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CYANOLICHENS AS INDICATORS IN BIOMONITORING OF POLLUTION AND SOURCE OF BIOMOLECULES: A LITERATURE REVIEW

CIANOLIQUENS COMO INDICADORES NO BIOMONITORAMENTO DA POLUIÇÃO E FONTE DE BIOMOLÉCULAS: UMA REVISÃO DE LITERATURA

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ABSTRACT

Lichens are characterized as a symbiotic association, being composed of one or more fungi (mycobiont) and one or more green algae or cyanobacteria (photobiont). Lichens whose main photobiont is a cyanobacterium are called cyanolichens, and their photobiont is called cyanobiont. In this context, this study aimed to perform a literature review focusing on cyanolichens as biomonitors of environmental pollution and biomolecule production. The studies were found in different databases, by crossing the descriptors using the Boolean operators "OR" and "AND". Most cyanolichens belong to the division Ascomycota and species of the order Peltigerles. The most representative families in terms of species numbers were: Peltigeraceae, Lobariaceae, Collemataceae and Stereocaulaceae. Regarding symbiosis, most species are associated with *Nostoc*. Cyanolichens were considered as excellent bioindicators of natural and/or anthropogenic changes due to their high sensitivity to environmental pollutants, with *Lobaria pulmonaria* being the main species. They were also considered as organisms of high biotechnological potential due to the versatility of some species in synthesizing biologically active substances surch as: lecanoric acid, usnic acid, orsellinic acid, lobaric acid, evernic acid, atranorin, stictic acid, nostoclide I and lobarioid A, in biological activities (anticancer, antimicrobial, antioxidants, and antivirals). The study showed that cyanolichens are important not only for the performance of several functions, but also for their ecological role in ecosystems. There are still large gaps for the study of these organisms, so their development is pertinent to obtain current and complete knowledge.

Keywords: Biomolecules; Biomonitoring; Cyanolichen; Lichenized fungi; Pollution.

RESUMO

Os liquens são caracterizados como uma associação do tipo simbiótica, sendo compostos por um ou mais fungos (micobionte) e uma ou mais algas verdes ou cianobactérias (fotobionte). Por essa razão são classificados de acordo com o fotobionte associado, dessa forma, os liquens cujo fotobionte principal é uma cianobactéria são denominados de cianoliquens, sendo o seu fotobionte chamado de cianobionte. Nesse contexto, este trabalho objetivou realizar uma revisão de literatura com foco nos cianoliquens como biomonitores de poluição ambiental e na produção de biomoléculas. Os trabalhos foram encontrados em diferentes bases de dados, por meio do cruzamento dos descritores utilizando os operadores booleanos “OR” e “AND”. A maioria dos cianoliquens são pertencentes à divisão Ascomycota e muitas de suas espécies correspondem ao grupo da ordem Peltigerales. As famílias mais representativas em termos de números de espécies foram: Peltigeraceae, Lobariaceae, Collemataceae e Stereocaulaceae. Com relação à simbiose, a maioria das espécies estão associadas com Nostoc. Os cianoliquens foram considerados como ótimos bioindicadores de alterações naturais e/ou antrópicas devido sua alta sensibilidade aos poluentes ambientais. Além disso, foram considerados como organismos de alto potencial biotecnológico pela versatilidade de algumas espécies em sintetizar substâncias biologicamente ativa com diversas atividades biológicas como: anticâncer, antimicrobiana, antioxidantes, e antivirais, por exemplo. Portanto, os cianoliquens mostraram-se altamente importantes não só pelo desempenho dessas funções, como também pelo seu importante papel ecológico nos ecossistemas. O estudo mostrou também que ainda há grandes lacunas em relação aos trabalhos com cianoliquens. Aliado a isso, a exploração desenfreada desses organismos, têm levado muitas espécies ao declínio nos ecossistemas devido suas lentas taxas de crescimento. Por isso, se faz necessário a realização de mais estudos, a fim de se obter conhecimentos mais atuais, completos e mais profundos a respeito desses organismos, bem como para uma melhor compreensão da forma como ocorre a interação nessas associações.

Palavras-chave: Biomoléculas; Biomonitores; Cianoliquen; Líquen; Poluição.

INTRODUCTION

Lichens can be characterized as a group of symbiotic organisms composed of one or more fungi (mycobiont) and one or more green algae or cyanobacteria (photobiont) or both (Spribille *et al.*, 2016). Green algae as photobionts are called "chlorobionts" or "phycobionts", and lichens are called "chlorolichens" or "phycolichens" (Muggia; Leavitt; Barreno, 2018). Cyanobacteria as photobionts are called "cyanobionts", while lichens are called "cyanolichens" (Rikkinen, 2015, 2017).

Green algae (Chlorophyta division), including at least 17,000 species, constitute the largest and most diverse group of algae, not only at the species level, but also in structural, morphological and reproductive patterns (Kennedy, 2026). They are characterized as autotrophs, unicellular or multicellular, colonial or coenocytic, immobile or free-living living beings, and can be found in various habitats, including the trunks of trees associated with fungi forming lichens (Paim, 2020; Kennedy, 2026). Most lichenized fungi, about 90%, found in nature, contain Chlorophyta as the sole photobiont or in company with cyanobacteria. Among the green algae that form lichens, those of the family *Trebouxiaceae* Friedl and those of the genre *Trentepohlia* C. Martius are the best known and most studied (Muggia; Leavitt; Barreno, 2018).

Cyanobacteria are autotrophic organisms, prokaryotes, which can be unicellular or filamentous, planktonic or benthic; in addition to occurring individually or grouped in colonies. Due to their morphophysiological characteristics, they can proliferate in the most diverse environments, including terrestrial and aquatic environments (Lau; Matsui; Abdullah, 2015). They are currently divided into five groups (Oscillatoriales, Chroococcales, Pleurocapsales, Nostocales *and* Stigonematales) are quite diverse, the last four being the ones that most appear in cyanolichens (Madigan *et al*., 2015; Tuero Septién, 2020). About 10% of lichenized fungi contain cyanobacteria as the sole photobiont or in company with Chlorophyta. The diversity of cyanobacteria as photobionts of lichens varies, from unicellular forms to heterocyst-forming filamentous forms. And among the cyanolichens, *Nostoc* and *Scytonema* are the most frequent genera in lichenic associations (Honda; Vilegas, 1999; Rikkinen, 2015, 2017).

The basic function of the mycobiont is to deliver adequate sustenance to the photobionts, while the latter are in charge of the production of carbon sources and other metabolic products (Fedrowitz; Kaasalainen; Rikkinen, 2011). In addition, they stand out for their high biotechnological potential, being used for the most varied purposes, especially in the pharmaceutical and cosmetics industries (Abed; Dobretsov; Sudesh, 2009; Rastogi; Sinha, 2009). And also, as biomonitors of air pollution due to their high sensitivity to SO_2, NO_2 and other polluting gasses, and ability to absorb and accumulate heavy metals from the environment (Mikhailova, 2007).

Air pollution in the urban-industrial environment is a problem that has only worsened in recent centuries. Due to this, it is increasingly necessary to implement control measures, especially in large urban-industrial centers. In this sense, the use of biomonitors or bioindicators (characterized as any living beings that have some interaction with the polluted environment, so that it is possible to verify, early, environmental changes, enabling intervention before they worsen) has aroused the interest of researchers for pollution biomonitoring, as it is a simple, fast and low-cost method (Martins; Käffer; Lemos, 2008). Among the biological organisms that are among the broadest biomonitors in the terrestrial environment, lichens stand out, as they demonstrate high sensitivity to environmental contaminants and polluting gasses such as: SO_2, NO_2, CO_2 and ozone, absorbing them directly, through their entire stem, since they are devoid of roots, stomata or cuticles (Cecconi *et al*., 2018; Tortora *et al*., 2017; Nimis *et al*., 2020)

Furthermore, the interaction between the photobiont and the mycobiont generates the synthesis of many chemically diverse organic compounds derived from their biologically active metabolites with a wide variety of effects (Sánchez Charry 2019). Thus, the versatility of some lichen species in producing bioactive substances gives these organisms insertion in numerous commercial applications, from the pharmaceutical and cosmetics industry, N_2 biofixation, bioremediation of urban and industrial effluents and in the production of biofuels (Nascimento, 2016). Therefore, this study aims to perform an integrative review of the literature on cyanolichens as biomonitors of environmental pollution and biomolecule production, seeking to contribute to the knowledge, in particular, of this important symbiotic association and to show the existing gaps.

MATERIALS AND METHODS

The study was an integrative review developed from the bibliographic search carried out in different databases: Google Scholar (Google), ScienceDirect (Elsevier) and PubMed Central (PMC). Studies on lichens associated with cyanobacteria (cyanolichens) were selected, focusing on their use in biomonitoring as biological indicators of pollution and in the production of biologically active substances.

The descriptors used in the literature search were: "lichen", "cyanolichen", "biomonitors", "pollution" and "biomolecules". The search for the works was carried out by crossing these words using the Boolean operators "OR" and "AND". The inclusion criteria were articles, scientific notes, scientific reports, books, monographs, dissertations, and theses on the topic of research, published between the years 1990-2021, in Portuguese, Spanish, and English. As exclusion criteria, review articles, book chapters, works published in annals of events, as well as articles with a focus on lichens that have green algae as photobionts were suppressed. In addition, studies that focused on cyanolichen diversity, taxonomy, and physiology, studies on the role of cyanolichens, comparative studies of the ability of cyanolichen species, and comparative studies of cyanolichens and moss, or cyanolichens and chlorolichens, were rejected.

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RESULTS AND DISCUSSION

A total of 544 articles were found with the proposed theme. After screening, 64 titles related to lichenized fungi associated with cyanobacteria remained, consisting of 42 articles that exclusively addressed cyanolichens producing bioactive substances and 22 articles on cyanolichens as pollution biomonitors (Table 1).

Table 1. Correlation of the cyanolichen studies used in this study with their respective developing countries and collection sites

Countries	Regions where the samples studied were collected	References
Brazil	Curitiba, Barbacena/MG, Rio Grande do Sul, Minas Gerais and Santa Catarina, Belém do Pará	Elifio *et al.*, 2000; Dutra *et al*., 2020; Gumboski *et al*., 2019; Vieira *et al.*, 2019;
Chile	Laguna San Rafael	Quilhot *et al*., 2002;
Colombia	Páramo de Anaime	Sánchez Charry, 2019
Paraguay	-	Fournet *et al*., 1997
Guatemala	Guatemala City	Berger, 2014
United States	Southeast Alaska, California, Idaho, Idaho County, Clearwater National Forest, Colorado, -	Geiser *et al*., 1998; Riddell; Padgett & Nash, 2012; Shrestha *et al*., 2014; ST. CLAIR, 1999; Yang & Shimizu, 1993
Canada	Aleza Lake Research Forest - Central British Columbia, Québec, Cape Breton Highlands National Park, Kejimkujik National Park and National Historic Site (Kejimkujik)	Botting & Fredeen, 2006; Carpentier *et al*., 2017; Darnajoux *et al.*, 2015; Fraser *et al*., 2007; Gibson *et al*., 2013; Mcmullin *et al*., 2017
Iceland	Akrafjall	Jensen *et al*., 2010
Portugal	Lisbon, Azores	Branquinho *et al*., 2011; Rodrigues, 2013
Italy	-, Valle d'Aosta, Mount Vesuvius	Bellio *et al*., 2015; Bellio *et al*., 2017; Pisani *et al*., 2011; Rankovic *et al*., 2007; Savino *et al*., 2017
Russia	-, Khibiny Mountains - Murmansk Region	Dembitsky, 2017; Lisov *et al*., 2012
Table 1 (Continued)		
France	Mount Singgalang – Indonesia, Saint	Ismed *et al*., 2012; Vu *et al*., 2015

	Just – Ille-et-Vilaine	
United Kingdom	-	Stevens *et al*., 2012
Norway	Southeastern Norway	Yemets; Gauslaa & Solhaug, 2015
Greece	Peloponnese	Riga-Karandinos & Karandinos, 1998
Serbia	Kopaonik	Ranković; Kosanić & Stanojković, 2014
Switzerland	Swiss Alps	Scheidegger & Schroeter, 1994
Slovakia	Village of Špania dolina, Murlo – Italy	Bačkor *et al.*, 2009; Goga *et al.*, 2021
Czech Republic	Mount Carmel – Israel and Muslumovo Village – Ural Mountains – Russia	Řezanka & Dembitsky, 2006
Turkey	-, Giresun, Artvin, Erzurum, Murgul District, Trabzon	Atalay *et al.*, 2011; Atalay *et al*., 2015; Karakus *et al.*, 2009; Karagöz *et al*., 2009; Odabasoglu *et al.*, 2004; Odabasoglu *et al.*, 2005; Ozturk *et al.*, 2019; Süleyman *et al.*, 2003
Armenia	Tavush Province	Sargsyan *et al*., 2021
China	-	Zhang; Guo & Lou, 2006; Zheng *et al.*, 2018
South Korea	Yunnan Province, Patagonia (Chile), King George Island, (Antarctica)	Luo *et al.*, 2010; Hong *et al*., 2018; Yang *et al.*, 2015; Yang *et al*., 2019; Youn *et al*., 2018
Japan	-, Osar-isawa (Akita), Hitachi (Ibaraki), Katsushika (Tokyo), Isehara (Ka-nagawa), Hakone (Kanagawa), Izu (Shizuoka), Hieisan (Shiga), In-agawa (Hyogo), Koyasan (Wakayama), and Niihama (Ehime), Isehara, Takao, Ueno, Tsukuba, Isehara, Katsushika and Chofu-	Bhattarai *et al.*, 2013; Nakajima *et al.*, 2013; Nakajima *et al*., 2015; Morita *et al.*, 2009
India	-Meerut	Kar; Gogoi; Argade, 2005; Shahi; Shahi & Upreti, 2011
Israel	Jerusalem	Dembitsky, 2017; Temina; Levitsky; Torres *et al.*, 2004
Indonesia	Bogor	Rindita; Sudirman & Koesmaryono, 2015

- Regions not identified in the study

The studies were organized into two tables, with Table 1 presenting the studies found that summarize and analyze the potential benefits of bioactive substances and cyanolichen extracts. The bioactive substances analyzed were: lecanoric acid, usnic acid, choleflaccinosides A and B, atranorin, nostoclides I and II, chloropanarin, lobaric acid, panarin, lectin, pulmonaryanine, stictic acid, isidiophorin, collemin A, colleman (Cf-5-s),ethyl-3-formyl-2,4-dihydroxy-5,6-dimethylbenzoate,methyl-2,4-dihydroxy-3,5,6-trimethylbenzoate, ethyl orselinate, lobarine, homodimeric (large) and monomeric (small) laccases, lobarstin, perlatholic acid, physciosporin, tridepside, lobarioid A, evernic acid and orselic acid. Some of the bioactives listed (the most frequent in studies with lichens) and their molecular structures are shown in table 2 and figure 1. In addition to the compounds, some species of cyanolichens were also analyzed regarding the extracts and their biological activities, the extracts analyzed were: methanolic, aqueous, acetone, rhizonyl alcohol and chloroform.

Table 2. Cyanolichens as Sources of Bioactive Compounds (1990 – 2021)

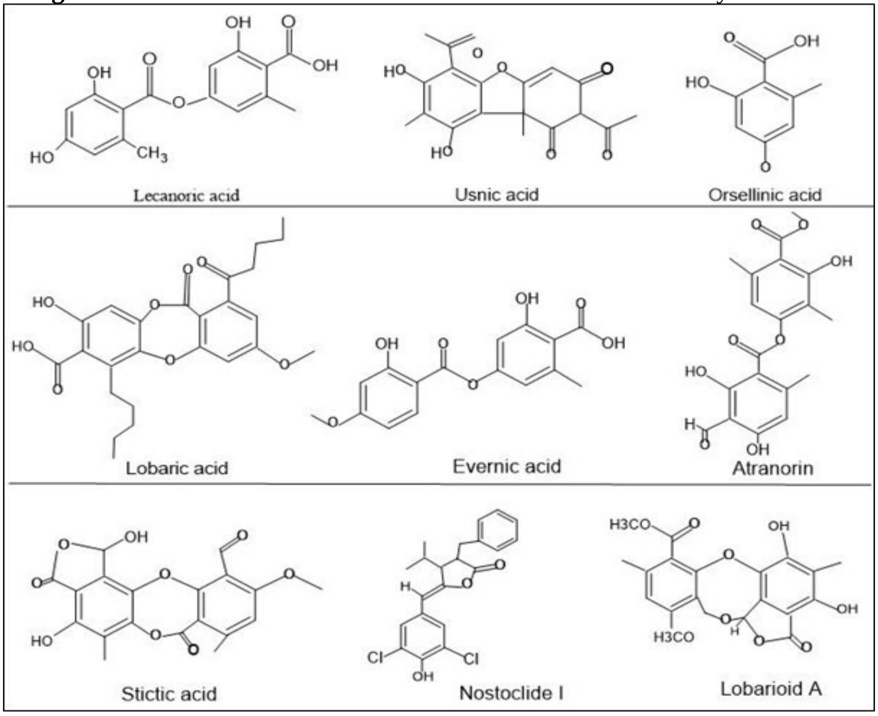
Cyanolichens		**Associated Cyanobacterium (Genus)**	**Bioactive Compounds / Extracts**	**Biological Activity**	**References**
Family	**Genus or Species**				
Peltigeraceae	Peltigera canina (L.) Willd.	Nostoc	Nostoclides I and II	Phytotoxic and cytotoxic	Yang & Shimizu, 1993; Kar; Gogoi; Argade, 2005
Pannariaceae	Erioderma leylandii (Taylor) Müll. Arg.	Scytonema	Chloropanarin, panarina, usnic acid	Antiparasitic, photoprotective	Fournet et al., 1997; Quilhot et al., 2002
Dictyonemataceae	Dictyonema glabratum D.Hawksw	Scytonema	Lectin	Hemagglutinator	Elifio et al., 2000
Lobariaceae	*Lobaria pulmonária (L.) Hoffm.	Nostoc	Aqueous, methanolic, acetone and rhizonyl alcohol extracts, pulmonaryanin, stactic acid, isidioforin	Anti-inflammatory and antiulcerogenic, gastroprotective, anticancer, antioxidant and antibacterial	Süleyman et al., 2003; Odabasoglu et al., 2004; Karakus et al., 2009; Atalay et al., 2011; Shrestha et al., 2014; Atalay et al., 2015; Ozturk et al., 2019; Goga et al., 2020

Collemataceae	Collema cristatum (L.) Weber ex F.H.Wigg.	Nostoc	Acetone, methanol and aqueous extract and collemin A	Antibacterial and photoprotective	Torres et al., 2004; Rankovic et al., 2007; Temina; Levitsky; Dembitsky, 2010; Dembitsky, 2017
Peltigeraceae	Peltigera rufescens (Weiss) Humb.	Nostoc	Water and methanol extracts	Antioxidant	Odabasoglu et al., 2005
Collemataceae	Collema flaccidum (Ach.) Ach.	Nostoc	Colleflaccinosides A and B, colleman (Cf-5-s) and colleflaccinoside B	Antitumor and possible immunomodulatory activity	Řezanka & Dembitsky, 2006; Jensen et al., 2010; Dembitsky, 2017
Lobariaceae	Sticta nylanderiana Zahlbr.	Nostoc	Phenolic compounds (ethyl-3-formyl-2,4-dihydroxy-5,6-dimethylbenzoate, methyl-2,4-dihydroxy-3,5,6-trimethylbenzoate, ethyl orselinate), methanolic extract and lecanoric acid	Photoprotective and antioxidant	Zhang; Guo & Lou, 2006; Heng et al., 2010
Stereocaulaceae	Stereocaulon paschale (L.) Hoffm.	Stigonema/ Nostoc	Methanolic Extract, Lichen Extract	Antioxidant, antimicrobial, anticancer and antidiabetic	Fraser Et Al., 2007; Ranković; Kosanić & Stanojković, 2014; Carpentier et al., 2017
Peltigeraceae	Peltigera polydactyla (Neck.) Hoffm.	Nostoc	Aqueous and methanolic	Antibacterial	Karagöz et al., 2009
Stereocaulaceae	Stereocaulon sasakii Zahlbr.	Nostoc	Lobaric acid	Antimitotic	Morita et al., 2009
Peltigeraceae	Peltigera praetextata (Flörke ex Sommerf.) Zopf	Nostoc	Methanol extracts	Antioxidant, antimicrobial	Heng et al., 2010; Sargsyan et al., 2021

Peltigeraceae	Peltigera paraetaxtala	Nostoc	Aqueous extract	Antifungal	Shahi; Shahi & Upreti, 2011
Stereocaulaceae	Stereocaulon halei I.M. Lamb	Nostoc	Lobarina	Antioxidant and possible antidiabetic and anti-obesity activity	Ismed et al., 2012
Peltigeraceae	Solorina crocea (L.) Ach.	Nostoc	Homodimeric (large) and monomeric (small) laccases	Depolymerization and discoloration of humic acids in the so	Lisov et al., 2012
Stereocaulaceae	Stereocaulon alpinum Laurer ex Funck	Nostoc	Lobaric acid and lobarstine	Antioxidant, anticancer, antimicrobial, and inhibitor of Escherichia coli RecA protein	Bhattarai et al., 2013; Bellio et al., 2015; 2017; Hong et al., 2018
Stereocaulaceae	Stereocaulon Hoffm.	Nostoc	Perlatholic acid	Antimicrobial and Escherichia coli RecA protein inhibitor	Bellio et al., 2015; 2017
Stereocaulaceae	Stereocaulon evolutum Graewe	Nostoc	Atranorin	Antiviral	Vu et al., 2015
	Pseudocyphellaria coriacea (Hook. & Taylor) D.Galloway & James	Nostoc	Acetone and Physciosporin Extract	Antimetastatic/ anticancer	Yang et al., 2015
Stereocaulaceae	Stereocaulon caespitosum Redinger	Nostoc	Tridepsid	Antidiabetic, anti-obesity, antiproliferative, cytotoxic, human leukocyte elastase and human cytomegalovirus protease inhibitory activities	Youn et al., 2018
Lobariaceae	Lobaria (Schreber) Hoffm.	Nostoc	Lobarioid A	Antibacterial	Zheng et al., 2018
Lobariaceae	Sticta parahumboldtii Moncada &	Nostoc	Usnic, Evernic, and Orselic Acids	Anticancer, antimicrobial, antiviral and	Sánchez Charry, 2019

	Lücking, Sticta. cf. andina Moncada & Lücking, Sticta cf. gyalocarpa (Nyl.), Sticta leucoblepharis (Nyl.) Tuck. & Mont			antioxidant	
Collemataceae	Leptogium (Ach.) Gray.	Nostoc	Chloroform and acetone extract	Antimicrobial	Vieira et al., 2019
Lobariaceae	Pseudocyphellaria granulata (C. Bab.) Malme	Nostoc	Acetone and Physciosporin Extrac	Anticancer	Yang et al., 2019

Figure 1. Chemical structure of bioactive substances related to cyanolichens.



It was found that the species presented both in their bioactives and in their extracts extensive biological activities, such as anticancer, antimicrobial, antioxidant, antiviral, antidiabetic, phytotoxic, cytotoxic, antiparasitic, photoprotective, hemagglutination, anti-inflammatory, antiulcerogenic, gastroprotective, antibacterial, immunomodulatory, antiobesity, inhibitor of the RecA protein of *Escherichia coli*, antiproliferative, cytotoxic, human leukocyte elastase, and human cytomegalovirus protease inhibitory activities. And an environmental biological activity was found in the species *Solorina crocea*, in the study by Lisov *et al*. (2012) through homodimeric (large) and monomeric (small) laccases, responsible for the depolymerization and discoloration of humic acids in the soil.

The table 2 shows that several trace elements were analyzed using the cyanolichen biomonitoring method, as well as the sensitivity assessment in relation to the exposure of these organisms to different pollutants. The trace element copper has been analyzed in *Peltigera praetextata*, in preserved (unpolluted) areas of Portugal (Branquinho *et al.*, 2011), and in *Stereocaulon japonicum*, however, in urban-industrial localities of Japan (Nakajima *et al*., 2013; 2015). The trace minerals Na, Mg, Al, P, K, Ca, Mn, Fe, Zn, Ti, V, Cr, Co, Ni, Cu, Mo, Cd and Pb deposited in the Province of Québec in Canada, were analyzed in *Peltigera aphthosa*, *Peltigera neopolydactyla*, *Peltigera scabrosa* and *Nephroma arcticum* (Darnajoux *et al*., 2015). In *Peltigera rufescens*, Al, Co, Cu, Fe, Ni, Pb, Sb, and Zn were analyzed in a disposal area in Slovakia (Bačkor *et al*., 2009). And in *Lobaria pulmonaria* Co and Zn were also analyzed, in Norway (Yemets; Gauslaa; Solhaug, 2015).

In addition, several authors have measured the elements N (nitrogen) and S (sulfur) using the cyanolichens biomonitoring method (Table 2). The study by Gibson *et al*., (2013) used *Nephroma laevigatum*, *Collema subflaccidum*, *Leptogium laceroides*, *Leptogium cyanescens*, *Lobaria quercizans*, *Lobaria scrobiculata*, and *Lobaria lungonaria* to analyze the levels of nitrogen dioxide (NO_2) chosen as a good marker for vehicles and local combustion sources, such as wood smoke, in Canada (Gibson, *et al*. 2013). Fumigation with gaseous HNO_3 in *Pseudocyphellaria anthraspis* has been used to predict air quality in the United States (Riddell; Padgett; Nash III, 2012). In other studies, the species *Lobaria pulmonararia*, *Sticta weigelii*, *Peltigera aphthosa*, *Peltigera canina*, *Peltigera didactyla*, *Peltigera rufescens*, and the genus *Leptogium* sp., were used to biomonitor areas polluted with sulfur dioxide

(SO_2). Other atmospheric pollutants and ecological disturbances were also biomonitored with the other cyanolichen species, listed in Table 2.

Based on symbiotic composition, cyanolichens are divided into bipartite and tripartite cyanolichens. In the first case, cyanobacteria are the only photobionts present, while in the second there is a phycobiont (algae) and a cyanobiont and there is a separation in the functions of photobionts, where the green algae fix carbon and cyanobacteria fix nitrogen. In split cyanolichens, cyanobacteria perform both processes. Tripartite lichens constitute only about 3-4% of total lichen diversity, while bipartite cyanolichens account for approximately 10% of lichenized fungal species (Grube; Berg, 2009; Rikkinen, 2016). As tripartite species, the following appeared: *Lobaria lungonaria* (L.) Hoffm., *Peltigera aphthosa* (L.) Willd., *Nephroma arcticum* (L.) Torss., and *Stereocaulon vesuvianum* Pers. (Tables 3).

Regarding symbiosis, most species are associated with *Nostoc*, four are associated with *Scytonema* and one with *Stigonema,* and it was found in the literature for the species *Stereocaulon paschale* (L.) Hoffm., association with more than one cyanobiont, which can be *Stigonema* or *Nostoc* (Tables 2). Corroborating these results, according to Rikkinen (2013) *Nostoc* is by far the most common genus of cyanobacteria in association with lichenized fungi, especially in temperate and cold regions of the world. All Nostoc species are filamentous and have complex life cycles. Its unbranched filaments consist of cylindrical or spherical vegetative cells with intercalary heterocyst (large nitrogen-fixing cells) developing into mature trichomes. The filaments are usually covered in mucilage and many free-living species can form large gelatinous colonies (Rikkinen, 2013).

Of the semiaquatic cyanolichens, the species *Ephebe brasiliensis* (Table 3) was found to be used in the study by Gumboski *et al.* (2019) as a biomonitor species due to its occurrence being exclusively in conserved areas (i.e., National Parks) and stands out for the fact that it can also be used as a bioindicator of water quality, due to its semiaquatic habit. This species is characterized by having a fruitful stalk, symbiosis with the cyanobacterium of the genus *Stigonema* determining the appearance of the entire stalk, and occurrence in freshwater environments in Brazil (Minas Gerais and São Paulo) and Uruguay. However, although this species may be locally abundant and have a "wide" distribution, it has been poorly studied and its actual distribution and ecological characteristics are not yet known for sure (Gumboski *et al.*, 2019; Lücking; Hodkinson; Leavitt, 2017) .

Table 3. Cyanolichens as Bioindicators in Environmental Pollution Monitoring (1990-2021)

Cyanolichens		**Associated Cyanobacterium (Genus)**	**Sensitivity Assessment/Pollutant**	**References**
Family	**Genus or Species**			
Collemataceae	*Collema nigrescens* (Hudson) DC.	*Nostoc*	Ozone sensitive	Scheidegger & Schroeter, 1994
Lobariaceae	**Lobaria pulmonária* (L.) Hoffm.	*Nostoc*	Sensitive to sulfur dioxide, ozone, high concentrations of salt (NaCl) and heavy metals, and intolerant to nitrogen dioxide (NO2)	Scheidegger & Schroeter, 1994; Riga-Karandinos & Karandinos, 1998; Gibson *et al.*, 2013; Rodrigues, 2013; Yemets; Gauslaa & Solhaug, 2015; Mcmullin *et al.*, 2017
Collemataceae	*Leptogium* (Ach.) Gray.	*Nostoc*	Sensitive to sulphur dioxide, nitrogen oxides, air pollution and intolerant to ecological disturbance	Geiser *et al.*, 1998; Rodrigues, 2013; Rindita; Sudirman & Koesmaryono, 2015; Mcmullin *et al.*, 2017; Dutra *et al.*, 2020
Collemataceae	*Collema cristatum* (L.) Weber ex F.H.Wigg., *Collema coccophorum* Tuck.,	*Nostoc*	Ozone sensitive	St. Clair, 1999

	Collema crispum (Hudson) Weber ex F.H. Wigg., *Collema fuscovirens* (With.) J.R. Laundon, *Collema glebulentum* (Nyl. ex Crombie) Degel., *Collema tenax* (Sw.) Ach.			
Lobariaceae	*Sticta weigelii* (Ach.) Vain	*Nostoc*	Sensitive to sulfur dioxide	St. Clair, 1999
Peltigeraceae	**Peltigera aphthosa* (L.) Willd.	*Nostoc*	Sensitive to sulfur dioxide, ozone, and anthropogenic disturbances (heavy metal deposition)	St. Clair, 1999; Darnajoux *et al*., 2015
Peltigeraceae	*Peltigera canina* (L.) Willd.	*Nostoc*	Sensitive to sulfur dioxide and ozone	St. Clair, 1999
Peltigeraceae	*Peltigera didactyla* (With.) J.R. Laundon	*Nostoc*	Sensitive to sulfur dioxide, ozone nitrogen deposition	St. Clair, 1999; Stevens *et al.*, 2012
Peltigeraceae	*Peltigera rufescens* (Weiss) Humb.	*Nostoc*	Sensitive to sulfur dioxide, ozone, and mercury and tolerant to heavy metals (copper)	St. Clair, 1999; Bačkor *et al.*, 2009; Pisani *et al.*, 2011
Peltigeraceae	*Peltigera membranacea* (Ach.) Nyl.	*Nostoc*	Sensitive to increased carbon dioxide (CO2) concentration	Botting & Fredeen, 2006

Peltigeraceae	*Peltigera praetextata* (Flörke ex Sommerf.) Zopf.	*Nostoc*	Sensitive to heavy metals (copper)	Branquinho *et al.*, 2011
Lobariaceae	*Pseudocyphellaria anthraspis* (Ach.) H. Magn.	*Nostoc*	Sensitive to gaseous nitric acid (HNO3)	Riddell; Padgett & Nash, 2012
Peltigeraceae	*Peltigera hymenina* (Ach.) Delise.	*Nostoc*	Sensitive to nitrogen deposition	Stevens *et al.*, 2012
Collemataceae	*Collema subflaccidum* Degel., *Leptogium laceroides* (B. de Lesd.) P.M. Jørg.	*Nostoc*	Intolerant to nitrogen dioxide (NO2)	Gibson *et al.*, 2013
Collemataceae	*Leptogium cyanescens* (Rabenh) Körb,	*Nostoc*	Intolerant to nitrogen dioxide (NO2) and sensitive to air pollution	Gibson *et al.*, 2013; Dutra *et al.*, 2020
Lobariaceae	*Lobaria quercizans* Michx., *Lobaria scrobiculata* (Scop.) DC.,	*Nostoc*	Intolerant to nitrogen dioxide (NO2) and ecological disturbance	Gibson *et al.*, 2013; Mcmullin *et al.*, 2017
Nephromataceae	*Nephroma laevigatum* Ach.	*Nostoc*	Intolerant to nitrogen dioxide (NO2) and ecological disturbance	Gibson *et al.*, 2013; Mcmullin *et al.*, 2017
Stereocaulaceae	*Stereocaulon japonicum* Th. Fr.	*Nostoc*	Tolerant to heavy metals (copper)	Nakajima *et al.*, 2013; 2015

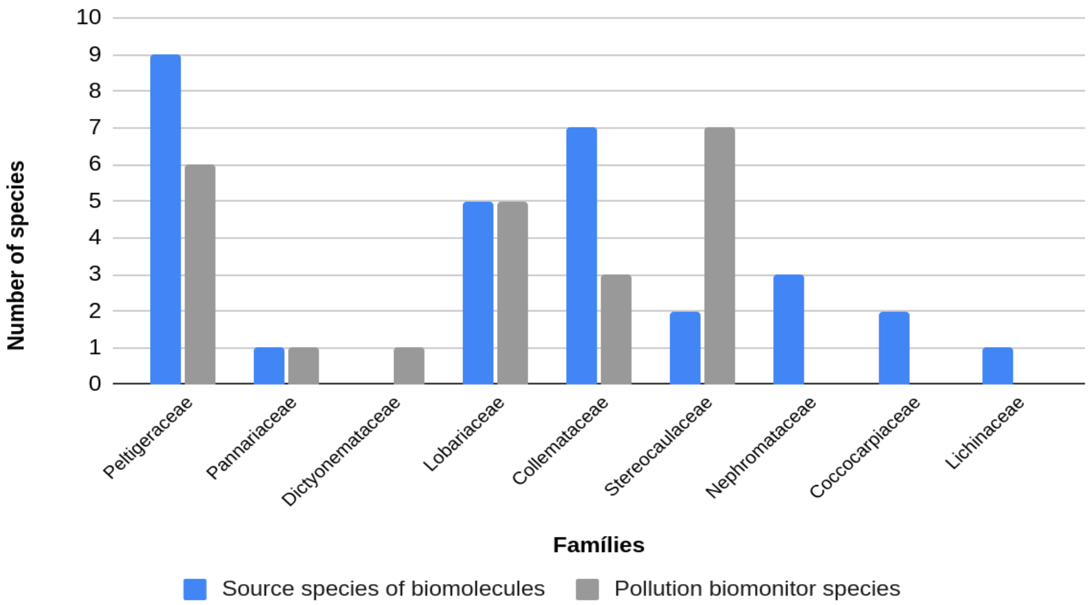
Collemataceae	*Leptogium azureum* (Sw. ex Ach.) Mont., *Leptogium milligranum* Sierk, *Leptogium chloromelum* (Ach.) Nyl., *Leptogium austroamericanum* (Malme) C.W. Dodge	*Nostoc*	Toxitolerant	Berger, 2014
Peltigeraceae	*Peltigera neopolydactyla* (Gyeln.) Gyeln., *Peltigera scabrosa* Th. Fr.	*Nostoc*	Sensitive to anthropogenic disturbances (heavy metal deposition)	Darnajoux *et al.*, 2015
Nephromataceae	**Nephroma arcticum* (L.) Torss.	*Nostoc*	Sensitive to anthropogenic disturbances (heavy metal deposition)	Darnajoux *et al.*, 2015
Coccocarpiaceae	*Coccocarpia* Pers.	*Scytonema*	Sensitive to air pollution	Rindita; Sudirman & Koesmaryono, 2015
Coccocarpiaceae	*Coccocarpia palmicola* (Sprengel) Arv. & D. J. Galloway	*Scytonema*	Intolerant of ecological disturbance	Mcmullin *et al.*, 2017
Collemataceae	*Collema* Fh Wigg., *Leptogium corticola* (Taylor) Tuck,	*Nostoc*	Intolerant of ecological disturbance	Mcmullin *et al.*, 2017

Lobariaceae	*Pseudocyphellaria perpetua* McCune & Miadl.	*Nostoc*	Intolerant of ecological disturbance	Mcmullin *et al.*, 2017
Nephromataceae	*Nephroma* Ach.	*Nostoc*	Intolerant of ecological disturbance	Mcmullin *et al.*, 2017
Pannariaceae	*Pannaria conoplea* (Ach.) Bory, *Pannaria rubiginosa* (Thunb.) Delise	*Nostoc*	Intolerant of ecological disturbance	Mcmullin *et al.*, 2017
Peltigeraceae	*Peltigera* Willd.	*Nostoc*	Intolerant - moderate tolerant of ecological disturbance	Mcmullin *et al.*, 2017
Stereocaulaceae	**Stereocaulon vesuvianum Pers.*	*Nostoc*	Radionuclide tolerant (137 Cs)	Savino *et al*., 2017
Lichinaceae	***Ephebe brasiliensis* (Vain.) Henssen	*Stigonema*	Sensitive to environmental and water pollution	Gumboski *et al*., 2019

*Tripartite species. **Semi-aquatic species

Figure 2 expresses the most representative families in terms of species numbers. They are: Peltigeraceae, Lobariaceae, Collemataceae and Stereocaulaceae, with 15, 10, 10 and 9 species, respectively. Stereocaulaceae and Peltigeraceae were more representative for the species that were sources of bioactive products; and Peltigeraceae and Collemataceae for the species used as biomonitors of environmental pollution.

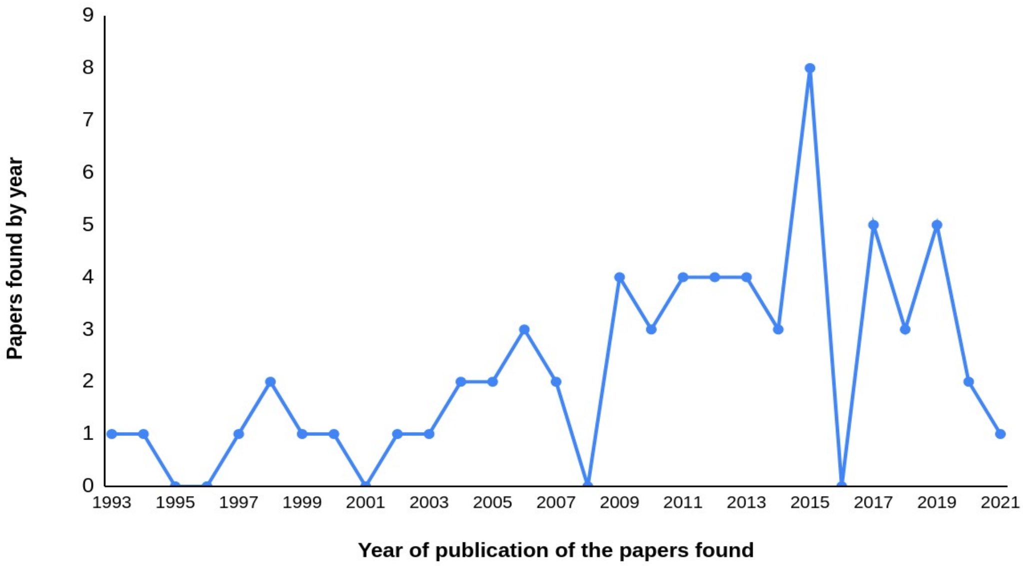
Figure 2. More representative families, in numbers of species, for cyanolichens that synthesize bioactive compounds and for cyanolichens used as biomonitors of environmental pollution.



The countries and the amount of work carried out with cyanolichens as sources of biocompounds and as pollution biomonitors are indicated in figure 1, in this regard we can observe that most of the studies are concentrated on the European and Asian continents, with Turkey being the country with the largest number of studies carried out (eight). In South America and North America, Brazil and Canada stand out, with four and six studies carried out, respectively.

Figure 3 shows the number of studies found between the years 1990-2021. In this regard, it is observed that the year with the highest publication was 2015, with 8 papers. And it is also possible to perceive a large gap in knowledge about the studies carried out in this time interval about cyanolichens as sources of bioactive substances and as biomonitors of pollution, and the available literature was found only from 1993 onwards. It is also observed that the amount of work made available over the years is too small. This low number of articles found corroborates this significant gap in knowledge regarding the subject, reiterated by the evaluation of the present research. These data only reinforce the need for urgency in producing knowledge on the subject in question.

Figure 3. Studies published between the years 1990-2021 on cyanolichens - sources of bioactive compounds and used as pollution biomonitors



Cyanolichens can occupy different substrates such as: tree trunks, rocks and others (Nimis *et al*., 2020). And although they have a relatively low percentage of species in relation to the total number of lichenized fungi, they are successful symbiotic associations. Being practically cosmopolitan, it appears in a wide variety of terrestrial habitats, from arctic tundra and semi-deserts to tropical rainforests (Milos, *et al*. 2018).

These organisms are commonly associated with moist and shady environments. And therefore, they need the presence of water for photosynthesis to be activated (González-Montelongo; Pérez-Vargas, 2019). However, as photosynthetic organisms, light is another primary factor for cyanolichens, which are able to take advantage of the low incidence of light that can pass through the tree trunks, thanks to substances called phycobilin’s, produced by cyanobacteria and, therefore, find an optimal habitat in environments that are relatively shaded (Rikkinen, 2017).

In more arid environments, the resistance of cyanobacteria to extreme drought and their dark pigmentation allows them to protect the symbiosis (cyanolichens) from insolation. In these places, a correlation has been found, considered positive, between the number of cyanolichens and the aridity of the terrain and, therefore, they are considered as good bioindicators of desertified areas (Matos *et al*., 2015) .

The difference between cyanolichens that inhabit wetter places and those in more arid places lies in their biology. While those from humid environments tend to have structurally more complete stalks, asexual reproduction, and filamentous cyanobionts, such as *Nostoc*, cyanolichens from drier regions tend to have more sensitive stalks, sexual reproduction by sporulation, and coccoid cyanobionts, (e.g., *Gloeocapsa*) (González-Montelongo; Pérez-Vargas, 2019; Nimis *et al*., 2020; Rikkinen; Oksanen; Lohtander, 2002; Spribille *et al*., 2014; Rikkinen, 2013; Rikkinen, 2017).

Most cyanolichens belong to the division *Ascomycota* and many of their species correspond to the group of the order Peltigerales Walt. Watson. The order Peltigerales is subdivided into two suborders, Collematinae Miadl. & Lutzoni and Peltigerinae Miadl. & Lutzoni. In the work of Lücking, Hodkinson, Leavitt (2016), 1,301 species of this order are described with 67 genera, being the fourth group with the greatest diversity of lichens and the group with the highest representation of cyanolichens (10 families) (Lücking; Hodkinson; Leavitt, 2017; Magain *et al*., 2018; Wedin *et al*., 2009).

Other species of cyanolichens are grouped in the order Lichinales Henssen & Büdel, also belonging to the division Ascomycota, divided into three families: Gloeoheppiaceae Henssen, Peltulaceae Büdel and Lichinaceae Nyl, the latter being the most diverse with almost all its representatives being cyanolichens. And the rest of the species are grouped in other orders such as lower diversity (Gibson *et al*., 2013; Rikkinen, 2002).

Regarding molecular identification methods of cyanolichens, they offer a practical way to accurately identify cyanobiont genotypes (Rikkinen, 2016). Studies on the whole genome are increasingly accessible due to the technological advancement of sequencing that not only points to the phylogeny but also the functioning of the lichenic association (James *et al.*, 2020). The genetic diversity of Nostoc cyanobionts in many cyanolichens has been studied using sequential tRNA nucleotides (UAA) as a genetic marker. In addition, 16S and 23S rDNA sequences were used for phylogenetic relationships. The metagenome sequencing of cyanolichens is also providing new insights into the genetic diversity of cyanobacterial symbioses (Rikkinen, 2016; Rikkinen, 2017).

However, attempts to characterize cyanobiont are still a tiny fraction of all known terrestrial symbioses. The study of photobionts is still very scarce, when compared to mycobionts, due to the numerous difficulties of isolation and correct identification at the morphological level (Rikkinen, 2016). And yet, the morphology of these organisms inside the lichenic thallus may be very different from the morphology of free-living organisms. All of this corroborates the scarcity of studies found, as well as the lack of knowledge regarding lichen photobionts. To this is added that it is sometimes complicated to obtain pure cultures of a symbiotic organism. Fortunately, the use of genetic markers, such as those already mentioned: 16S or 23S and comparison with databases have facilitated the identification of phycobionts and cyanobionts of lichens (Rikkinen, 2015; Tuero Septién, 2020).

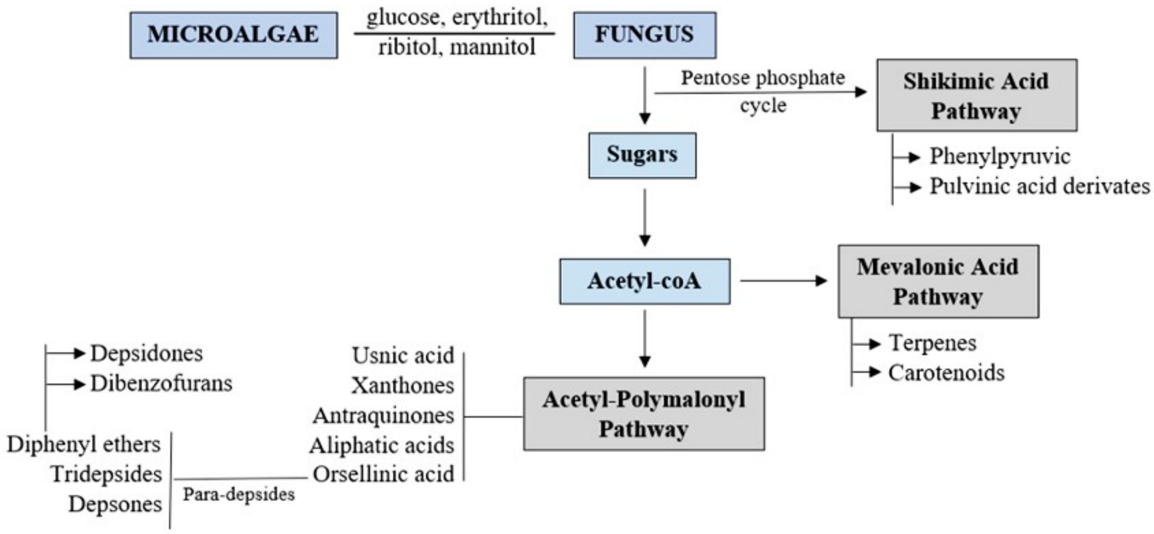
Due to the unique substances in lichens, their medicinal potential has attracted several researchers (Zhao; Wang; Xu, 2021) . In addition, the versatility of some lichen species in producing these compounds gives these organisms insertion in numerous other commercial applications such as cosmetics, N2 biofixation, bioremediation of urban and industrial effluents and in the production of biofuels (Nascimento, 2016). The interaction between the photobiont and the mycobiont generates the synthesis of these substances that are often unique, with only a small number of them found in other organisms such as fungi and higher plants; and chemically diverse, which are derived from their primary and secondary metabolisms (Sánchez Charry 2019).

In this context, primary metabolites play an active role in the processes of photosynthesis, respiration and nutrition. Secondary metabolites, on the other hand, are associated with defense strategies against herbivory and competition against other species for space and light (Upreti, 2015) . The latter have been of great interest to researchers since the nineteenth century, since from many of them their biomolecules have important biological, therapeutic and medicinal activities (Latkowska, 2015). Therefore, the secondary metabolites of lichens are characterized as bioactive molecules resulting from the chemical reactions carried out in the cells of these organisms presenting various properties and biological activities (Pereira; Hacon, 2017; Sánchez Charry, 2019).

The primary metabolites of lichen mainly include amino acids, polyols, vitamins, pigments, chitin, and polysaccharides (Podterob, 2008). Some of these metabolites, such as lichenic polysaccharides, have been verified in the works of Olafsdottir & Ingólfsdottir (2000). Ullah *et al* (2019) and have been described as having antitumor, immune activation, cytotoxicity, antiviral, antithrombotic, antioxidant, and other activities (Olafsdottir; Ingólfsdottir, 2001).

Meanwhile, there are some secondary metabolites that are almost exclusive to lichens (González-Burgos; Fernández-Moriano; Gómez-Serranillos, 2019). Most of these substances can be classified as phenolic compounds, dibenzofurans, depsides, depsidones, depsones, lactones, quinones, and derivatives of pulvinic acid (Shukla; Joshi; Rawat, 2010). They are primarily organic polycyclic compounds synthesized in fungal cells through various pathways such as the acetyl-polymalonil pathway, the shikimic acid pathway, and the mevalonic acid pathway (Figure 4) (González-Burgos; Fernández-Moriano; Gómez-Serranillos, 2019; Morales; Lücking; Anze, 2022; Stanojkovic, 2015). These metabolites are thought to play an important role in self-protection (including antioxidant resistance, photoprotection, antifungal or antibacterial chemicals, and herbivores) and niche competition. In addition, they also play a major role for steady-state in metal homeostasis and pollution tolerance (Beckett; Minibayeva, 2013; Molnár; Farkas, 2010).

Figure 4. Synthesis of secondary lichenic substances from a metabolic pathway perspective



In addition, lichens that colonize fine earth or disturbed soil often act as stabilizers of their substrate preventing surface erosion. Thus, in addition to the numerous medicinal activities, lichens also contribute to the primary accumulation of soil organic matter through the products of stalk decomposition or with leached organic compounds. Among the cyanolichens studied that presents bioactive products, it is worth highlighting the species *Solorina crocea*, which produces two types of Lacases, homodimeric (large) and monomeric (small), which in turn are responsible for the depolymerization and discoloration of humic acids in the soil. Once released or leached into the soil, they have a potential to participate in extracellular reactions of humus synthesis or degradation. This finding suggests that in some ecosystems leached lichen enzymes may play an important role in the transformation of natural organic matter and thus play a previously unsuspected role in the global carbon cycle (Lisov *et al*., 2012).

Furthermore, the monitoring and indication of environmental quality by means of cosmopolitan organisms has developed remarkably in recent decades (Aiyub; Awang; Abas, 2020). Due to the number of people affected, mainly by air pollution. In view of this, several studies have been carried out to identify, find ways to monitor, control pollution and minimize its effects. Biomonitoring is one of the ways to monitor the evolution of pollution. However, biological indicators are important, but they cannot characterize pollution alone. They serve to indicate the presence of the pollutant, but do not quantify it. Thus, the categorization of pollutants enables better ways to deal with the detection and identification of pollutants, as well as to make the subsequent work of searching for and adopting countermeasures possible to apply to each case to minimize the problems caused by the different polluting agents (Maki *et al*., 2013).

Regarding trace elements, they are considered essential micronutrients for living organisms, but in excessive quantities they can be considered dangerous for them. Meanwhile, polycyclic aromatic hydrocarbons (PAHs) are ubiquitous environmental pollutants generated primarily during the incomplete combustion of organic materials (e.g., coal, petroleum, and wood) (Nadzir *et al*., 2017). Trace elements often occur excessively in areas that involve human activities. The sources of the trace elements are usually from traffic, factories and incinerator emissions, which is why more studies have been focused on urban areas. The concentration and type of trace elements may vary depending on the source of the pollution (Incerti *et al*., 2017) .

The N and S elements include various compounds, such as ammonium nitrate (NH3), nitrogen dioxide (NO2), and sulfur dioxide (SO2). These elements are among the essentials that are important in the growth of plants and other living things (Sert *et al*., 2011). In recent decades, several studies have shown that lichens can measure the N and S elements using monitoring techniques. Aas and Awang (2017) they divided the lichen tolerant species in urban areas into two groups: nitrogen-loving (nitrogen-loving) and acidophilus (sulfur-loving). Tolerance can be defined as the range of an environmental factor within which an organism or population can survive (Lincoln *et al*., 2001).

A variety of mechanisms contribute to the tolerance and sensitivity of these organisms to environmental pollutants, including their biology. Because they live for long periods, and because of their nature of absorbing water and substances from the environment, especially from the air, they are subject to the cumulative effect of pollutants. Mists and dew are the main sources of water for lichens, but they offer a high concentration of pollutants, which are accumulated in the nutrient concentration mechanisms. In addition, the ability to prevent dehydration is another point that increases the concentration of pollutants in the water, which can break the association between the mycobiont and photobiont (Nash III, 2008).

When compared to other groups of lichens, cyanolichens are even more sensitive to environmental pollution, since they have a slower metabolism and, therefore, tend to accumulate more polluting compounds, in addition to their needs (Geiser *et al*., 2019). In addition, these organisms are devoid of protective layers, have no stomata or cuticle, which means that water, gasses and aerosols can be absorbed directly by the stalk and diffuse quickly through the tissue where the photobiont is. Therefore, they do not depend on a root system, but directly on the availability of water and light. In addition, they also have an absence of excretion structures, so the toxic substances, or the selection of these, that are absorbed are not possible to be excreted and can accumulate in the thallus and be deleterious to the photobiont (Geiser *et al*., 1998).

Due to their sensitivity, cyanolichens are able to absorb and retain radioactive elements, excess trace elements, among others, and this makes them effective in use as biological indicators of air pollution (Moreira *et al*., 2017; Osyczka; Rola, 2019; Varela *et al*., 2018) Therefore, according to Dutra *et al* (2020), biomonitoring with the use of these organisms is a low-cost form of pollution analysis, especially atmospheric, considering that Brazil, as well as other countries, lacks air quality monitoring centers. However, it is worth noting that the use of biological indicators does not replace the evaluation of pollutant concentration using physical-chemical procedures, but still provides important complementary information (Nimis *et al*., 2020).

Thus, the assessment of air quality using these organisms emerges as a viable method for measuring and estimating the environmental risks to which the populations of polluted areas are subjected, as they provide data that will support the development of prevention and health protection measures. Therefore, the existence, quantity, and distribution of lichens in an area are factors that can be considered in assessing the environmental impacts of a locality (Moreira *et al*., 2017).

The species *Lobaria lungonaria* stands out as a biomonitor species of multiple environmental factors due to its heterothallic nature, self-incompatibility, low dispersion capacity, long generation cycles (up to 25 years) and susceptibility to environmental parameters. In addition, in the studies analyzed, it is also considered as an "umbrella" species that requires spatial and temporal continuity of the forest habitat to maintain viable populations. It is often accompanied in its habitat by other lichens that are rare or endangered and sensitive to abrupt changes in light conditions (especially in the dry state), such as those that occur after forest clearing (Bianchi *et al*., 2022).

In addition to these, the other cyanolichens species reported in this study that are used in biomonitoring are widely recommended by the authors for this purpose. Considering that this method of analysis using observation and quantification of these organisms as biomonitors, as already mentioned, is relatively simple, low cost and quick result, showing the environmental impacts and assisting in the possible identification and diagnosis of possible causes and stressors, thus obtaining a biological response. It is worth noting that through this method of observing the occurrence of lichens, it is possible to evaluate the effectiveness of mitigating actions and even propose solutions to minimize environmental impacts (Moreira *et al*., 2017). In addition, learning and understanding the morphophysiological changes that occur in the lichenic community after exposure to pollutants is also very important to get a better idea of how air pollution can cause physiological damage to humans (Paoli *et al*., 2020).

The study of bioactive compounds from cyanolichens, as well as its use in biomonitoring, generates great implications, especially as an indicator of the health of individuals, according to the present review. Therefore, the wide variety of bioactivities identified so far reinforces the need for further studies, especially in relation to cyanolichens in which they are scarcer in terms of research. In addition, this study verifies the efficiency of biomonitoring using cyanolichens, however it reinforces once again the need for more research. It can be seen in many of the studies that have already been carried out with this group of organisms that many of them remain misunderstood, as well as some even unknown. Because there is still little information about this symbiosis. And those that already exist do not yet characterize them as well as they do in the studies of the mycobiont and chlorolichens.

CONCLUSION

The present study reviewed 65 articles exclusively on cyanolichens and their bioactive compounds, as well as their use in the biomonitoring process for environmental quality studies. This study also revealed the peculiarities and gaps in knowledge about cyanolichens. In addition, it was found that despite the scarcity of published studies, the number of studies on this symbiosis and relating them to biomonitoring and the knowledge of its metabolites has increased somewhat in recent years. Most of the studies were carried out in Europe and Asia, with Turkey being the country with the highest number of published works.

Among the cyanolichens studied, there was a prevalence for those of the Peltigeraceae family and among the cyanobionts, the genus Nostoc prevailed in the majority in the symbiotic association. This study confirms that cyanolichens have high environmental pollution indicator properties, since they are highly sensitive to environmental contaminants and polluting gasses from the atmosphere. As well as their great biotechnological potential, they are, therefore, very promising as a source of biomolecules, which gives them great economic importance, since their substances with bioactive activities may eventually result in the production and synthesis of possible new drugs and treatments against diseases, such as cancer, for example.

However, it is worth noting that there were several limitations and gaps in this review study involving cyanolichens as biomonitors and in the use of their bioactive substances. In addition to the scarce literature on the diversity, physiology and ecology of these organisms, information on biomonitoring and the use of these organisms as sources of biomolecules is still minimal, or not even available in the literature, in several regions of the world, including several locations in Brazil.

In addition, combined with the lack of information, as well as the unbridled exploitation of these lichenic organisms (as a whole, cyanolichens and chlorolichens), mainly by continuous sampling by economic interests, have led these organisms to their loss in ecosystems due to their slow growth rate. In addition, it is emphasized once again the need for more studies to obtain more current, complete and deeper knowledge about biology and functioning and for a better understanding of how the interaction in these associations occurs.

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