<i>Proteus mirabilis</i>	ZOI: 8 to 10 mm; MIC: 1.25 mg/mL		
				<i>Staphylococcus aureus</i>	ZOI: 10 to 12 mm; MIC: 0.625 to 1.25 mg/mL		
				<i>Pseudomonas aeruginosa</i>	NA		
				<i>Enterobacter aerogenes</i>	NA		
<i>Sonchus uliginosus</i>	Aerial part	Methanol	Phenolic acid and flavonoid	<i>Staphylococcus aureus</i>	ZOI: 11.0 mm; MIC: 0.05 mg/mL	Disc diffusion method	[52]
				<i>Escherichia coli</i>	ZOI: 13.0 mm; MIC: 0.06 mg/mL		
				<i>Salmonella enterica</i>	ZOI: 12.5 mm; MIC: 0.08 mg/mL		
				<i>Vibrio parahaemolyticus</i>	ZOI: 7.5 mm; MIC: 0.12 mg/mL		
<i>Sonchus brachyotus</i>	Aerial part	Methanol	Phenolic acid and flavonoid	<i>Staphylococcus aureus</i>	ZOI: 8.5 mm; MIC: 0.08 mg/mL	Disc diffusion method	[52]
				<i>Escherichia coli</i>	ZOI: 11.0 mm; MIC: 0.08 mg/mL		
				<i>Salmonella enterica</i>	ZOI: 11.5 mm; MIC: 0.10 mg/mL		
				<i>Vibrio parahaemolyticus</i>	ZOI: 6.5 mm; MIC: 0.15 mg/mL		
<i>Sonchus lingianus</i>	Aerial part	Methanol	Phenolic acid and flavonoid	<i>Staphylococcus aureus</i>	ZOI: 13.5 mm; MIC: 0.02 mg/mL	Disc diffusion method	[52]
				<i>Escherichia coli</i>	ZOI: 16.0 mm; MIC: 0.04 mg/mL		
				<i>Salmonella enterica</i>	ZOI: 15.5 mm; MIC: 0.05 mg/mL		
				<i>Vibrio parahaemolyticus</i>	ZOI: 10.0 mm; MIC: 0.05 mg/mL		
Antifungal							
<i>Sonchus oleraceus</i>	Leaves	Methanol	Phenolic acid, flavonol, glycoside, flavone, and glycoside	<i>Aspergillus fumigatus</i>	MIC: 0.9 mg/mL	Microdilution method	[55]
				<i>Aspergillus ochraceus</i>	MIC: 0.037 mg/mL		
				<i>Aspergillus niger</i>	MIC: 0.9 mg/mL		
				<i>Penicillium funiculosum</i>	MIC: 0.6 mg/mL		
	Leaves	Water extract	Phenolic acid and flavonoid	<i>Aspergillus flavus</i>	ZOI: 4.4 to 13.7 mm	Agar well diffusion method	[60]
				<i>Aspergillus ochraceus</i>	ZOI: 7.1 to 22.8 mm		
				<i>Aspergillus parasiticus</i>	ZOI: 6.6 to 20.5 mm		
	Stem, root, leaves, inflorescence	Methanol	Alkenes, fatty acid, methyl esters, fatty alcohols, phenolics, and aliphatic aldehyde	<i>Macrophomina phaseolina</i>	% Inhibition of fungal biomass for different parts of the plant – Stem: 54% to 84%; leaves: 7% to 73%; root: 49% to 82%; inflorescence: 51% to 87%	Mycelial growth inhibition assay	[59]

Table 2. Antibacterial, antifungal, antiparasitic, and antiviral activities of *Sonchus* species (continued).

<i>Sonchus</i> plant	Part used	Type of extract	Bioactive compounds	Microorganism(s)	Findings	Used method	Ref
<i>Sonchus asper</i>	Whole plant	Methanol, <i>n</i> -hexane, chloroform, butanol, ethyl acetate, and water	-	<i>Aspergillus niger</i>	% Inhibition of fungal growth: 33.3% to 91.1%	Agar tube dilution method	[56]
				<i>Fusarium solani</i>	% Inhibition of fungal growth: 12.50% to 93.75%		
				<i>Aspergillus flavus</i>	% Inhibition of fungal growth: 5.0% to 64.5%		
				<i>Aspergillus fumigatus</i>	% Inhibition of fungal growth: 27.70% to 88.15%		
	Root	Methanol	Phenolic, retinoid, fatty acid, amino acid, and pyridines	<i>Rhizoctonia solani</i>	% Inhibition of fungal biomass at concentrations of 1.56 to 200 mg/mL: 52% to 97%	Mycelial growth inhibition assay	[61]
<i>Sonchus erzincanicus</i>	Aerial part	Methanol	Phenolic	<i>Candida albicans</i>	ZOI: 25 mm; MIC: 0.156 mg/mL	Disc diffusion method	[58]
Antiparasitic							
<i>Sonchus arvensis</i>	Leaves	<i>n</i> -hexane, ethyl acetate, and ethanol	Terpenoid, flavonoid, alkaloid, saponin, and polyphenol	<i>Plasmodium falciparum</i> (in vitro); <i>Plasmodium berghei</i> (in vivo)	<i>In vitro</i> % inhibition (IC ₅₀ at concentrations of 0.01 to 100 µg/mL) – <i>n</i> -hexane: 31.7% to 100% (5.1 µg/mL); ethyl acetate: 34.8% to 100.0% (2.9 µg/mL); ethanol: 13.1% to 93.6% (8.0 µg/mL) <i>In vivo</i> % inhibition, ED ₅₀ at concentrations of 1 to 200 mg/kg – Inhibition = 32.86% to 77.48%; ED ₅₀ = 46.31 mg/kg	Giemsa-stained microscopic assay	[62]
Antiviral							
<i>Sonchus arvensis</i>	Leaves	<i>n</i> -hexane	Terpenoid	SARS-CoV-2	Inhibited the replication of SARS-CoV-2 virus through binding with virus protein helicase, RdRp, Mpro, and RBD-spike protein	Molecular docking simulation	[63]

(-): Unpresented data; ZOI: zone of inhibition; MIC: minimum inhibitory concentration; NA: not available; IC₅₀: half-maximal inhibitory concentration; ED₅₀: median effective dose; SARS-CoV-2: severe acute respiratory syndrome coronavirus 2; RdRp: RNA-dependent RNA polymerase; Mpro: main protease; RBD-spike: receptor-binding domain-spike.

phenolics, flavonoids, alkaloids, coumarins, and terpenoids. Notably, phenolic and flavonoid compounds are well-recognized for their antioxidant and antimicrobial activities [48–50].

4.1. Antibacterial activity

Bacterial infections continue to pose a major obstacle in the field of infectious diseases, prompting more than five decades of extensive research aimed at identifying novel antimicrobial drugs from diverse origins. The continuous rise of multidrug-resistant bacteria highlights the pressing necessity to discover new antibacterial medicines, despite the significant advancements made in the development of antibacterial treatments [51].

The antibacterial properties of *Sonchus* species against a wide range of pathogens have been consistently documented in scientific literature over the years. For instance, Xia *et al.* [52] reported that *S. oleraceus* and *S. arvensis* exhibited the highest levels of phenolic acids and flavonoids among six selected *Sonchus* species, which likely contributed to their notable antibacterial effects against both Gram-positive and Gram-negative bacteria. Specifically, the

methanolic extract of *S. oleraceus*, *S. arvensis*, and *Sonchus lingianus* displayed strong antibacterial activity against *Escherichia coli* (*E. coli*), *Salmonella enterica*, *Vibrio parahaemolyticus* and *Staphylococcus aureus* (*S. aureus*), with minimum inhibitory concentrations (MICs) of 0.02 to 0.10 mg/mL. Meanwhile, *Sonchus uliginosus* and *Sonchus brachyotus* showed lower antibacterial activity, which correlated with their lower phenolic and flavonoid content, suggesting the importance of phenolic and flavonoid content in modulating antibacterial activity [52].

Moreover, the ability of *S. oleraceus* to inhibit both *S. aureus* and *E. coli* with relatively low MIC values (5 mg/mL) aligns with previous research findings by Li *et al.* [53], where aqueous extract of *S. oleraceus* showed the highest antibacterial activity among several other traditional Chinese medicinal plants, namely *Scutellaria baicalensis* and *Coptis chinensis*. Meanwhile, a study on *S. oleraceus* roots showed the presence of several bioactive compounds ranging from benzofurans, sesquiterpenes, and triterpenoids like loliolide, 15-*O*-β-glucopyranosyl-11β,13-dihydrourospermal A, ursolic acid, lupeol and β-sitosterol-3-*O*-glucopyranoside, which exhibited significant inhibitory effects against *S. aureus*, *Bacillus subtilis*

(*B. subtilis*), *E. coli* and *Neisseria gonorrhoeae*. The same study highlighted that among these compounds, loliolide and 15-*O*- β -glucopyranosyl-11 β ,13-dihydrourospermal A displayed notable antibacterial activity, with inhibition zones ranging from 7 to 16 mm at concentrations of 5 and 10 μ g/mL, depending on the bacterial strain tested[54]. In a previous study[55], *S. oleraceus* extract also showed significant and higher bacteriostatic and bactericidal efficacy (MICs ranged from 0.15 to 0.30 mg/mL) against *Bacillus cereus* and *Salmonella typhimurium*, as compared to the positive control ampicillin (MICs ranged from 0.25 to 0.75 mg/mL). Furthermore, ten individual phenolic compounds were also detected in *S. oleraceus* aerial parts extracts, with luteolin and apigenin derivatives being the most abundant[55].

In addition to *S. oleraceus*, *S. asper* is another commonly studied species for combating these pathogens; however, its efficacy depends on the extraction methods and bioassay conditions performed. For instance, a study on the methanol, ethanol, and aqueous extracts of *S. asper* leaves reported that the methanolic extract especially showed strong antibacterial effects against multidrug-resistant pathogens, particularly *S. aureus* ATCC43300, with an inhibition zone of 24 mm, which closely matches that of the antibiotic streptomycin (26 mm)[17]. Additionally, the methanolic extract also significantly inhibited *B. subtilis* (17 mm), *E. coli* (19 mm), and *Pseudomonas aeruginosa* (15 mm). While the ethanolic and aqueous extracts exhibited antibacterial activity against the same bacteria, their effects were not more prominent than those of the methanolic extract[17]. Likewise, the acetone extract of *S. asper* also elicited inhibitory activity against three Gram-positive bacteria, namely *S. aureus*, *Bacillus cereus*, and *Micrococcus kristinae*[5]. In contrast, the acetone extract of *S. oleraceus* demonstrated a more significant antibacterial effect against seven bacteria: *S. aureus*, *Bacillus cereus*, *Staphylococcus epidermidis*, *Micrococcus kristinae*, *E. coli*, *Serratia marcescens* and *Pseudomonas aeruginosa*. Acetone extracts of *S. asper* and *S. oleraceus* exhibited MICs of 2.0 to 5.0 mg/mL and 1.0 to 5.0 mg/mL, respectively, which was in agreement with another study[52] that reported higher antibacterial efficacy in *S. oleraceus* compared to *S. asper*. The study also found that both *Sonchus* species are rich in minerals, flavonoids, flavonols, proanthocyanidins, and total phenols and had low levels of saponins, phytate, and alkaloids[5].

Previously, Khan *et al.*[56] also observed the efficacy of *S. asper* extracted with different solvents against both Gram-positive and Gram-negative bacteria, encompassing *E. coli*, *B. subtilis*, *Micrococcus luteus*, *Klebsiella pneumoniae*, *S. aureus*, and *Pseudomonas aeruginosa*. Notably, the methanolic extract of *S. asper* exhibited the highest activity, achieving MICs of 2.5 μ g/mL for *S. aureus* and 1 μ g/mL for *Klebsiella pneumoniae*. Furthermore, Gram-positive *B. subtilis* and *Micrococcus luteus* are also susceptible to the methanolic extract, with MICs of 1 μ g/mL and 2.5 μ g/mL, respectively[56].

In an antibacterial study on *S. arvensis*, Xia *et al.*[57] successfully isolated two new sesquiterpene lactones along with eight previously known compounds from *S. arvensis* and evaluated their inhibitory

activity against *Streptococcus mutans*, a key pathogen in dental caries. Among the compounds tested, two sesquiterpene lactones, namely 1 β -sulfate-5 α , 6 β H-eudesma-3-en-12, 6 α -olide (compound 1) and (1 β , 6 α)-1, 6, 14-trihydroxyeudesma-3,11 (13)-dien-12-oic acid- γ -lactone (compound 2) exhibited significant antibacterial effect, with MICs of 15.6 μ g/mL and 62.5 μ g/mL, respectively[57]. In a previous study, the methanol and water extracts of *Sonchus erzincanicus* significantly reduced the growth of *Proteus mirabilis* at a MIC of 1.25 mg/mL[58].

4.2. Antifungal activity

Sonchus species have gained attention for their antifungal properties against a range of pathogenic fungi, thus offering promising avenues for the development of new treatments in response to increasing drug resistance. For instance, an antifungal assay conducted by Banaras *et al.*[59] found that methanolic extracts (10 to 50 mg/mL) derived from different parts of *S. oleraceus*, effectively inhibited the growth of *Macrophomina phaseolina*, a pathogenic fungus. The stem extract displayed the most potent antifungal activity, reducing fungal biomass by 56% to 84%, followed closely by root extract, which reduced the fungal biomass by 51% to 87%, in comparison to inflorescence (49% to 82%) and leaf extracts (7% to 73%). Furthermore, it was also observed that the chloroform subfraction exhibited the strongest antifungal activity against *Macrophomina phaseolina*, with a 60% to 90% reduction in fungal biomass compared to the *n*-hexane fraction, which achieved a 15% to 66% reduction. According to the GC-MS analysis of the chloroform subfraction, several key bioactive compounds were identified, including 2-decenal (*Z*), 1-docosene, hexadecanoic acid methyl ester, 11-octadecanoic acid methyl ester, and 1,2-benzenedicarboxylic acid diisooctyl ester, which likely contributed to the antifungal activity of *S. oleraceus* against *Macrophomina phaseolina*[59].

Moreover, the significant antifungal potential of *S. oleraceus* has been further validated by recent findings[60]. Specifically, *S. oleraceus* methanol extract exhibited an inhibition zone of 4.4 to 13.7 mm against *Aspergillus flavus* (*A. flavus*) and even higher against *Aspergillus ochraceus* (7.1 to 22.8 mm) and *Aspergillus parasiticus* (6.6 to 20.5 mm) at three concentrations (1.5, 2.5 and 5 mg/mL). Interestingly, the study also revealed that the methanolic extract of *S. oleraceus* demonstrated a strong ability to mitigate the production of harmful mycotoxins produced by *Aspergillus*, indicating that the extract effectively inhibited aflatoxin B1 production by up to 78.03% in *A. flavus* and reduced ochratoxin A production by 77.5% in *Aspergillus ochraceus* at the highest concentration tested (5 mg/mL)[60].

Similarly, Khan *et al.*[56] documented that all solvent extracts and various fractions of *S. asper* inhibited the growth of various phytophagous fungi strains, namely *Aspergillus niger*, *Fusarium solani*, *A. flavus*, and *Aspergillus fumigatus*, to some extent, at a concentration of 200 μ g/mL. The methanolic fraction of the extract displayed the highest activity against *Aspergillus niger* and

Aspergillus fumigatus, with inhibition rates of 91.1% and 88.15%, respectively. Meanwhile, the ethyl acetate and butanol extracts significantly inhibited *Fusarium solani*, with inhibition rates of 88.7% and 93.75%, respectively. In contrast, the chloroform extract demonstrated the strongest inhibition against *A. flavus*, achieving a maximum inhibition rate of 64.5% when compared to other extracts[56].

In another recent study, the methanolic root extract of *S. asper* was also evaluated against *Rhizoctonia solani*[61]. Indeed, results showed that the methanolic extract of *S. asper* significantly reduces the fungal biomass by up to 97% in a dose-dependent manner. The antifungal action was attributed to several key bioactive compounds identified using GC-MS analysis, including benzoic acid, 4-hydroxy-3-methoxy, methyl ester, 13-*cis*-retinoic acid, pyridine, 2-pentyl, 9-octadecenamide, (Z)- and L-proline, indicating the extract's potential as a fungicidal agent against *Rhizoctonia solani*[61].

Moreover, previous investigations also pointed out the fungicidal activity of *Sonchus erzincanicus* against *Candida albicans*, a common commensal fungus responsible for candidiasis. Meanwhile, the antifungal effects of water and methanolic extracts of *Sonchus erzincanicus* were evaluated against 20 fungal strains of *Candida albicans*[58]. It was reported that *Candida albicans* is the most susceptible to the methanolic extract, exhibiting a 25-mm inhibition zone and MIC of 0.156 mg/mL[58].

4.3. Antiparasitic activity

A recent study evaluated the *in vitro* inhibitory effects of different types of *S. arvensis* leaf extract on *Plasmodium falciparum* 3D7 using a Giemsa-stained microscopic assay, as well as their *in vivo* effects in *Plasmodium berghei*-infected mice using Peter's suppressive test model[62]. Among all the extracts, the ethyl acetate extract of *S. arvensis* was the most potent, with an IC_{50} of 2.9 μ g/mL. *In vivo* results showed that after 14 days of treatment, the disease severity in mice treated with *S. arvensis* ethyl acetate was significantly reduced in a dose-dependent manner (1 to 200 mg/kg), achieving up to 77.48% parasite inhibition with an ED_{50} of 46.31 mg/kg body weight[62].

4.4. Antiviral activity

Although research on the antiviral properties of the *Sonchus* species is still in its infancy, with only one published study to date, the findings are promising and warrant further investigation. A recent study has shed light on the potential of *S. arvensis* as an antiviral agent, particularly against SARS-CoV-2, the virus responsible for COVID-19[63]. The study identified several bioactive compounds within the *n*-hexane fraction of *S. arvensis* leaves, such as α -amyrin, β -amyrin, betulin, and taraxasterol, which exhibit strong inhibitory effects on key viral proteins of SARS-CoV-2. Moreover, the molecular docking study has also unveiled the potential mechanism of action employed by the dual inhibitory potential of α -amyrin

and β -amyrin, which can target more than one viral protein. This dual activity could make them more effective as broad-spectrum antivirals, contributing significantly to the development of new therapeutic strategies against SARS-CoV-2 and other viruses[63].

5. Mechanistic insights into the antimicrobial activities of *Sonchus* species

The antimicrobial activity of the *Sonchus* species is likely influenced by its rich content of bioactive compounds such as flavonoids, alkaloids, phenolic acids, and terpenes. Based on research involving other medicinal plants with similar constituents, *Sonchus* species will likely employ similar antimicrobial mechanisms. Specifically, the phytochemical profile of *S. arvensis* suggests that its flavonoids may alter lipid polarity within bacterial DNA, while its alkaloids could disrupt the peptidoglycan structure of bacterial cell wall, compromising cell integrity and blocking the creation of nucleic acids and proteins[21,63]. Another plausible antimicrobial action of alkaloids is their role as ATP-dependent efflux pump inhibitors, which can decrease efflux pump activity and prevent the active expulsion of antibiotics from bacterial cells. This inhibition mitigates antibiotic resistance and enhances antimicrobial efficacy[64,65]. Meanwhile, the mechanism of action of terpenoids remains incompletely understood, but it is hypothesized to involve disruption of cellular membranes by lipophilic compounds, interference with the proton motive force, and coagulation of cellular contents[66]. Furthermore, phenolic acids exhibit multifaceted actions against different bacterial strains, including synergistic effects through efflux pump inhibition, interactions with the cell membrane, inhibition of cell wall biosynthesis, and suppression of key enzymes such as urease, sortase A and dihydrofolate reductase, suggesting that phenolic acids isolated from *Sonchus* species may employ similar strategies in exerting antimicrobial effects[67].

Another potential antimicrobial strategy of *S. oleraceus* was shown in a study conducted by Al-Hussaini *et al.*[68]. Their findings revealed that the ethanolic extract of *S. oleraceus* exhibited prominent anti-quorum sensing activity against Gram-negative *Chromobacterium violaceum*, which in turn may interrupt bacterial communication and biofilm formation, thereby leading to attenuation of bacterial virulence. These findings suggest the prospects of *Sonchus* species as novel anti-quorum sensing agents against disease-causing bacteria.

On the other hand, Li *et al.*[69] investigated the novel antibacterial mechanism of ethanol extract from *Sonchus brachyotus* and found that the extract targeted the bacterial membrane in *E. coli* by inducing apoptosis-like death *via* reactive oxygen species generation. Similarly, Han *et al.*[70] reported that β -amyrin, found in *Sonchus* species, also induced reactive oxygen species accumulation in *E. coli*, which disrupted glutathione homeostasis, a key antioxidant defense mechanism, causing membrane depolarization and the release of apoptotic factors such as caspase-like proteins. These

proteins subsequently promoted the cleavage of DNA into single strands, which is a hallmark of apoptosis-like death in bacteria[70].

The antiparasitic activity of *Sonchus* species remains an area of interest, with several mechanisms of action postulated for various natural antiplasmodial agents. However, the specific mode of action underlying the antiplasmodial potential of *Sonchus* species has yet to be thoroughly investigated. Previous studies have reported that quercetin, a flavonoid, exerts its antiparasitic effect through the destruction of mitochondrial function and the inhibition of different important enzymes and molecules, including heat-shock protein, acetylcholinesterase, DNA topoisomerase, and kinase[71,72]. Interestingly, quercetin has also been isolated from the leaves of *S. arvensis*[63], suggesting that quercetin may contribute to the antiparasitic activity of the *Sonchus* species.

Meanwhile, the antifungal effects of flavonoids and phenolics derived from *Sonchus* species have been observed through several potential mechanisms, which specifically impact fungal cellular processes. The key mechanisms involve disrupting membrane functions by changing the permeability of cellular membranes, interfering with cell division, inhibiting RNA and protein synthesis, and inducing lipid oxidation in cells, ultimately leading to fungal growth inhibition[60].

The antiviral mechanisms of *Sonchus* species, particularly through the compounds α -amyrin and β -amyrin, have garnered attention for their potential efficacy against viral infections, including SARS-CoV-2. Recent *in silico* studies indicate that these compounds can effectively bind to important viral proteins such as helicase, RNA-dependent RNA polymerase (RdRp), and main protease (Mpro), showing stronger binding than standard antiviral drugs. By blocking RdRp, they can prevent the replication of viral RNA, thereby reducing the viral load in the host. Additionally, they disrupt Mpro's role in processing viral proteins and hinder helicase's function in unwinding RNA for replication[63]. Moreover, quercetin, a flavonoid found in *Sonchus* species, has been identified as a novel antiviral agent due to its ability to modulate the inflammatory response and efficiently improve the outcome of influenza disease[73]. It has been shown to significantly upregulate the expression level of anti-inflammatory cytokine IL-27 and downregulate the pro-inflammatory cytokine TNF- α induced by influenza viruses *in vitro*[73]. The upregulation of IL-27 promotes IL-10 production by antiviral CD4⁺ cytotoxic T lymphocytes, mitigating excessive immune responses[74]. This regulatory effect suggests that quercetin can enhance the immune response by promoting anti-inflammatory pathways while simultaneously inhibiting detrimental pro-inflammatory signals[75]. Additionally, quercetin has been shown to induce the expression of interferons (IFNs), which are critical components of the innate immune response against viral infections[76,77]. By enhancing IFN signaling pathways, quercetin may further bolster the antiviral defenses of host cells, facilitating a more robust immune response against pathogens[78]. Similarly, another study[68] also demonstrated

the inhibition of pro-inflammatory cytokines such as TNF- α , IL-1 β , and IL-6 in lipopolysaccharide-stimulated macrophages by extracts of *S. oleraceus*. This inhibition suggests that *Sonchus* extracts can help regulate inflammatory responses, preventing excessive inflammation that could lead to tissue damage[79]. Collectively, the compounds derived from *Sonchus* species not only exhibit direct antiviral properties but also enhance the host's immune response by the modulation of inflammatory pathways and upregulation of key immune mediators like IFNs and interferon-stimulated genes. This dual mechanism positions *Sonchus* species as promising candidates for further research in antiviral therapeutics.

6. Conclusion

Research has shown that extracts from *Sonchus* species, including *S. oleraceus*, *S. asper*, and *S. arvensis*, exhibit broad-spectrum antimicrobial activity. This includes antibacterial effects against both Gram-positive and Gram-negative bacteria, as well as antifungal, antiparasitic, and antiviral properties. The diverse phytochemical composition of *Sonchus* species, ranging from terpenes, flavonoids, phenolic acids, esters, steroids, and polysaccharides, underpins their therapeutic potential. However, while many species within the genus have been studied for *in vitro* antimicrobial activity, understanding the underlying molecular mechanisms remains limited. This gap highlights the need for molecular pharmacological studies to develop potent antimicrobial agents from the *Sonchus* genus. Moreover, while current studies have highlighted the biological activities of *Sonchus* species, their potential for treating human diseases remains underexplored. Expanding *in vivo* research could significantly enhance the medicinal applications of *Sonchus* species. In addition, future research should expand upon the limited findings regarding the antiviral activity of *Sonchus* species, as only a single study has explored this potential to date. Comprehensive investigations should aim to isolate, identify, and characterize the bioactive antiviral compounds within the *Sonchus* species, followed by elucidating their structural attributes and mechanisms of action against pathogens.

In conclusion, *Sonchus* species demonstrate inhibitory effects against various pathogens, making them promising candidates for developing natural-resource-based pharmaceuticals. Their rich reservoir of bioactive compounds offers significant potential for next-generation antimicrobial agents, warranting further research into their therapeutic mechanisms and clinical applications.

Conflict of interest statement

All authors declare that they have no conflict of interest.

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Data availability statement

The data supporting the findings of this study are available from the corresponding authors upon request.

Authors' contributions

NNZ and KLC conceptualized the review, designed the structural and intellectual content and drafted the original manuscript. KLC and DKW, as the corresponding authors, supervised the overall organization of the work. Meanwhile, NZ SM and KDR revised and refined the manuscript.

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