*Macedonian Pharmaceutical Bulletin*, 72 (Suppl 1) 573 - 574 (2026)
Online ISSN: 1857-8969
DOI: 10.33320/maced.pharm.bull.2026.72.03.276
*Short communication*

# Phytochemical and vibrational spectroscopic markers in medicinal plants as indicators of urban and anthropogenic ecological stress

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## Introduction

Urbanization and anthropogenic activities are major factors affecting environmental quality and inducing physiological and biochemical changes in plants. Due to their ability to respond to environmental stress through modifications of secondary metabolism, medicinal plants represent valuable bioindicators of ecological disturbances (Qaderi et al., 2023).

It is widely evidenced that environmental conditions influence the presence of secondary metabolites. Particularly polyphenols, iridoids and mucilages are considered as important indicators of adaptive responses to environmental conditions (Salam et al., 2023). By comparing the phytochemical composition of the plant samples collected from locations with different degrees of urbanization, can be assessed whether variations in the concentration of the main phytochemical markers can serve as reliable indicators of anthropogenic environmental stress.

In recent years, Fourier-transform infrared (FTIR) and Raman spectroscopy have been increasingly applied as rapid, non-destructive tools for both qualitative and quantitative characterization of phytochemical constituents in herbal materials.

In order to assess whether plants can serve as indicators for ecological stress, this study aims to investigate the influence of urban and anthropogenic stress on the phytochemical profiles of four widely distributed medicinal plant species.

## Materials and methods

*Plant material and sample preparation*

The study included 4 medicinal plant species: *Plantago spp.* (*P. major and P. lanceolata.*, *Chamomilla recutita, Malva sylvestris*, *Capsella bursa-pastoris*. Plant samples were collected during the same vegetation period from locations characterized by different levels of urbanization and anthropogenic influence, including urban, suburban, and relatively unpolluted control sites. The plant samples were taxonomically determined, cleaned, air-dried under controlled conditions, and ground into a homogeneous powder. Extraction procedures were applied depending on the target phytochemical compounds according to the European Pharmacopoeia monographs.

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*Phytochemical and data analysis*

HPLC was employed for quantitative and qualitative phytochemical characterization. Vibrational spectroscopic techniques, including FTIR and Raman spectroscopy, were used to obtain spectral fingerprints of the plant samples. The recorded spectra were analyzed to identify characteristic spectral regions associated with changes in phytochemical composition induced by environmental stress (Geskovski et al., 2021).

The phytochemical and spectroscopic data obtained from samples collected at different sites were statistically processed. Correlation analyses were performed to evaluate the relationship between environmental conditions and variations in phytochemical markers. Multivariate statistical methods were done to identify potential biomarkers of anthropogenic ecological stress and to assess the suitability of the investigated species for environmental biomonitoring.

## Results and discussion

All investigated species (*Plantago spp.*, *Matricaria chamomilla*, *Malva sylvestris*, and *Capsella bursa-pastoris*) exhibited a stable qualitative phytochemical profile across urban, suburban, and control sites, while showing significant quantitative variation depending on the level of urbanization.

*Plantago spp.* showed consistent presence of iridoid glycosides and phenolic compounds with increased variability in urban samples. *Matricaria chamomilla* maintained a stable flavonoid profile, particularly apigenin derivatives, with concentration differences between sites. In *Malva sylvestris*, mucilaginous polysaccharides were the dominant constituents with moderate environmental variation. *Capsella bursa-pastoris* showed the highest variability in phenolic and flavonoid content.

Spectroscopic analysis (FTIR and Raman) confirmed minor but consistent differences in functional group regions associated with secondary metabolites, supporting chromatographic findings.

These results were consistent with previous reports indicating that environmental stress primarily induces quantitative modulation of secondary metabolism rather than qualitative changes. *Plantago* species are known to accumulate iridoid glycosides such as aucubin as part of stress-adaptive defense mechanisms. Similarly, flavonoid variability in *Matricaria chamomilla*, particularly apigenin derivatives, has been reported to depend strongly on environmental and ecological conditions. In *Capsella bursa-pastoris*, increased phenolic variability aligns with findings that Brassicaceae species enhance antioxidant metabolite production under oxidative and environmental stress (Salam et al., 2023). Overall, these patterns confirm that the studied species respond to anthropogenic pressure through metabolic plasticity, supporting their applicability as bioindicators of urban ecological stress.

## Conclusion

The present study demonstrates that urban and anthropogenic stress does not alter the qualitative phytochemical composition of investigated plant species, but significantly influences the quantitative content of key secondary metabolites. The observed variations in iridoid glycosides, flavonoids, phenolic compounds, and polysaccharides reflect metabolic adaptation to environmental stress, primarily associated with oxidative pressure in urban habitats. Among the investigated species, *Capsella bursa-pastoris* and *Plantago spp.* showed the highest phytochemical sensitivity, indicating their strong potential as reliable bioindicators of ecological disturbance. Vibrational spectroscopic techniques showed potential for fast screening of plant samples for environmental stress monitoring based on the phytochemical composition.

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