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Editorial

Special Issue "Antimicrobial Substances in Plants: Discovery of New Compounds, Properties, Food and Agriculture Applications, and Sustainable Recovery"

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Microbial contamination of agriculture and food commodities may cause significant losses, with economic, social and environmental consequences. Therefore, the search for new, promising substances that demonstrate antagonism towards different microorganisms has been observed in recent years. Plants are a valuable source of different bioactive compounds that exhibit antimicrobial activity. These substances usually play a key role as a defense factor against different microorganisms and predators, as well as acting as growth regulators. Plant antimicrobials are varied in their chemical nature and include different compounds, such as polyphenols, terpenoids and essential oils, alkaloids, lectins and polypeptides. Due to the high diversity of their structure and properties, these substances may be applied against bacteria and fungi in the whole food chain, including pathogens and spoilage microorganisms. Taking into account the increased interest in natural antimicrobials, plant metabolites seem to be an important alternative for chemical pesticides in plant protection, as well as for preservatives in food or food packaging. Therefore, research on the discovery of new substances and their antimicrobial activity against bacteria and toxigenic fungi occurring in food and food processing, as well as those responsible for plant infections during their growth, is expanding the current knowledge about plant metabolites. Considering that the majority of research concerns planktonic cells, the activity of plant antimicrobials should be equally important in relation to biofilms formed by pathogenic and spoilage microorganisms. Moreover, the implementation of new technologies, as well as the sustainable recovery of antimicrobial substances from waste materials, is a subject of concern.

The contributed articles belong to the following two groups: (i) concentrated on the biological activity of the plant-derived extracts and oils as well as (ii) novel extraction techniques for obtaining plant derived-extracts.

Plant extracts accommodate a wide diversity of secondary metabolites, which are useful as alternative strategies to control infectious diseases, but are also increasingly used as preservatives in the food industry, in pharmaceuticals and cosmetics and as natural fungicides in agriculture. Nowadays, studies concerning the effect of plant extracts are focusing on the qualitative and quantitative state of the bioactive compounds (e.g., phenolic acids, flavonoids) and their interactions with different microorganisms within the food, cosmetic and agricultural products. A few papers are focused on the study of the phenolic content and antioxidant capacities of, subjected to their studies, plant extracts, indicating the relation of these values on the biological properties of extracts, including antibacterial, antifungal as well as cytotoxic activity.

Ziarno et al. (2021) [1] tested the viability of lactic acid bacteria (LAB) during the fermentation and passage of milk products, enriched with different plant extracts, through the in vitro gastrointestinal digestive tract. In the studies of *Valeriana officinalis* L., *Salvia officinalis* L., *Matricaria chamomilla* L., *Cistus* L., *Tilia* L., *Plantago lanceolata* L. and *Althaea* L.,

plant extracts were added at the beginning of the controlled milk fermentation process in order to obtain information about their interaction with the starter cultures. The results showed that small amounts of the extracts did not influence the fermentation processes; therefore, yogurts enriched with such extracts enable the introduction of new functional food products to the market [1].

In turn, in the research by Gwiazdowska et al. (2022) [2], fungistatic activity of cinnamon bark (*Cinnamomum zeylanicum*), verbena leaves and flowers (*Thymus hiemalis*) and palmarosa leaves (*Cymbopogon martini*) essential oils (EOs) against *F. graminearum* in corn and wheat grain was investigated. All the tested EOs effectively inhibited the growth of fungi in concentrations of 5% and 10%. Cinnamon and verbena EOs also effectively reduced the ergosterol (ERG) content in both grains at the concentration of 1%, while at the 0.1% EO concentration, the reduction in the ERG amount depended on the EO type, as well as on the grain. Moreover, the effect of EOs on the reduction in biosynthesis of the two main *Fusarium* mycotoxins deoxynivalenol and zearalenone has been shown. The degree of zearalenone (ZEA) reduction was consistent with the inhibition of ERG biosynthesis; however, the reduction in deoxynivalenol (DON) was not consistent with this parameter [2].

Nguenha et al. (2021) [3] described the use of plant-derived substances to reduce the growth and mycotoxin production by filamentous fungi in maize grains. The authors evaluated the effect of the combination of photosensitization and curcumin to inactivate *Aspergillus flavus* spores and minimize aflatoxin B1 (AFB1) production, in vitro, in maize grain. In this study, the maintenance of carotenoid content in three maize varieties after photosensitization was also evaluated. Photosensitization of maize resulted in a complete viability reduction in *A. flavus* and, therefore, the inhibition of AFB1 production, but did not affect the carotenoid content. On the other hand, no significant effect was observed using either light or curcumin. The obtained results indicate that photosensitization may be a successful green preservation method for AFB1 decontamination of the maize, without any negative effect on carotenoid content [3].

The studies performed by Petropoulos et al. (2021) [4] concerned linseed, purslane, luffa, and pumpkin seed oils' antimicrobial and cytotoxic activities, along with the fatty acid compositions. The obtained results showed the highest antibacterial activity of linseed oil and pumpkin seed oil towards most of the tested bacteria, with the most promising results towards *Enterobacter cloacae* and *Escherichia coli*; the MIC and MBC values of these seed oils were similar to the positive controls used. All the tested seed oils were determined with antifungal properties, obtaining results more effective than the positive controls in the case of *Aspergillus versicolor*, *Aspergillus niger* and *Penicillium verrucosum* var. *cyclopium*. Regarding the cytotoxic properties, luffa seed oil was the most effective against the tested HeLa cancer cell lines (cervical carcinoma) and NCI-H460 (non-small cell lung cancer). Petropoulos et al. 2021 [4] proved that selected vegetable seed oils pose promising antimicrobial and cytotoxic properties, which might be related to the fatty acid composition of the tested oils.

Plants, due to the large biological and structural diversity of their components, constitute unique and renewable sources for the discovery of new antibacterial, and antifungal substances. Recent insights regarding the possibilities of fruit and vegetable waste-derived antimicrobial substances, which contain a wide variety of secondary metabolites, are proving their usefulness as alternative strategies for food, cosmetic and agriculture applications.

The extraction techniques of the plant-derived bioactive compounds have a significant impact on the quality of the extracts and their chemical composition. Therefore, new sustainable extraction methods have emerged in recent years that provide faster and more efficient transfer of solutes from the sample to the solvent. Using different optimized extraction approaches may enable plant extracts with more defined, stronger antimicrobial activity to be obtained, compared to the ones obtained conventionally. Supercritical fluid extraction (SFE) is one of the alternative methods to conventional systems that in the last decade has gained acceptance in the extraction of valuable substances. In order to obtain the best qualitative and quantitative values of bioactive compounds in the extracts,

the choosing of the extraction techniques must be followed by the right choice of the solvents and extraction conditions applied. Gwiazdowska et al. 2022 [5] investigated *Glechoma hederacea* var. *longituba* plant extracts obtained by SFE with carbon dioxide (SC-CO2), using methanol as a co-solvent. According to the obtained results, SC-CO2 extracts of *Glechoma* are a promising source of bioactive constituents that can be beneficial in a sustainable manner, acting as natural antioxidants and antibacterial agents. Nevertheless, the biological activity of *G. hederacea* extracts obtained under different conditions of the process was affected by the increasing temperature of the process. The results indicate that the obtained *Glechoma* extracts are characterized by high total phenolic content (TPC) values, which differ depending on the extraction conditions. The high TPC values correlate with high antioxidant properties, as well as antimicrobial (excluding filamentous fungi) and antibiofilm activity (the prevention of biofilm formation) [5].

The research of Giordano et al. 2022 [6] included optimization of the ultrasound-assisted extraction (UAE) of phenolic compounds from kiwi peel, contributing to this fruit waste valorization. This low-cost raw material was determined by its promising bioactive properties, among which antioxidant and antimicrobial effects, and no toxicity to Vero cells were observed. Optimization of the UAE coupled with the response surface methodology (RSM) included different process parameters, including time, ultrasonic power and ethanol concentration. The extraction efficiency was determined gravimetrically and the contents of phenolic compounds identified by HPLC-DAD-ESI/MSn were also used in the optimization. In turn, the polynomial models were fitted to the experimental data and used to determine the optimal conditions. The sonication of the sample under appropriate conditions allowed for the experimental validation of the predictive model. The studies are consistent with the current trends concerning the development of natural ingredients (such as food preservatives) from waste and also the resource-use efficiency and circular bioeconomy [6].

Despite the fact that the Special Issue has been closed, the research concerning the discovery of new sufficient antimicrobial substances, characterized by broad biological properties, is the matter of constant ongoing research. As the newly developed approaches of extraction are investigated, new opportunities for obtaining plant-derived antimicrobials are observed. Furthermore, the application for food products and agriculture of such substances enables the exclusion of their chemical equivalents. Sustainable recovery seems to be an important trend in view of the need to care for the environment. Novel approaches of obtaining antimicrobial substances should be more environmentally friendly and pollution-free; therefore, there is a great need to develop and optimize such methods.

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