Chapter 13

Taraxacum Genus: Potential Antibacterial and Antifungal Activity

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.71619

Abstract

Plants have been used in traditional medicine for centuries as antibacterial and antifungal agents. *Taraxacum* spp., commonly known as dandelion, is a well-known herbal remedy with a long history; however, limited scientific information is available to explain its traditional use. This review aims to provide current information and a general overview of the available literature concerning the antibacterial and antifungal properties of the *Taraxacum* genus to support its potential as a powerful herbal medicine. Though *Taraxacum* has demonstrated that it is capable of inhibiting the growth of a wide range of bacteria and fungi, the technical aspects of methodology lack standardization, and, therefore, the overall results of processing are difficult to compare between studies. Phytochemical composition and antimicrobial activity in *Taraxacum* are neither directly related, nor does the published data provide sufficient information for identifying the group of unique extraction conditions that are optimal against specific microorganisms. Antimicrobial research indicates that this plant is a promising species for treating several common infections in humans, animals, and plants.

Keywords: antimicrobial, antifungal, ethnopharmacology, extraction, *Taraxacum* species

1. Introduction

Plants have been used in traditional medicine for centuries due to the synthesis of several molecules that provide antibacterial and antifungal properties, the majority of which probably evolved as defenses against infection or predation [1]. The medicinal potential of many plants is still largely unexplored. Among the estimated 250,000–500,000 plant species, a relatively small percentage have been investigated phytochemically and the fraction submitted for

biological or pharmacological screening is even smaller [2]; approximately 20% of the plant species in the world have been investigated for these properties [3]. In this context, dandelion serves as an interesting species with which to unify decades-old information regarding its biological potential against diverse microorganisms. This review gathers the existing results to advance the search for products that could strengthen the domestication and mass production of this plant.

The *Taraxacum* spp. commonly called dandelion is an herbaceous perennial plant of the *Asteraceae* (Compositae) family. This common weed is found worldwide, though originally introduced from Eurasia, and can be found growing in parks, gardens, pastures, orchards, roadsides, vegetable gardens, and among agricultural and horticultural crops [4]. Primarily used as food, the role of *Taraxacum* in traditional medicine was mentioned during ancient times by the Greek physician Dioscorides in the first century and during the renaissance by monks in Cyprus [5]. This plant has been used to treat cystitis, liver and gastric ailments, hepatic and renal detoxification, diabetes, as an anti-inflammatory and anticarcinogenic agent, and, to a lesser extent, as an antimicrobial and antiviral agent, as described in several reviews [6, 7]. Ethnopharmacologically, its use as an antimicrobial agent has been known worldwide among varying cultures, though it has always been administered as a cataplasm (poultice) or infusion. The traditional antimicrobial uses of *Taraxacum* worldwide are displayed in **Table 1**.

Asia and Europe have an important historical background regarding the traditional uses of *Taraxacum*, primarily *T. officinale*, *T. mongolicum*, and *T. coreanum*. This traditional knowledge has been the principal reason for studying the potential uses and crop requirements of *Taraxacum*; studies in America remain scarce [18]. Due to the unscientific approach often present in oral traditions, uncertainty surrounds whether *Taraxacum* use effectively treats microbial infection or, instead, treats only the symptoms. Therefore, scientific research is extremely important in avoiding misinterpretation and myths regarding *Taraxacum* or any other plant.

The first antibacterial scientific study for *Taraxacum* was reported a mere 35 years ago [19]. More than a decade later, studies related to *Taraxacum* antimicrobial activity gained significant

Species	Common use	Country	Part used	Consumption	References
T. cyprium	Catarrh and common cold, cough	Greece	Roots, leaves	—	[5]
T. mongolicum	Urinary tract infections	China	Leaf	Infusion	[8]
T. officinale	Malaria	Venezuela	Roots, leaves	Decoction	[9]
	Tuberculosis	Italy	—	—	[10]
	Cough	Italy	—	—	[11]
	Bacterial infection	Mexico	—	—	[12]
	Diuretic	Chikar	Roots	Tonico	[13]
T. panalpinum	Malaria	Portugal	Roots, leaves, juice	—	[14, 15]
T. platycarpum	Pleurodynia	Korea	Leaf, stem	Infusion Brewing	[16, 17]

Table 1. Ethnopharmacological information of *Taraxacum* genus used as an antimicrobial traditional medicine.

relevance as part of an Italian program between the University of Ferrara and the University of Naples for screening medicinal plants [20]. Nowadays, this plant is becoming a promising species in the treatment of several bacterial and fungal diseases due to the results of various antimicrobial-related studies. This chapter seeks to elucidate both the traditional uses and current state of *Taraxacum* in antimicrobial research to determine the potential that this genus has to become an industrial medicinal crop worldwide. Due to the high potential value that could be derived from the use of new technologies and industrial products developed from this type of plant species, the conservation and protection of the crop should be considered and sustainable global production strategies are developed in accordance with assessments of ecological, economic, and social factors.

2. Antimicrobial properties of the *Taraxacum* genus

Literature reviews providing information on the antimicrobial aspects of natural products, which had until now only been considered empirical, have been recently scientifically confirmed as a means of countering the increasing reports of pathogenic microorganisms resistant to synthetic antimicrobial agents. Some plant-derived compounds can control microbial growth, either separately or in association with conventional antimicrobials [21]. Currently, numerous studies seek to improve pathogen prevention by combining the application of medicinal herb extracts with an antibiotic or effective antipathogenic pesticide to reduce the active synthetic ingredient and resistant pathogenic strains.

2.1. *Taraxacum* species tested for antimicrobial properties

Among the *Taraxacum* genus, *T. officinale* is the most frequently reported species, with almost 80% of mentions in documents related to antimicrobial properties (see **Table 2**), followed by *T. mongolicum* and *T. coreanum*, though over 2500 *Taraxacum* species are currently identified [67]. Other, less studied species include *T. platycarpum*, *T. farinosum*, *T. ohwianum*, and *T. phaleratum*; however, the relevance of these species is confined to specific areas (mostly in Asia) in which they grow naturally since they are not deliberately cultivated for medicinal benefit. This indicates that the microbial properties of less than 1% of all *Taraxacum* species discovered have been studied, revealing the enormous research potential of this genus.

2.2. Bacterial and fungi strains tested

Taraxacum extracts have been tested on different bacterial and fungal strains affecting humans, animals, and plants to determine its antimicrobial profile, confirm its traditional usage, and expand its known uses. Antimicrobial agents are categorized based on the spectrum of action, namely "narrow" and "broad" spectrum, which indicates whether its use is specific for certain bacterial strains or active on a wider range. Bacterial infections can result in mild to life-threatening illnesses that require immediate antibiotic intervention. Alternatively, a superficial fungal infection is rarely life-threatening but can have debilitating effects and may spread to other people or become invasive or systemic, resulting in a life-threatening infection. The widespread, and sometimes inappropriate, use of chemical compounds can create antibiotic

Species	Autentification/ Voucher	C: Collected P: Purchase	Zone	Season	Plant part*	Sample manipulation	Ratio	Solvent	Extraction time	Temp.	Agitation	Inhibition activity**	Ref.
T. officinale Wigg.	No/No	NI	NI	NI	Flower	NI	1:10	Acetic acid 10%	1 h	RT	Homog.	+	[22]
T. officinale Wigg.	No/No	C	NI	Yes	Seeds	Grounded	1:10	Acetic acid 10%	1 h	RT	NI	+	[23]
T. officinale Weber	Yes/No	C	Yes	Yes	NI	Dried	NI	Water, ethanol and ethyl acetate	1 h	80°C	Maceration	+	[24]
T. officinale	Yes/Yes	C	Yes	NI	NI	Air-dried	1:14	Acetone	30 min	NI	NI	+	[25]
Taraxacum spp.	No/No	C	Yes	NI	NI	NI	1:10	Dichloromethane	3 h	20°C	Homog.	+	[26]
T. officinale	No/Yes	C	Yes	Yes	NI	NI	NI	Dichloromethane	3 days	NI	Homog.	+	[27]
T. coreanum	No/No	NI	NI	NI	NI	NI	1:3.3	Ethanol 75%	9 h	60°C	Reflux	+	[28]
T. mongolicum	No/No	C	NI	NI	Aerial	Frezee-dried and grounded 20-mesh	1:5	Ethanol 75%	2 days	NI	Soaked	+	[29]
T. officinale Weber	No/Yes	C	Yes	Yes	Root	Dried and grounded	NI	Ethanol 80%	NI	NI	Reflux	+	[20]
T. officinale F. H. Wigg	Yes/Yes	C	NI	NI	Aerial	Air-dried and crushed	1:1	Ethanol 90%	2 days	RT	Intermitent shaking	+	[30]
T. mongolicum H.					NI		1:10	Ethanol 95%	3 h	80°C		+	[31]
T. ohwianum	No/No	NI	NI	NI	NI	Freeze-dried, air-dried (40°C, 24 h), grounded 24-mesh	1:16	Ethanol 95%	24 h	RT (23°C)	Shaking	+	[32]
T. officinale	Yes/No	NI	NI	NI	Leaves	Air-dried	1:5	Ethylacetate	24 h	RT	150 rpm	+	[22]
T. officinale F.H. Wigg.	Yes/Yes	P	NI	NI	Root	Freeze-dried and blended	1:10	Hexane	Overnight	RT	70 rpm	+	[33]

http://dx.doi.org/10.5772/intechopen.71619

Species	Autentification/ Voucher	C: Collected P: Purchase	Zone	Season	Plant part*	Sample manipulation	Ratio	Solvent	Extraction time	Temp.	Agitation	Inhibition activity**	Ref.
T. officinale	No/No	NI	NI	NI	Leaves	Air-dried 1 month and grounded	1:1.4	Methanol 75%	NI	NI	NI	+	[34]
T. officinale Weber	No/No	C	Yes	NI	Aerial	Air-dried a 40°C (36–48 h) and grounded	1:5	Methanol 80%	1 h	100°C	Reflux	+	[35]
T. officinale Weber ex. F. H. Wigg	No/Yes	NI	NI	NI	Leaves	NI	1:4	Methanol	5 days	RT	NI	+	[36]
T. officinale Weber	No/No	C	NI	NI	Aerial	Dry under shade and ground	1:10	Methanol	3 weeks	25°C	Homog.	+	[37]
T. platycarpum	No/No	NI	NI	NI	NI	Dried	NI	Methanol	3 h	80°C	NI	+	[38]
T. platycarpum	No/No	NI	NI	NI	NI	Dried	NI	Methanol	3 h	80°C	NI	+	[39]
T. officinale					NI		NI	Methanol	16 h	50°C		+	[40]
T. officinale	No/No	C	NI	NI	Leaves	Dried under shade and grounded	1:2.5	Methanol	24 h	37°C	120 rpm	+	[41]
T. mongolicum Hand-Mazz	Yes/Yes	C	Yes	Yes	NI	Air-dried and grounded	NI	Water	3 h	100°C	By boiling	+	[36]
T. officinale					NI		1:05	Water	NI	NI	Homog.	+	[42]
T. officinale	No/No	NI	NI	NI	NI	Dried at 25–30°C for 1 week., ground with a mortar	1:20	Water	24 h	35°C	Shaking	+	[43]
T. officinale F.H. (Webb)	No/No	C/P	NI	NI	Root	Cleaning prior freeze-dried, grounded	1:10	Water	3 h	RT	170 rpm	+	[44]

Species	Autentification/ Voucher	C: Collected P: Purchase	Zone	Season	Plant part*	Sample manipulation	Ratio	Solvent	Extraction time	Temp.	Agitation	Inhibition activity**	Ref.
T. officinale	No/No	NI	NI	NI	NI	NI	1:04	Water	45 min	100°C	NI	+	[45]
T. officinale Weber ex Wigger	No/No	NI	NI	NI	leaves	Grounded	1:01	Water	5 min	NI	NI	+	[46]
T. mongolicum	No/No	NI	NI	NI	NI	Grounded	NI	Water	1 h	100°C	By boiling	+	[47]
T. officinale	No/No	NI	NI	NI	NI	Dried at 60°C × 2 h and grounded 60-mesh	1:10	Water	NI	NI	NI	+	[48]
T. officinale H.	NI/NI	NI	NI	NI	NI	NI						+	[49]
T. officinale F.H. Wigg	NI/NI	C	Yes	Yes	Honey	NI	NI	NI	NI	NI	NI	+	[50]
T. farinosum Hausskn. & Bornm	NI/NI	C	NI	Yes	Root	NI	NI	NI	NI	NI	NI	+	[51]
T. officinale	Yes/No	C	Yes	Yes	NI	Dried 40°C × 5 days and grounded	NI	NI	NI	NI	Reflux	+	[52]
T. officinale	NI/NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	+W	[53]
T. officinale	No/No	P	NI	NI	NI	NI	NI	Ethanol 35%	NI	NI	NI	+W	[54]
T. platycarpum	No/No	P	NI	NI	NI	Grounded 50-mesh	1:10	Ethanol	24 h	RT	Homog.	+W	[55]
Taraxacum sp.	No/No	NI	NI	NI	Aerial	Grounded	1:10	Water	4 h	100°C	By boiling	+W	[56]
T. officinale F.H. Wigg.	No/No	C	Yes	Yes	Aerial	Frozen, cut and grounded	1:01	Ethanol 20%	24 h	RT	NI	–	[57]
T. officinale	No/No	NI	NI	NI	Leaves	Dried	NI	Ethanol 40%	NI	NI	NI	–	[58]

Species	**Autentification/ Voucher**	**C: Collected P: Purchase**	**Zone**	**Season**	**Plant part***	**Sample manipulation**	**Ratio**	**Solvent**	**Extraction time**	**Temp.**	**Agitation**	**Inhibition activity****	**Ref.**
T. officinale	No/No	Extract (P)	NI	NI	NI	Diluted	NI	ethanol 45%	NI	NI	NI	–	[59]
T. phaleratum G. Hagl et Rech	Yes/Yes	C	Yes	NI	Aerial	Air-dried and grounded	NI	Ethanol 70%	NI	RT	NI	–	[60]
T. officinale Cass.	No/No	P	NI	NI	Root	Dried	1:04	Ethanol	24 h	NI		–	[61]
T. officinale	No/No	C	Yes	NI	flower	Chopped and frozen	NI	Methanol 90%	30 min	4°C	Homog.	–	[62]
T. officinale Weber	Yes/Yes	NI	NI	NI	NI	Dried and grounded	1:40	Methanol	Overnight	RT	NI	–	[63]
T. mongolicum Hand-Mazz	No/Yes	C	NI	NI	Whole	NI	1:10	Water	Overnight	NI	Homog.	–	[64]
T. officinale	No/No	P	NI	NI	Root	Grounded	1:8.3	Water	30 min	100°C	By boiling	–	[65]
T. officinale	No/No	C	Yes	Yes	Leafs, roots	NI	1:03	Water		RT	Homog.	–	[66]

*NI, No indicated.

Table 2. Physical parameters on *Taraxacum* extracts for testing antimicrobial activity.

http://dx.doi.org/10.5772/intechopen.71619

resistance. Due to this issue, the potential of *Taraxacum* as a useful, broad-spectrum antimicrobial and antifungal agent that can be "easily and worldwide grown," is highly valuable. A list of the strains against which *Taraxacum*'s antimicrobial activity has been tested is displayed in **Table 3**.

Bacterial strains	**Fungi strains**
Aeromonas hydrophila (−) [22]	*Alternaria alternata* (+) [46, 68]
Agrobacterium tumefaciens (+) [24]	*Aspergillus carbonarius* (+) [35]
Bacillus cereus (+) [22, 33, 36, 44] (−) [66]	*A. niger* (+) [23, 35, 37, 68, 69] (−) [27, 66]
B. pumilus (−) [66]	*A. flavus* (+) [37] (−) [66]
B. subtilis (+) [20, 24, 25, 27, 29, 34, 38, 39, 41, 48, 69] (−) [37, 64, 66]	*A. fumigatus* (+) [37](−) [66]
Campylobacter jejuni (+) [54, 59]	*Bipolaris sorokiniana* (+) [23, 67] (−) [68]
Chromobacterium violaceum (+) [66] (−) [65]	*Botrytis cinerea* (+) [23, 35, 67]
Clavibacter michiganense (+) [69]	*Candida albicans* (+) [27, 34, 36, 52] (−) [55, 57, 66]
Cupriavidus sp. (−) [66]	*C. glabrata* (−) [55, 66]
Enterobacter coccus (−) [37]	*C. krusei* (−) [66]
Enterococcus faecalis (+) [53] (−) [37, 66]	*C. parapsilesis* (−) [55, 66]
Erwinia carotovora (+) [24]	*C. utils* (−) [55]
Escherichia coli (+) [22, 24, 25, 27, 29, 34, 36, 38, 39, 41, 43, 45, 47, 48, 58, 70] (−) [20, 32, 33, 37, 44, 57, 62, 64, 66]	*C. tropicalis* (+) [55]
	Cladosporium herbarum (+) [71]
Helicobacter pylori (+) [31, 54]	*Cochliobolus sativus* (+) [68]
Klebsiella aerogenes (−) [66]	*Colletotrichium gloesporoides* (−) [68]
K. penumoniae (+) [29, 36] (−) [20, 37, 45, 66]	*C. lagenarium* (+) [42]
Listeria monocytogenes (+) [38, 39] (−) [66]	*Cryptococcus neoformans* (+) [36]
Micrococcus kristinae (+) [25]	*Exophiala (Wangiella) dermatitidis* (−) [66]
M. luteus (+) [37, 41]	*Fusarium avenaceum* (+) [68]
Mycobacterium aurum (−) [63]	*F. graminearum* (−) [69]
M. bovis (−) [63]	*F. oxysporum* (+) [23, 56, 69]
M. smegmatis (−) [63]	*Microsporum canis* (+) [51]
M. tuberculosis (−) [60]	*Monilinia laxa* (+) [35]
Propionihacterium acnes (+) [49]	*Mucor piriformis* (+) [46]
Proteus mirabilis (+) [43] (−) [20]	*Penicillium sp.* (−) [66]
P. vulgaris (+) [25, 29] (−) [70]	*P. digitatum* (+) [35]
Pseudomonas sp. (−) [50]	*P. expansum* (+) [26, 46] (−) [35]
P. aeruginosa (+) [24, 27, 29, 36, 41, 49, 70] (−) [20, 37, 57, 64, 66]	*P. italicum* (+) [35]

Bacterial strains	Fungi strains
P. fluorescens (+) [24]	*Ph. betae* (+) [23, 68]
P. syringae (+) [69]	*Phytophthora infestans* (+) [69]
Serratia/Rahnella sp. (−) [66]	*Pityrosporum ovale* (+) [49]
Salmonella typhimurium (+) [36] (−) [33, 44]	*Pythium debaryanum* (+) [69]
S. abony enterica (+) [58]	*Rhizoctonia solani* (+) [37, 56]
S. poona (−) [66]	*Saccharomyces cereviseae* (+) [34]
S. typhi (+) [44, 51] (−) [20]	*Saprolegnia australis* (−) [61]
Sarcina lutea (+) [24]	*Scedosporium apiospermum* (−) [66]
Serratia marcescens (+) [25] (−) [66]	*Trichophyton longifusus* (+) [51]
Shigella fiexeri (−) [70]	*T. mentagrophytes* (+) [27]
S. sonnei (+) [36]	*Verticillium albo-atrum* (+) [23] (−) [68]
Staphylococcus aureus (+) [22, 24, 25, 28, 29, 32–34, 36, 38, 39, 41, 43–45, 48–52, 70] (−) [20, 27, 37, 57, 58, 62, 64, 66]	
S. epidermidis (+) [28] (−) [66]	
Streptococcus haemolyticus (+) [20]	
S. agalactiae (+) [47]	
S. dysgalactiae (+) [47]	
Vibrio cholerae (+) [37]	
V. parahaemolyticus (+) [38, 39]	
Xanthomonas campestris (+) [69]	

(+) Extracts of *Taraxacum* active against the pathogen; (−) extracts of *Taraxacum* inactive against the pathogen.

Table 3. Bacterial and fungal strains on which *Taraxacum* extracts have been tested.

2.2.1. Human pathogens

In the study of antibacterial properties of these plants, most attention has been focused on human pathogenic strains, including *S. aureus*, *E. faecalis*, *V. cholerae*, *B. subtilis*, *P. aeruginosa*, *K. pneumonia*, and *E. coli*. These are the pathogens commonly responsible for infections in gastrointestinal and massive organ systems such as the lungs and skin. *Taraxacum officinale* is the species generally studied to combat these pathogens, but it has demonstrated diverse results depending on the extraction characteristics or the bioassay performed. For instance, a methanolic extract of *T. officinale* at 0.2 mg/mL was as effective as an antibacterial agent against *M. luteus* and *V. cholera* with minimum inhibitory concentration (MIC) values of 1.0 and 12.5 mg/mL, respectively, but displayed no activity against *S. aureus*, *E. faecalis*, *E. bacter*, *V. cholerae*, *B. subtilis*, *P. aeruginosa*, *K. pneumonia*, *or E. coli* [37]. In the same study, the inhibition percentages achieved for mycelial growth of *A. niger*, *A. flavus*, *A. fumigatus*, and *R. solani* were 37, 71, 85, and 78%, respectively. Other works indicate that methanolic *T. officinale* leaf extracts ranging from 0.003 to 0.5 mg/mL were active against *S. aureus*, *P. aeruginosa*, *B. cereus*, *S. sonnei*,

S. enterica serovar *typhimurium*, *E. coli*, *K. pneumonia*, *C. albicans*, and *C. neoformans* with MIC values ranging from 0.04 to 5.0 mg/mL [36]. A similar extract at 10 mg/mL displayed moderate growth diameter inhibition for *S. typhi*, but was highly active for *S. aureus*, *B. cereus*, and *E. coli*, even when no activity was observed for *A. hydrophila* [22]. Ethanolic extracts of 2.0 mg/mL were active against *A. aureus*, *MRSA* clinical, and *B. cereus*, with MIC values between 0.38 and 0.5 mg/mL, but were not effective against *E. coli* or *S. typhi*. In the same work, a water extract at the same concentration showed no activity against any strain tested [33]. Moreover, 21 ethanolic extracts from various plants were tested against 20 *Salmonella* serovars. *Taraxacum* inhibited only 5% of these, and was therefore not considered for additional antimicrobial studies [72].

Recently, methanolic and chloroformic leaf extracts of *T. officinale* were found to be effective against *M. luteus*, *P. aeruginosa*, *B. subtilis*, *E. coli*, and *S. aureus* with MIC values of 0.3 mg/mL and no observable activity for water extracts [41]. In this study, the highest impact was noted with methanol and chloroform extracts against *S. aureus* and *E. coli*, respectively, and the lowest with both extracts against *P. aeruginosa*. Furthermore, an ethanolic extract was effective against *E. coli* and *S. aureus*, but no activity was observed for either extract against *K. pneumonia* and *P. aeruginosa* at 50, 100, and 200 mg/mL. Nevertheless, a water extract was effective only for *E. coli* at 100 and 200 mg/mL [45]. Water and ethanolic extracts at 1.0 mg/mL exhibit effective inhibition against *S. aureus* and fewer inhibitory effects were observed for *P. mirabilis*; against *S. aureus*, an ethanolic extract was active at 0.5 mg/mL, but a water extract was only active at 1.0 mg/mL; and inhibition was not achieved for either extracts at 0.1 mg/mL [73]. An ethanolic extract was slightly active against *B. subtilis* and *S. haemolyticus*, but was inactive against other Gram positive and Gram negative strains, resulting in no further studies with this extract [20]. Furthermore, only weak activity was achieved by methanolic extracts of this plant against *P. syringae* [74].

Both ethanolic and water extracts of *T. officinale* were active for *S. marcescens* and *M. kristinae*. The ethanolic extract alone was active on *P. vulgaris*, *E. coli*, *B. subtilis*, and *S. aureus* with MIC values ranging from 1.0 to 7.0 mg/mL for all strains tested [25]. Similar extracts had antimicrobial effects on four species that induce acne (*P. ovale*, *P. acnes*, *P. aeruginosa*, and *S. aureus*) in broth dilution tests with effects depending on the extract concentration, but no further information was available [49]. Moreover, a leaf extract (0.04 mg/well) was reported as a bactericidal agent against *S. aureus* and fungistatic against *C. albicans* [52]. Contrarily, extracts of 130 and 200 mg/mL from aerial parts were unable to prevent the growth of 34 microorganisms from genera *Bacillus*, *Enterobacter*, *Klebsiell*a, *Listeria*, *Pseudomonas*, *Salmonella*, *Staphylococcus*, *Aspergillus*, and *Candida*, among others; therefore, it was considered inactive at these concentrations in a disc diffusion assay [66]. A methanolic *T. officinale* flower extract was not active against *E. coli* or *S. aureus* at 1.0 mg/mL in a diffusion agar assay [62] and no activity was found on *S. aureus*, *E. coli*, *P. aeruginosa*, or *C. albicans* using a leaf ethanolic extract when 0.05 mL were placed in sterile discs [57]. Furthermore, an ethanolic extract of leaves displayed no activity against *S. aureus*, *E. coli*, or *S. abony* by the serial dilution method [58], with the same results for root and leaf extracts on *M. aurum* and *M. smegmatis* at 0.5 mg/mL [63].

Raw extracts of *T. officinale* have been widely tested, as well as solvent fractions. In a study in which the methanolic leaf extract was fractioned by different solvents, the methyl chloride,

ethyl acetate, and butanol fractions were active on *E. coli*, *S. aureus*, *B. subtilis*, *C. albicans*, and *S. cerevisiae* at 50 mg/mL, with inhibition percentages ranging from 13 to 76%. The water fraction showed moderate inhibition via the broth dilution method (10 and 14% for *E. coli* and *B. subtilis*, respectively) but no effect on the disc diffusion assay [34]. The only report in which a *Taraxacum* extract was compared to another natural antibacterial substance besides other plants extracts evaluated the use of *T. officinale* extract as an irrigation agent in endodontic treatments against *E. faecalis* in root canal infections. Leaf and root extracts at 0.7% were slightly active but propolis was more effective for this purpose [53]. In the case of commercial preparations, high activity has been reported for a commercial *T. officinale* ethanolic extract, showing antibacterial activity against *H. pylori* at 20 mg/mL with 26% inhibition but no observable activity for *C. jejuni* [54].

Considering other *Taraxacum* species, *T. platycarpum* anticandidal activity was determined against five different *Candida* sp. by agar diffusion assay. An ethanolic extract at 0.2 mg/mL weakly inhibited *C. tropicalis* but no other Candida strains [55]. A methanolic extract was active against *B. subtilis*, *S. aureus*, *L. monocytogenes*, *E. coli*, and *V. parahaemolyticus* at concentrations ranging from 0.5 to 2.0 mg/mL, with growth inhibition ranging from 5.1 to 100%, correlating to the concentration. In that study, chloroform, butanol, and ethyl acetate fractions were active in the disc diffusion assay for almost every strain tested, but an aqueous extract was inactive [38, 39].

An ethanolic extract of *T. mongolicum* at 0.2 mg/mL was not able to achieve growth inhibition in a microdilution assay for *B. subtilis*, *S. aureus*, *E. coli*, or *P. aeruginosa* [64]. In contrast, an ethanolic extract of this species was active for *E. coli*, *S. aureus*, and *P. aeruginosa* in the disc diffusion assay with MIC values between 0.05 and 0.1 mg/mL, which was three times higher than the values obtained for erythromycin. However, no activity was achieved for *S. fiexneri* or *P. vulgaris* [75]. Another report indicated that only the butanol fraction of an ethanolic extract of this plant was active on *H. pylori,* but water and methyl chloride fractions were inactive. Nevertheless, a different report indicated that a butanol fraction exerted higher inhibition (13%) than the aqueous fraction, possibly due to the flavonoid and luteolin content (28 and 1.1%, respectively) [31]. Against *S. aureus* and *S. epidermis,* an acetyl acetate fraction of an ethanolic *T. coreanum* extract was active at 0.5, 1.0, and 3.0 mg/disc, a chloroform fraction was active at 1.0 and 3.0 mg/disc, and a butanol fraction at 1.0 mg/mL, but displayed no activity against *MRSA* displayed [28]. An ethanolic *T. ohwianum* extract was active against *E. coli* at 240 and 320 mg/mL, but not against *S. aureus* [32]. These authors indicate that the pH and temperature of the bioassay were important parameters in the antimicrobial performance of the extract. An extract of the aerial parts of *T. phaleratum* was inactive at 0.2 mg/mL against *M. tuberculosis*, even when several solvent fractions were tested [60].

Limited studies have been conducted on humans establishing the antimicrobial potential of *Taraxacum* extracts. Chinese language studies have reported the effects of various formulas containing *T. mongolicum* for medical treatment. An herbal formula known as "fu zheng qu xie" was just as effective as the antibiotic gentamycin in 75 cases of gastric disease caused by *H. pylori.* Furthermore, an herbal formula called "jie du yang gan gao," which includes *T. mongolicum*, was significantly more effective than another botanical formulation in lowering elevated liver enzymes and curing patients with hepatitis B in a 96-person, double-blind trial [76].

2.2.2. Plant pathogens

Plant extracts have also been tested on bacteria and fungi that affect fruits and vegetables, causing rot diseases during postharvest handling, to find an alternative to chemical pesticides, which are harmful to the environment and human health. An aqueous *T. officinale* root extract (S) at different dilutions (S, S/2 to S/100) caused significant inhibition to mycelial growth in *A. alternata* (70% for S to 17% for S/100), *P. expansum* (67% for S to 5.3% for S/100), and *M. piriformis* (70% for S to 16% for S/100) [46]. In the case of *R. solani* and *C. sativus*, a *Taraxacum* acetyl acetate extract at a concentration of 100 mg/mL exhibited a weak effect on the growth of these plant pathogens and no inhibition of *F. oxysporum* [22]. A methanolic extract of *Taraxacum* at 0.2 mg/mL was not effective against *A. niger*, *A. flavus*, *A. fumigates*, or *R. solani* [37]. A methanolic extract of *Taraxacum* sp. displayed weak activity against *C. sativus*, *F. oxysporum*, and *R. solani* at 5 mg/disc and a water extract displayed no activity at all [56].

A *T. officinale* hydro-methanolic extract tested the inhibition of conidial germination and inhibition of germ tube elongation for several plant pathogens at several dilutions (0.25×, 0.5×, and 0.75×) using a microassay method on slides. Dilution at 0.75× showed inhibition of conidial germination values of 2, 3, 4, 9, 11, and 12% for *P. italicum*, *A. niger*, *A. carbonarius*, *B. cinerea, M. laxa*, and *P. digitatum,* respectively. For these same strains, excluding *A. carbonarius*, inhibition of germ tube elongation values were 56, 45, 38, 5 and 42%, respectively. For *P. expansum*, the plant extract did not show positive results for inhibition of conidial germination or inhibition of germ tube elongation. In artificially inoculated fruits, the extract applied to nectarines was not protective against brown rot development from *M. laxa*, while for apricots effects were similar to those of the negative control for *P. digitatum* [35]. Dichloromethane and diethyl ether *T. officinale* extracts were tested on *P. expansum* by applying either a solution or its vapor to paper discs. The dichloromethane extract was more active of the two models, though direct inoculation in apples offered no observable inhibition [26]. Water extracts of *T. officinale* and *T. platycarpum* were tested against *C. lagenarium* in cucumber, exhibiting inhibition rates of the anthracnose lesions of 1.9 and 13% in treated leaves, and 11 and 5.3% in untreated leaves, respectively. These results were not significant compared to other plant extracts [42]. *In vivo* evaluation of protective effects in plant tissue has not been as successful as the *in vitro* assays, which is typical in cases of inhibitory activity validation. To avoid these ineffective results, concentrations are increased to demonstrate the pathogen control effect.

2.2.3. Animal pathogens

Regarding animal pathogens, *Saprolegnia* infections can account for significant salmonid losses. Treatment is difficult and there are reservations regarding efficacy, prompting a search for suitable alternatives. A *T. officinale* root extract was not as effective as a fungistatic at 10, 100, 1000, or 10,000 mg/mL [61]. The effects of *Taraxacum* polysaccharides were studied on the preservation of white shrimp (*Penaeus vannamei*) during refrigerated storage (10 days at 4°C) by soaking the shrimps in aqueous extracts (1–3% w/v). Samples were periodically evaluated for total viable count, pH value, and total volatile basic nitrogen, which resulted in 2–3% of shrimp in fresh conditions (<30 mg/100 mg of total volatile basic nitrogen) and a total viable count that only increased slightly during storage. This indicated that the treatment effectively

retarded bacterial growth during refrigerated storage, prolonging shrimp shelf life for up to 10 days [76].

In the case of the meat industry, an herb mixture including *T. officinale* as a substitute for fodder antibiotics in pig feeding revealed positive growth of the animal and no change in meat quality, confirming the possibility of using herbs as an antibiotic substitute in pig feed [77, 78]. Aqueous and ethanolic extracts of *T. mongolicum* could also inhibit four pathogenic bacteria responsible for cow mastitis, a serious disease in the cow industry, at concentrations of 0.13, 0.25, and 0.5 g/mL. In this case, the ethanolic extracts displayed slightly better antibacterial activities than aqueous extracts. For *E. coli*, *S. aureus, S. agalactiae*, and *S. dysgalactiae*, inhibition zone diameters were slightly larger for aqueous than for ethanolic extracts but showed between medium and high sensitivity [79]. Dandelion extract can not only be used to control pathogens but also to supplement the diet of animals, which could result in increased meat, milk, whey, and other yields, contributing to the food industry. Alternatively, the extracts could be utilized in the agricultural industry as biofertilizers to promote plant growth and strengthen the plant against biotic and abiotic stress.

2.3. *Taraxacum* antimicrobial action mechanisms

Innate plant immunity involves various defense responses, including cell wall reinforcements, lytic enzyme biosynthesis, secondary metabolite production, and pathogenesis-related proteins. To protect themselves from non-beneficial microorganisms, plants accumulate secondary metabolites that form chemical barriers to microbial attacks (phytoanticipins) and produce antimicrobials (phytoalexins) [80]. Phenolics and terpenoids are considered the primary mechanisms for plant defenses because these reduce microbial attacks by disrupting the cell membranes in microorganisms, bind to adhesins and cell wall compounds, and inactivate enzymes, among other roles [81]. The action mechanisms of natural compounds are related to the disintegration of the cytoplasmic membrane and destabilization of the proton motive force, electron flow, active transport, coagulation of the cell content, inhibition of protein synthesis, inhibition of DNA synthesis, and the synthesis of metabolites used for DNA synthesis [82]. Some action mechanisms are specific to certain targets and some targets may also be affected by more than one mechanism [83]. A general scheme of the action's sites and antimicrobial potential mechanism is presented in **Figure 1** of Supporting Information.

Even though *Taraxacum* is a plant with extremely high pathogen resistance, the underlying molecular mechanisms of antimicrobial activity are poorly studied [68]. Until now, most of the research on *Taraxacum* has focused on elucidating the compounds present in the extract, and, to a lesser extent, on the mechanism involved in the antimicrobial activity itself. One study specifically illustrated the effect of four proteins from *T. officinale* flowers on fungi by light microscopy and distinguished two modes of antimicrobial action, depending on the fungus tested. *Taraxacum* proteins completely blocked conidia germination or induced thickening of multiple local hyphae and irreversible cytoplasm plasmolysis [68, 69]. Different extracts from this genus showed positive inhibitory activity in controlled studies and were characterized by protein synthesis inhibition (e.g. chloramphenicol, tetracycline, gentamicin, and kanamycin) and cell wall synthesis (e.g. amphotericin, cefixime, cephalothin, and penicillin). These

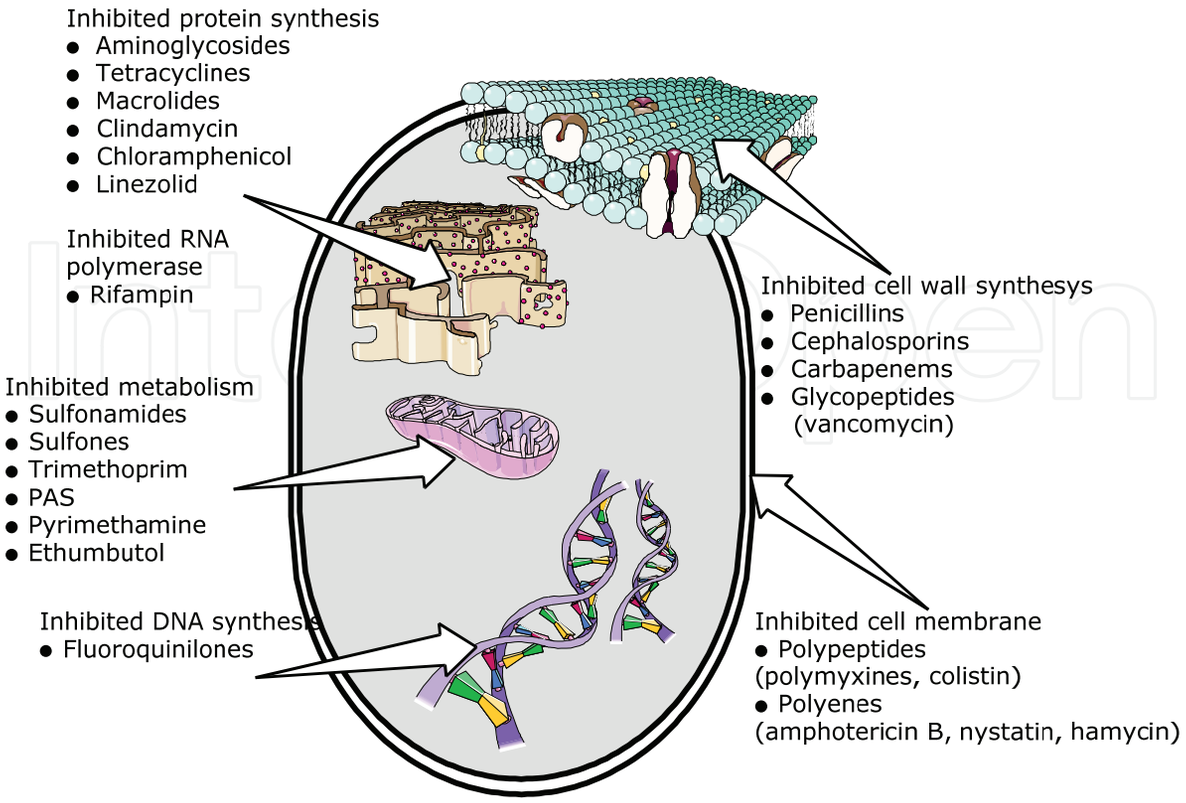

Figure 1. Main action mechanisms for antimicrobial agents (adapted from Mulvey and Simor [84]).

mechanisms need to be addressed to elucidate the *Taraxacum* active compound action mechanisms because a direct relation with the positive controls cannot be pursued.

Another response that has been studied is the modulation of microbe adherence to body tissues. Adhesion to epithelial cells has been represented as the first step in the subsequent bacterial invasion of host cells [59]. These authors reported the partial inhibition of intestinal adherence of *C. jejuni* HT-29 cells using a commercial ethanolic *Taraxacum* extract. Cytotoxic activity was less than 10%, but no antibacterial activity was observed. Moreover, *Taraxacum* has been tested with the aim of controlling bacterial diseases by inhibiting communication between bacteria. An ethanolic extract of *T. officinale* aerial parts disturbed bacterial communication systems (or quorum sensing) for *C. violaceum*, showing the moderately positive effect of the extract on the attenuation of microbial pathogenicity [30]. In contrast, an ethanolic and water extract of the rhizomes of the same plant showed no significant activity in the same assay [65].

2.4. *Taraxacum* compounds related to antimicrobial action

Several studies have named a wide range of compounds, including terpenes, flavonoids, and phenolic compounds, as responsible for the medicinal activity of different plants [85, 86]. For *Taraxacum*, only a few studies concerning its antimicrobial properties have considered

chemical identification of the obtained extracts and this identification is chiefly qualitative (e.g. using colorimetric methods indicating presence or absence). Authors report the presence of terpenoids, triterpenoids, steroids, coumarins, phenols, saponins, flavonoids, flavones, flavonols, chalcones, phlobatannins, and cardiac glycosides in antimicrobial extracts [22, 27, 34, 36, 37, 43–45, 87, 88] but neither compound isolation nor further identification were performed.

Taraxasterol acetate, lupeol acetate, tranexamic acid, and squalene, among others, were identified in the dichloromethane extract of *T. officinale* leaves, which show low activity against *E. coli*, *P. aeruginosa*, *B. subtilis*, *C. albicans*, and *T. mentagrophytes* in an agar well assay at 30 μg but no observed activity against *S. aureus* or *A. niger* [27]. Terpenoids and flavonoids were identified in the ethanolic extracts of the *T. farinosum* root, which displayed antibacterial activity against *S. aureus*, *S. typhi*, *M. canis*, and *T. longifusus* in an agar well diffusion and agar tube dilution, while the herb extract was active only against the latter two strains [51]. Fractions of a methanolic root extract indicated the significant presence of phenolic-based compounds and hydroxyl-fatty acids with liquid and mass spectrometry, and were active against *S. aureus*, *MRSA* clinical, and *B. cereus* at 2 mg/mL, with MIC values ranging from 0.05 to 0.19 mg/mL, and crude extracts indicating values of 0.25–0.5 mg/mL [33]. An oligosaccharide extract (DOs) from this species exhibited high antibacterial activity against *E. coli*, *B. subtilis*, and *S. aureus* at 100 mg/mL, indicating that these oligosaccharides could potentially be used as antibacterial agents [48].

Concerning specific compounds, isolated *Taraxacum* peptides displayed antimicrobial activity at 6 μg/μL, corresponding to 52–79% of kanamycin activity against *P. syringae*, *B. subtilis*, and *X. campestris* at the same concentration [69], which is a promising value that warrants further experiments. These authors indicated that though *A. niger* appeared sensitive to four proteins (ToAMP1, ToAMP2, ToAMP3, and ToAMP4) from *T. officinale* flowers, *F. graminearum* was not susceptible to any of these proteins. All proteins displayed inhibition activity against *B. cinerea*, *B. sorokiniana*, *A. niger*, *P. debaryanum*, *F. oxysporum*, and *P. infestans*, with IC50 values ranging between 1.2 and 5.8 μM. The ToAMPs were also active against *P. syringae*, *B. subtilis*, and *X. campestris*, similar to a kanamycin control. Additionally, ToAMP2 was active against *C. michiganensis* at up to 0.5 μg/μL. The disease development of *P. infestans* was inhibited by ToAMP2 at 1.3 μM (20–40%) to 5.2 μM (10–20%). In further studies, *B. sorokiniana*, *C. gloeosporioides*, and *V. albo-atrum* were insensitive to ToAMP4, another peptide isolated from the seed extract of *T. officinale*, at concentrations below 15 mM. The IC50 values for the agent-sensitive fungi *A. alternata*, *A. niger*, *F. avenaceum*, and *P. betae* ranged from 2.9 to 13.1 mM, with MIC values from 1.0 to 8.0 mM; no activity was observed for *P. syringae, B. subtilis*, *E. coli*, or *C. michiganensis* [68, 69]. Peptides supposedly have broad-spectrum activity, lack of microbial resistance, and high efficacy [69], but some action mechanisms in these molecules are still poorly defined [89]. Peptides related to albumin 2S from *Taraxacum* seeds are active against phytopathogenic fungi and bacteria. Antifungal assays displayed different activities for the 2S isoforms (ToA1, ToA2, and ToA3). The spore germination of *B. cinerea*, *A. niger*, and *P. debaryanum* were the most tolerant, and *H. sativum*, *P. betae*, and *V. albo-atrum* were the most sensitive at concentrations ranging from 0.063 mg/mL to 0.25 mg/mL. *H. sativum* and *P. betae* were inhibited by ToA1, ToA2, and ToA3, but *F. oxysporum* and *V. albo-atrum* were only inhibited by ToA2 and ToA3, respectively. In potato tubers, *P. infestans* was inhibited by ToA3 at 0.06 mg/mL at 96 and 120 h, but at 144 h ToA2 inhibited better at 0.13 mg/mL [23].

Interestingly, an antimicrobial filtrate isolated from the fungal strains of *P. betae* (PG23) from *T. mongolicum* was proven active against *E. coli*, *S. aureus*, *A. hydrophila*, *E. tarda*, and *P. multocida*, and proposed as a potential antimicrobial product for poultry and aquatic disease control [88].

3. Driving forces and tendencies in *Taraxacum* antimicrobial research

Between 2000 and 2010, approximately 40 new drugs originating from terrestrial plants, terrestrial microorganisms, marine organisms, and terrestrial vertebrates and invertebrates against different bacteria, fungi, and viruses were launched on the market [90]. This follows distinct research tendencies. Studies related to antimicrobial and antifungal properties generally aim, in developing and developed countries, to respond to the necessity of finding new drugs or products based on traditional medicine at a low cost, confirming already established activity originating from oral tradition. The driving force behind studying new antimicrobial alternatives is the necessity of finding new drugs or natural products that act against diseases due to the increased drug resistance in the latter. Furthermore, the toxicity of synthetic compounds currently utilized in farming and agricultural industries has created a market for natural compounds that are safer, cheaper, and more effective against pathogens.

Modern phytochemistry, scientific equipment, and technology have had a significant impact on natural product chemistry, including isolation, extraction, purification, and structure determination. However, this discipline still demands that research investigators establish the clinical significance of natural compounds and recognize them as drugs or industrial products (pesticides, bactericides, pharmaceutical products, etc.) [91]. Bioactive compounds in botanical drugs are purportedly superior to monosubstances because of synergistic effects. Similarly, multidrug therapy is highly important against resistant microbial strains due to the enhanced efficacy, reduced toxicity, decreased adverse side effects, increased bioavailability, lowered dosage, and reduced evolution of antimicrobial resistance [92].

Even when antibiotics have been effective in treating infectious diseases, resistance to the action mechanisms has led to the emergence of new and the re-emergence of old infectious diseases. Several plant extracts exhibit synergistic activity against microorganisms, with natural products (including flavonoids and essential oils) and synthetic drugs effectively combating bacterial, fungal, and mycobacterial infections. The mode of action of combinations differs significantly from the individual use of the same drugs; hence, isolating a single component may not highlight its importance, simplifying the task of the pharmacological industries [93].

Acknowledgements

This work has been supported by Innova Chile CORFO Code FCR-CSB 09CEII-6991 and a doctoral fellowship awarded by the Pontifical Catholic University of Valparaíso, Chile Project DI Iniciación COD 039.454/2017 Pontificia Universidad Católica de Valparaíso.

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