

# Estudos sobre bioindicadores vegetais e poluição atmosférica por meio de revisão sistemática da literatura

## RESUMO

O uso de biomonitoramento vem sendo cada vez mais considerado como método complementar na análise de poluentes urbano-industriais. Este trabalho teve por objetivo identificar espécies vegetais (vasculares, musgos e líquens) utilizadas como bioindicadores e associadas a poluentes atmosféricos, em estudos experimentais e observacionais por meio de revisão sistemática de literatura. De um total de 4775 trabalhos pré-selecionados, foram analisados 507 estudos por aplicação de dois testes de relevância, resultando na inclusão de 265 trabalhos científicos sobre o tema estudado. Os resultados revelaram a utilização de 224 espécies vegetais como bioindicadores de processos de poluição atmosférica, sendo: 147 pertencentes à divisão angiosperma; 22 à divisão coniferófito; 30 a líquens; e, 25 a musgos. Os estudos selecionados eram relacionados ao monitoramento dos seguintes poluentes atmosféricos: metais pesados, ozônio, material particulado, dióxido de enxofre, óxidos de nitrogênio, monóxido de carbono, fluoretos, compostos orgânicos voláteis e hidrocarbonetos. Foi possível constatar nesses estudos, o uso de algumas espécies vegetais em processos de avaliação da qualidade do ar em várias partes do mundo, indicando a potencial utilização do biomonitoramento vegetal como um novo instrumento de monitoramento e controle da qualidade do ar, em espaços urbanos.

**PALAVRAS-CHAVE:** Bioindicador vegetal; poluição do ar; avaliação de risco ambiental; biomonitoramento.

## ABSTRACT

The use of biomonitoring is being increasingly considered as a complementary method in the analysis of urban-industrial pollutants. This study aimed to identify vegetal species (vascular, moss and lichen) used as bioindicators associated with air pollutants, in experimental and observational studies through a systematic literature review. Out of a total of 4,775 pre-selected scientific papers were analysed 507 studies by applying two tests of relevancy, of which we included 265 scientific studies on the theme. The results revealed the use of 224 vegetal species as bioindicators of air pollution processes, as follows: 147 species belonging to the angiosperm division, 22 to the coniferofit division, 30 to the lichens, and 25 to mosses species. The selected studies were related to the monitoring of the following air pollutants: heavy metals, ozone, particulate matter, sulfur dioxide, nitrogen oxides, carbon monoxide, fluorides, volatile organic compounds and hydrocarbons. It was possible to note in the selected studies the use of some plant species in assessing air quality in various parts of the world, indicating the potential use of the vegetal biomonitoring as a new tool for monitoring and controlling air quality in urban areas, which will enable the verification of risk situation by the presence of air pollutants in urban areas.

**KEYWORDS:** Vegetal bioindicator; air pollution; environmental risk evaluation; biomonitoring

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## INTRODUÇÃO

A qualidade do ar tem sido avaliada a partir de estimativas das concentrações ambientais dos principais poluentes, sendo comumente utilizados métodos físico-químicos cientificamente consagrados. Por esses métodos, pode-se verificar se normas e valores limites para concentrações de poluentes no ar estão sendo respeitados. Porém, nem sempre os resultados obtidos permitem conclusões imediatas sobre os impactos das concentrações atuais de poluentes em seres vivos (KLUMPP et al., 2001).

A partir de meados do século passado, iniciou-se o processo de utilização de organismos vivos em método auxiliar de detecção de alterações perigosas da qualidade do ambiente, denominado de biomonitoramento, que se constitui em método experimental indireto de verificação da presença de poluentes numa determinada área. Os organismos vivos utilizados são conhecidos como bioindicadores, e respondem ao estresse a que se encontram submetidos por modificações nos seus ciclos vitais ou pela acumulação de poluentes (GARTY; KLOOG; COHEN, 1998; CARRERAS; PIGNATA, 2001; CARNEIRO, 2004).

Os bioindicadores podem ser utilizados de forma passiva, quando já habitam a área de estudo; ou em método ativo, quando são introduzidos de forma controlada no ambiente a ser investigado (DOMINGOS et al., 1998; SILVA et al., 2000; SUMITA et al., 2003).

Dentre os organismos utilizados como bioindicadores, destacam-se os líquens, os musgos e certas plantas superiores, que podem apresentar alterações típicas nas folhas, perdas foliares, redução de crescimento, alterações nos padrões de floração, ou ainda, alterações na frequência e abundância de populações quando expostas a poluentes atmosféricos (KLUMPP; DOMINGOS; KLUMPP, 1996; KRUPA; LEGGE, 1999; SCERBO et al., 1999; KLUMPP, A.; KLUMPP, G.; ANSEL, W., 2003; BURGER, 2006).

Visando-se reunir conhecimento referente ao uso de bioindicadores vegetais, como método complementar de monitoramento da contaminação

atmosférica, foi realizada esta pesquisa, de caráter descritivo, com base em revisão sistemática da literatura - RSL (MUÑOZ et al., 2002).

## METODOLOGIA

Foram levantados estudos publicados na literatura acadêmica relacionados ao uso de bioindicadores em processos de poluição atmosférica, sendo os critérios iniciais de inclusão: estudos experimentais ou observacionais nos idiomas inglês, espanhol ou português sobre o tema bioindicador vegetal de poluição atmosférica, publicados no período compreendido entre janeiro de 1997 e dezembro de 2007.

Tomou-se por base a metodologia da revisão sistemática da literatura (RSL), que busca a integração da informação acadêmica produzida em diferentes situações, locais e por diversos grupos de pesquisadores, possibilitando o conhecimento das evidências científicas existentes na área (GREENHALGH, 1997; MUÑOZ et al., 2002).

As bases de dados utilizadas foram: Biological Abstracts, da Electronic Reference Library (ERL), MedLine, Agris, ProQuest e, também, os bancos e bases de dados nacionais e latino-americanos Lilacs, Instituto Brasileiro de Informações em Ciências Tecnológicas (IBCT) e Dedalus.

Os instrumentos de coleta de dados constituíram-se de dois formulários denominados Teste de Relevância 1 (TR1) e Teste de Relevância 2 (TR2), elaborados para avaliar a inclusão ou a exclusão dos artigos levantados junto aos bancos e bases de dados selecionadas, de acordo com os critérios estabelecidos para o estudo.

Os critérios de inclusão dos estudos no TR1 foram: período e idioma da publicação; tipo de estudo; e, a pertinência do tema. Para o TR2, os critérios foram também: análise direta ou indireta de qualquer um dos poluentes selecionados para esta investigação (PTS, MP-10, metais pesados, SO<sub>2</sub>, NO<sub>x</sub>, O<sub>3</sub>, CO, VOCs, hidrocarbonetos, HF e demais fluoretos gasosos); registro da presença de danos verificáveis a olho nu em folhas, caule, flores ou frutos dos vegetais analisados, bem

como modificações anatômicas, metabólicas, fisiológicas e genéticas, não visíveis a olho nu; e, a indicação do vegetal como um bioindicador ou bioacumulador.

## RESULTADOS

A presente pesquisa foi baseada em 305 estudos analisados na íntegra, sendo uma continuação do estudo acadêmico realizado por Carneiro (2004), no Brasil, considerado um dos únicos estudos nacionais dessa natureza e com essa abrangência.

Os resultados obtidos são apresentados segundo o uso do método de revisão sistemática da literatura empregado neste estudo e também quanto à utilização de vegetais em sistemas de biomonitoramento da qualidade do ar.

### Quanto à revisão sistemática da literatura

O levantamento bibliográfico efetuado conduziu, inicialmente, a um universo de 4775 estudos científicos, dos quais nem todos se referiam, exclusivamente, ao tema pesquisado, abrangendo diversas formas de bioindicadores vegetais, animais e do metabolismo humano, utilizados para avaliação da contaminação do ar, da água, do solo, ou ainda relativos à saúde humana. Após uma leitura prévia seletiva, foram selecionados 507 trabalhos referentes exclusivamente a bioindicadores vegetais de poluição atmosférica, incluindo, além de artigos científicos, três dissertações de mestrado e uma tese de doutorado defendidas em universidades brasileiras e americanas, segundo as informações obtidas nas bases de dados e periódicos selecionadas.

Com a aplicação do TR1, foram avaliados os 507 artigos científicos por dois revisores, tomando-se por base os seus resumos, resultando em 391 inclusões e 116 exclusões. Dos 391 estudos selecionados, obteve-se acesso a 305. O motivo da perda de 86 (22%) estudos selecionados foi a sua não disponibilização nos meios eletrônicos ou na forma impressa. Assim, a amostra final para aplicação do TR2, foi de 305 estudos na íntegra.

A aplicação do TR2 nos 305 estudos na íntegra encontrados resultou na inclusão de 265 artigos (86,8 % do total analisado), que constitui a amostra final deste estudo, e na exclusão dos outros 40 estudos (13,1 % do total de 305 analisados), por motivos de não atendimento aos critérios de seleção para o TR2.

#### **Quanto ao uso de bioindicadores vegetais em processos de poluição atmosférica**

Tomando-se como referência evidências científicas sobre o uso de bioindicadores vegetais em processos de poluição atmosférica, foram identificadas 224 diferentes espécies nos 265 estudos incluídos nesta revisão, sendo 147 pertencentes à Divisão Angiospermae, 22 à Divisão Coniferophyta, 25 à Classe Musci da Divisão Bryophyta (musgos) e 30 líquens. Verificou-se que algumas espécies são mais frequentemente associadas a determinados poluentes, como: *Nicotiniana tabacum*, usada como bioindicador da presença de ozônio; musgos *Pleurozium schreberi*, *Hypnum cupressiforme* e *Hylocomium splendens*, usados como bioindicadores da presença de metais pesados; e, o gênero *Tridascantia*, usado como bioindicador associado a poluentes urbanos, dentre outros. Também a investigação da biodiversidade de líquens em ambientes próximos a fontes emissoras de poluentes atmosféricos foi uma técnica frequentemente encontrada nos estudos selecionados (CARNEIRO, 2004).

Os trabalhos levantados nesta investigação são apresentados no Quadro I, em forma de uma lista com as referências dos estudos e o ano de publicação.

#### **Discussão**

O uso da metodologia de revisão sistemática da literatura permitiu levantar o conhecimento acadêmico gerado sobre uso de bioindicador vegetal em processos de poluição atmosférica, embora os resultados obtidos possam ser considerados parciais em relação à produção acadêmica mundial sobre esse tema, devido a limitações da metodologia empregada, em termos das

palavras-chave e bancos/bases de dados utilizados, bem como por dificuldades com o acesso a todos os estudos selecionados.

As revistas eletrônicas tiveram papel relevante na concretização desta pesquisa, tendo em vista que mais de 90 % dos estudos foram obtidos por essa via. A busca efetuada conduziu a apenas quatro trabalhos de dissertação ou tese, o que pode ser devido a um caráter de vanguarda do tema selecionado ou, então, por não indexação de estudos nas bases e bancos de dados utilizados nesta investigação.

Os resultados também revelaram a utilização de 224 espécies vegetais como bioindicadores de processos de poluição atmosférica, utilizadas em diversas situações climáticas e geológicas e em diferentes regiões do mundo.

Os estudos também apontaram para o uso individual ou em grupo de algumas espécies, relacionadas ao monitoramento de um ou vários poluentes atmosféricos, entre os mais comuns, destacando-se: metais pesados, ozônio, material particulado, dióxido de enxofre, óxidos de nitrogênio, monóxido de carbono, fluoretos, compostos orgânicos voláteis e hidrocarbonetos.

No entanto, com os dados levantados foi possível constatar uma ampla rede de situações de uso de algumas espécies vegetais em avaliação da qualidade do ar em várias partes do mundo. Acredita-se que o biomonitoramento vegetal seja um novo instrumento de monitoramento e controle da qualidade do ar, em espaços urbanos, que possibilitará a verificação de situações de risco pela presença de poluentes atmosféricos, juntamente com os instrumentos usualmente utilizados na quantificação desses poluentes.

Acredita-se que o uso de biomonitoramento com vegetais bioindicadores, a partir de sistemas conhecidos e padronizados, possibilitará a verificação de situações de risco pela presença de poluentes atmosféricos, facilitando, ainda, a decisão sobre locais que devam ser sistematicamente monitorados com a ajuda de instrumentos destinados à quantificação desses poluentes.

## **CONSIDERAÇÕES FINAIS**

A presente pesquisa revela um interesse crescente, de amplitude mundial, na busca por métodos auxiliares de detecção de alterações ambientais provocadas por poluentes atmosféricos, visando o diagnóstico precoce de situações de risco. Também, esta revisão sistemática da literatura amplia os achados de Carneiro (2004), trazendo novas contribuições acadêmicas na área de controle da poluição atmosférica por uso de bioindicador vegetal.

Corroborando, ainda, os estudos de Klumpp et al. (2001), Reiss et al. (2007) e Krewski (2009), destacando a necessidade de motivar a opinião pública, incluindo a administração pública e os setores de produção privada, sobre a importância de adoção de novos meios de controle da qualidade do ar mediante efeitos negativos da poluição.

Baseado nos achados desta investigação, considera-se que a adoção de métodos alternativos de verificação de risco ambiental, como o uso de bioindicadores vegetais em processos de poluição atmosférica, poderá auxiliar na minimização das consequências desses contaminantes sobre a saúde humana e sobre a qualidade ambiental dos centros urbanos.

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Autor	Título do artigo	Referência
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Autor	Título do Artigo	Referência
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