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SCIENTIFIC BASIS FOR USING LICHENS AS BIO-INDICATORS OF SO_2 CONTENT IN THE AIR ENVIRONMENT IN SOME PROVINCES AND CITIES IN NORTH OF VIETNAM

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Abstract

Scientific research using lichens as indicators of the air environment is carried out based on research results from around the world, as well as surveyed and collected data in Bac Ninh province (Northern Vietnam). The results of studying the biological and ecological characteristics of lichens show that lichens have a fairly simple structure and connection between the constituent parts of lichens. The life of lichens is associated with many types of substrate and direct absorption of substances in the air environment. Therefore, lichens are easily affected by factors in the atmospheric environment and expressed through their biodiversity indicators. Research around the world has determined the species composition and physiological and biochemical characteristics of lichens related to atmospheric environmental factors. Since then, there have been studies using lichens as indicator organisms to assess air quality. In Vietnam, research results in Bac Ninh province show that the correlation between the AQI_SO_2 *index and lichen coverage in habitats has a fairly close linear relationship and a negative correlation through the correlation coefficient R = -0.881. The diversity indices (d, H', J') of lichens have a less close linear relationship with the* AQI_SO_2 *index as shown by the low correlation coefficient. This result shows that lichen biodiversity indices may have a nonlinear relationship with the* AQI_SO_2 *index. These data are considered the scientific basis of research on using lichens as biological indicators of the air environment, specifically indicators of* SO_2 *content in the air in some provinces/cities in Northern Vietnam.*

Keywords: Scientific basis; Lichens; Bio-indicators; SO_2; North of Vietnam.

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1. Introduction

Air plays a vital role in life, an indispensable element for all living things' survival and development. Along with economic growth, industrialization, and modernization, in recent years, the problem of air pollution has become increasingly increasing, especially in large cities. Air pollution and its effects on human health have become increasingly evident. Big cities and industrial zones are the epicenters of this situation.

In provinces/cities in Northern Vietnam, high traffic density, people's daily activities, industrial parks, and economic activities have emitted many types of gases, including SO_2, which have greatly affected the quality of surrounding air and affected the health of people, as well as large-scale and long-term natural ecosystems. To have appropriate solutions to cope with and limit the effects of air pollution, it is first necessary to monitor and evaluate SO_2 content and quality of the air environment.

The authors used many different methods to monitor air environment quality, such as using periodic environmental monitoring points using automatic monitoring stations with devices that operate automatically continuously over time. In addition, it is also possible to use organisms as Environmental indicators. In particular, using organisms as indicators of the air environment is an effective method. This method has advantages such as easy classification, easy sampling, high adaptability, and wide distribution,... in addition to being economical and more accessible to implement than other methods.

Among the groups of terrestrial organisms, lichens are a group of symbiotic organisms between algae and fungi (incomplete structural organization), so they are easily affected by atmospheric environmental factors, especially SO_2 that cause them to change in appearance, physiological, biochemical, and morphological characteristics of lichens, and can change the quantity, density, and composition of lichen species. Therefore, research into using lichens as indicators of SO_2 content is necessary for monitoring and assessing air environment quality.

2. Approach and research methods

Biological-ecological approach: Collecting documents, analyzing the structural characteristics, growth and development of lichens, characteristics of the relationship between organisms and the environment, and impacts of environmental factors on organisms; Structural composition of lichen, biological and ecological characteristics of lichen.

Practical approach: Field survey and data collection, analyze the influence of environmental factors on lichens, as well as the relationship between lichens and habitat factors, such as SO_2 content in the air in Bac Ninh province.

3. Results and discussion

3.1. Biological and ecological basis of lichens

Research by scientists shows that lichen is a complex organism with different components. The main components in lichen are usually fungi and algae that live symbiotically. Algae in lichens are usually unicellular Chlorophyceae or Cyanobacteriae or both [14].

- Based on appearance, there are

three types of lichens [4].

+ Mosaic lichens (Crustose): These are lichens in which the thallus is firmly attached to the substrate without leaving any free margin, and it isn't easy to collect it. Most of these lichens are collected with their substrate, there are no pseudo roots (rhizines) and lower cortex in these lichens.

+ Foliose lichens: These are lichens in which the foliage is loosely attached to the substrate leaving free edges, they look like a scale leaf and hence are also called Foliose lichens.

+ Fruticose lichens: Fruticose lichens can be pendant and hair-like, upright and shrubby, or upright and cup-like. Many fruticose lichens have round branches with a central core, and others are hollow in the middle. Other fruticose lichens have flat branches that tangle up with each other.

In this symbiotic relationship, the fungus (as a pseudoroot) will synthesize water and inorganic salts from the surrounding air to provide to the algae so that the algae (with chlorophyll) photosynthesize and form algae. Organic substances are used for the growth and development of the lichens. Larry McKane and Judy Kandel, (1996) said that, with this characteristic, lichens can be present all over the world, from familiar environments to harsh habitats. However, because lichens absorb water, mineral salts, and many other compounds directly from the surrounding air environment, these factors (temperature, humidity, light, NOx gases, SOx, etc.) all affect the physiology, biochemistry, growth, development, and diversity of lichens [7].

The growth rate of lichens depends on many factors in the habitat, including soil structure, weather, humidity, nutrient absorption, and metabolism. These factors affect the ability of lichens to absorb and store water and nutrients. Lichens grow very slowly: Crustose lichens grow from 0.1 - 10 mm/year, and Foliose lichens grow from 2 - 4 cm annually. Lichens are susceptible to damage from air pollutants and can be considered biological indicators of air quality [5].

The above data shows the body structure and connection between parts of lichens are pretty simple. Lichens' living environment is attached to many substrates and directly absorbs substances. Therefore, lichens are easily affected by factors in the atmospheric environment and expressed through their biodiversity indicators.

3.2. Sensitivity of lichens to the effects of the atmospheric environment

With symbiotic living characteristics, the composition of algae and fungi quickly changes and combines to create many species of lichen depending on environmental conditions, especially climatic and air environmental factors.

The influence of environmental factors, especially the air environment such as temperature, light, humidity, and gases emitted by human activities into the environment (NO_2, SO_2, CO, CO_2, etc) will affect lichens and cause them to change in morphology, physiology, and biochemistry due to variation or mutation, the loss of some species (natural selection mechanism), or the existence of several species (adaptation mechanism), this demonstrates the relationship between lichens and environmental quality [1].

Lichen species, especially those

that live on plants, are susceptible and respond clearly to environmental changes, including changes in structure, plant composition, air quality, and climate. The disappearance of lichens in an area may indicate that the environment contains factors or gases unfavorable to lichens, which are often contaminated, for example, pollutant gases such as sulfur dioxide and nitrogen oxides at a high level [6].

The area's air quality greatly influences lichens diversity because lichens are sensitive to toxic gases, especially sulfur dioxide (SO_2), which weakens the photosynthetic apparatus by converting chlorophyll a into phaeophytin. Therefore, in areas surrounding industrial parks and roads with high SO_2 content in emissions causing air pollution, it will significantly affect the coverage and composition of lichen species, especially the disappearance of species belonging to the Foliose and Fruticose lichen groups [3].

In ecological research, lichens are used as indicators of environmental pollution, especially in places with high traffic density: They absorb toxic heavy metals released by vehicles (such as cars, and motorbikes) discharged into the environment. Therefore, it can be said that air pollutants easily damaged lichens and can be considered indicator organisms of air quality [3].

Like many other organisms, most lichens are vulnerable to damage caused by air pollution. When lichens disappear, it is a warning signal of harmful conditions for the environment and humans. It was also discovered that many lichen species often disappear in areas downwind from the exhaust source. Scientists use lichens to monitor air quality by comparing current and recorded lichen diversity. In this way, it was discovered that nearly 80 % of the original lichen species were lost in some places after traffic and urban development [2].

3.3. The relationship between lichens and SO_2 in the air, the possibility of applying lichens as indicators of the air environment

At a laboratory scale, scientist Rebecca and her colleagues have demonstrated that SO_2 gas in the air can destroy the cell membranes of lichens (Fields and St Clair, 1984) [11]. Based on sensitivity and time, membrane permeability testing was determined to be the most effective method to evaluate the impact of SO_2 on lichens. The optimal method of determining the sensitivity for testing membrane permeability is to expose lichens for 4 hours to 2 ppm SO_2. However, after 8-h and 12-h exposures, the potassium amount and conductivity determined both changed significantly. Regardless of exposure time, photosynthesis and respiration continued with little change. However, as exposure increases, photosynthesis and respiration activity decrease. Significant differences in species responses were detected only during photosynthesis.

Studies by LeBlanc & Rao, (1975) [8], Ronen & Galun, (1984) [12], and Zambrano & Nash, (2000) [15] suggest that chlorophyll a + b concentrations are changed due to exhaust pollution from vehicles and urban emissions. Lichens in heavily trafficked vehicle areas show increased in chlorophyll a + b concentrations corresponding to increased emissions. Such impacts are generally due to emissions from vehicles, and in particular sulfur and nitrogen oxides. In areas with high traffic intensity and high levels of industrial pollution, Chl b/Chl a ratio values are also high.

Regarding the ability to accumulate environmental pollutants in lichens: Research by Rope & Pearson, (1990) showed a close correlation between sulfur concentration accumulated in lichens and SO_2 gas in the air [13]. Specifically, the author used two measurement techniques to evaluate the feasibility of using lichens as in situ biomonitors of atmospheric pollution in a semiarid climate - trace element analysis and electrolyte leakage from cells. Trace element concentrations in tissues of *Lecanora melanophthalma* (Ram.) were generally higher than previously measured in plants (*Artemisia tridentata*) and perennial grasses in the exact location but lower in soil.

According to statistics, concentrations of 10 elements, especially lead and zinc of lichens in an urban area (Idaho Falls) were higher than those from the Idaho National Engineering Laboratory (INEL) and the volcano's Caldera National Memorial. Fluoride, nickel, and seven other elements at INEL were higher than at other sites. Boron and lead concentrations in lichen stands collected downwind from the Idaho Chemical Processing Plant (ICPP) at INEL were significantly higher than those collected at upwind sites: Levels of the 11 elements in lichens collected at 5 or 10 km from ICPP were significantly higher than in lichens collected at 2 km. Electromagnetic leakage at thalli was the most significant in the downwind direction at night from the ICPP. However, daytime winds blew in the opposite direction more often, suggesting that in a semi-tropical climate, pollution damage atmospheric emissions of SO_2 and NO are the most significant when lichen tissues are wet from morning dew or other sources. These results demonstrate that some lichen species, especially *Lecanora melanophthalma*, can potentially biomonitor atmospheric pollutants in semiarid regions.

** Studies on the relationship between lichen diversity and SO_2 content in the air in Vietnam*

In Vietnam, Nguyen Thanh Luc, (2020) [9] researched lichens and epiphytes on tree trunks with the air condition in Ho Chi Minh city. In this study, the author collected samples in the field and analyzed lichen samples, combining data collection of indicators (TSP, PM10, CO, SO_2, NO_2) from several monitoring stations. Then determine the correlation between species composition, lichen coverage, and mosses with the concentration of substances in the air using multivariate statistical analysis. The results show a correlation between the coverage of lichen species and epiphyte on tree trunks with environmental factors such as CO, NOx, total suspended dust (TSP), PM10, and bark pH.

In 2022, we studied lichens' biodiversity and SO_2 emissions in the air in Bac Ninh province. The results of surveying, sampling, and analyzing lichen samples at habitats in Bac Ninh province have detected 18 species, belonging to 14 genera, 9 families, 9 orders, and 4 classes. Lichen coverage tended to decrease in areas at risk of pollution due to the operation of machinery, engines using petroleum fuel such as highways and industrial parks, or areas where straw burning, as well as gas emissions caused by compostable organic substances, occur in rural areas. Lichen biodiversity indicators tended to gradually reduce the survey habitat that generated a risk of air pollutants.

Table 1. Lichen biodiversity index in studied habitats in Bac Ninh province

Biodiversity index / Habitat	Number of species(S)	Coverage (v %)	Margalef index (d)	Shannon-Weiner index (H’)	Pielou index (J’)
Industrial Park (KCN)	11	2.021	2.171	1.408	0.587
Highways (GT)	7	2.386	1.303	1.110	0.570
Urban area 1 (ĐT_1)	9	4.413	1.737	1.540	0.701
Urban area 2 (ĐT_2)	6	6.718	1.086	1.457	0.813
Rural areas (NT)	11	5.787	2.171	2.101	0.876

Principal component analysis (PCA) analysis of the occurrence of lichen species in different habitats reveals that there are certain characteristic species groups in different habitats. In the industrial park, there was a significant occurrence of *Arthonia pyrrhuliza*. In the highway and urban habitat 2 near the road, there was the appearance of *Graphis crebra*. In addition to urban area 2, there was also the species *Fissurina dumastioides* and *Graphina marcescens, Lepra multipuncta,* on the other hand, was featured in urban habitat 1.

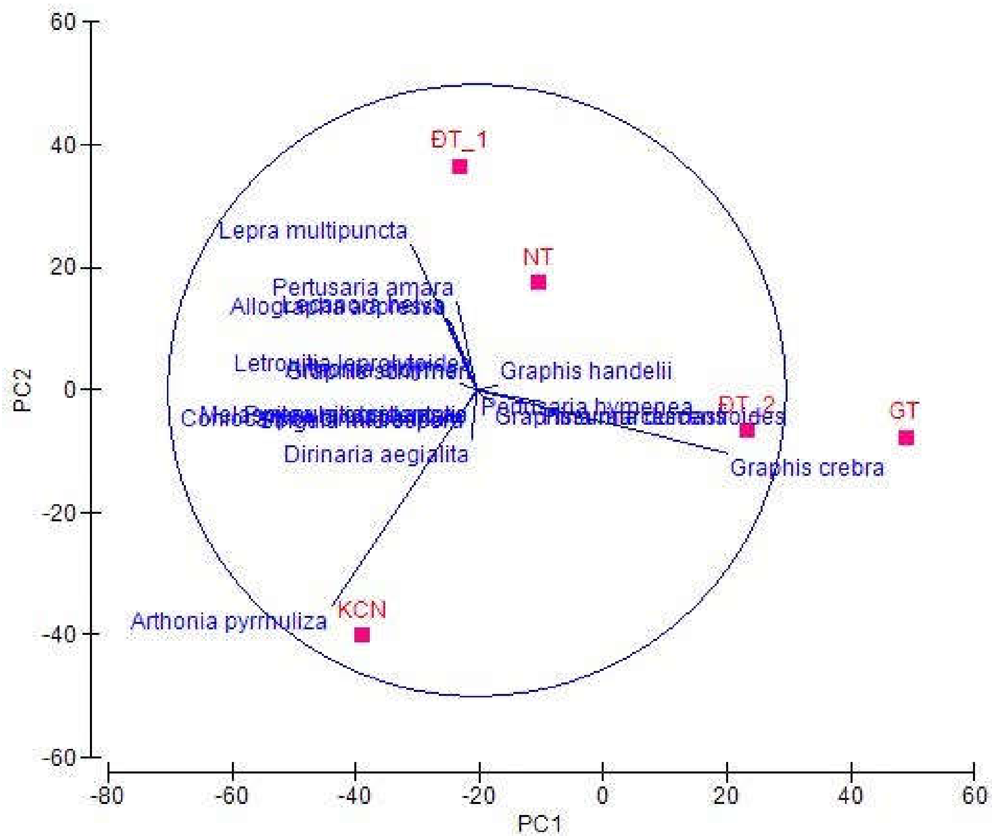

Figure 1: Principal component analysis (PCA) diagram showing typical lichen species by habitat in the study area

The average AQI of SO_2 parameters from January to May of the habitats was at a reasonable level, but in habitats that had the risk of generating air pollutants, there was a higher AQI_SO_2 value than in other habitats.

Figure 2: AQI_SO_2 index at survey habitats in Bac Ninh province

The correlation between the AQI_SO_2 index and lichen coverage in habitats had a relatively close linear relationship and an inverse correlation through the correlation coefficient R = -0.881. This relationship can be expressed by the linear regression equation y = -5.3417x + 42.251.

The diversity indexes (d, H', J') of lichens had a less close linear relationship with the AQI_SO_2 index expressed by a low correlation coefficient. For the species abundance index (d), r = 0.125; for the Shannon - Weiner diversity index (H'), r = -0.552; and for the Pielou equilibrium index (J') r = -0.535. This result suggests that lichen biodiversity indicators may have nonlinear relations with AQI_SO_2 indices.

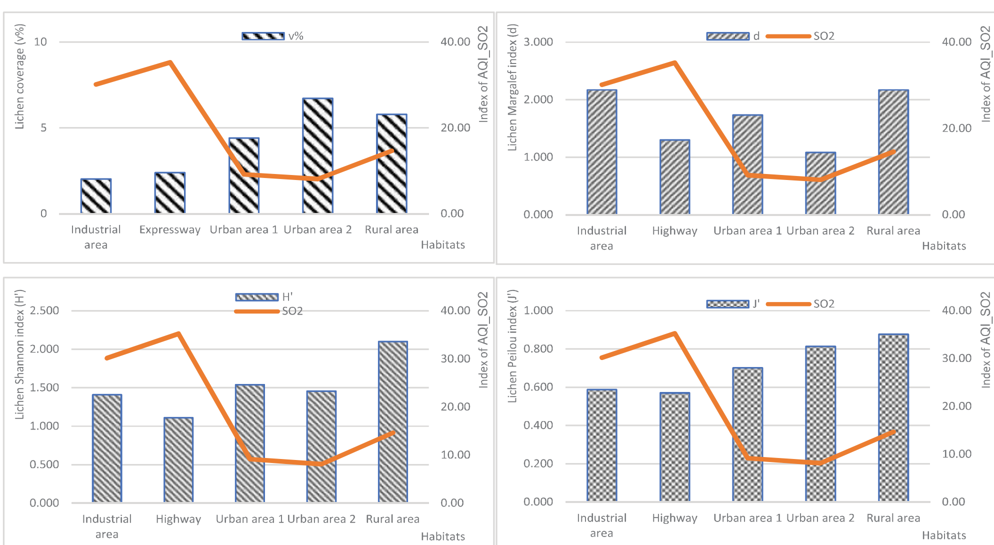

Figure 3: The relationship between the AQI_SO_2 index and the biodiversity index (v %, d, H', J') of lichens

3.4. The use of lichens in air environmental indicators in the world and Vietnam

Over the years, several studies have emphasized the feasibility of using lichens in biological monitoring to assess environmental air quality (Nimis, 1990). Epiphytic lichens on olive trees were used as bioindicators for sulfur dioxide (SO_2) pollution in La Spezia (Northern Italy). Data analysis was based on multivariate classification and ordination methods and contamination maps were produced using automated mapping programs. Based on the frequency of species in the sampling grid, the index showed a very high statistical correlation with pollution data measured by recording gauges. The results of taxonomy and ordination indicate that *Parmelia caperata* is the species whose distribution is best related to the lichen index [10].

In Jovan's (2008) report on lichen biodiversity indicators, air quality, and climate change based on monitoring results in Washington, Oregon, and California. This report summarizes the primary results of the lichen community indicator (U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis - FIA). During this period, FIA conducted 972 surveys of arboreal lichen communities to monitor both temporal and spatial trends in forest status. Key research results are presented with an emphasis on lichen biodiversity and lichen bioindicators of air quality and climate. The remarkable result is to create a distribution map and identify suitable indicator lichen species to estimate air quality and climate and identify indicator species or groups for each pollutant group. Through indicator species, lichen community models are closely related to the deposition of specific pollutants such as SO_2, NO_2, etc. The study identified air quality indicators for the West Coast of the Pacific Northwest, California's Central Valley, and surrounding Nevada. The identified air quality in each area is mapped and a summary of relevant information is recorded. This study also identified two groups of promising indicators: acidic lichens and neutral lichens [6].

Up to now, in Vietnam, research has mainly been on lichen species composition in some areas. There have yet to be studies in Vietnam on the relationship between the biological characteristics of lichens and the content of air pollutants, on the ability of lichens to accumulate environmental pollutants, and on using lichens in forecasting air ecological quality, especially in large cities and industrial zones.

Thus, research has only focused partly on determining species composition in the South Central, Southern, and Central Highlands regions in Vietnam. There are a few studies on the chemical composition of lichens and some studies on the relationship between biological characteristics, biodiversity index of lichens, and environmental factors in Northern Vietnam. These data are the scientific basis of research on using lichens as biological indicators of the air environment, precisely indicators of SO_2 content in the air in some provinces/cities in Northern Vietnam.

4. Conclusion

Research on the biological and ecological characteristics of lichens shows that lichens have a relatively simple structure and connection between the constituent parts of lichens. Lichens are associated with many types of substrates and direct absorption of substances in the air environment. Therefore, lichens are easily affected by factors in the atmospheric environment and expressed through their biodiversity indicators.

Worldwide research has determined the species composition and physiological and biochemical characteristics of lichens related to atmospheric environmental factors. Thereby, there is quite a lot of research on lichens globally, especially using lichens as indicator organisms to assess air quality.

In Vietnam, there have been several studies on lichen diversity and initial analysis and determination of the correlation between lichen diversity and some atmospheric environmental factors. Research results in Bac Ninh province show that the correlation between the AQI_SO_2 index and lichen coverage in habitats has a relatively close linear relationship and a negative correlation through the correlation coefficient R = -0.881. The diversity indices (d, H', J') of lichens have a less close linear relationship with the AQI_SO_2 index, as shown by the low correlation coefficient. This result indicates that lichen biodiversity indices may have a nonlinear relationship with the AQI_SO_2 index.

These data are considered the scientific basis of research on lichens as biological indicators of the air environment, precisely indicators of SO_2 content in some provinces/cities in Northern Vietnam.

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