EXTRACTION AND VALORIZATION OF ACTIVE PRINCIPLES FROM MEDICINAL PLANTS – A PERSPECTIVE FOR THE SUSTAINABLE DEVELOPMENT OF FARMS IN ROMANIA
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EXTRACȚIA ȘI VALORIFICAREA PRINCIPIILOR ACTIVE DIN PLANTE MEDICINALE – O PERSPECTIVĂ PENTRU DEZVOLTAREA SUSTENABILĂ A FERMELOR DIN ROMÂNIA

Ana-Maria TĂBĂRAȘU [1,2], Nicolae-Valentin VLĂDUȚ [1], Iuliana GĂGEANU [1], Florin NENCIU[1], Melania-Elena CISMARU [2]*, Teofil-Alin ONCESCU [1], Gabriel-Valentin GHEORGHE [1], Alin HARABAGIU [1], Dragoș-Nicolae ANGHELACHE [1]*, Dan CUJBESCU [1], Iulian VOICEA [1]

[1] INMA Bucharest / Romania; [2] National University of Science and Technology POLITEHNICA Bucharest / Romania
Tel: +40730221773; E-mail: celenamelania2@gmail.com
Tel: +40728034500, E-mail: dragos1989anghelache@gmail.com
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ABSTRACT
Medicinal plants represent an important resource for diversifying agricultural production and creating new economic opportunities in rural areas. The extraction of active principles from these plants is becoming increasingly significant, as the demand for natural, ecological, and high-quality products continues to rise on both domestic and international markets. In this context, the present paper is a review study that analyses the role and potential of extraction technologies for bioactive compounds from medicinal plants, highlighting their applicability on farms and their contribution to the development of sustainable agriculture. Beyond their economic importance, modern extraction technologies can contribute to sustainable development through several mechanisms: economically, by enabling the production of value-added products and reducing dependence on conventional crops; ecologically, by employing efficient and environmentally friendly procedures that minimize resource consumption and waste; and socially, by generating new employment opportunities and supporting farmers' access to local markets.

REZUMAT
Plantele medicinale reprezintă o resursă importantă pentru diversificarea producției agricole și pentru crearea de noi oportunități economice în mediul rural. Extracția principiilor active din aceste plante devine tot mai importantă, pe măsură ce cererea pentru produse naturale, ecologice și de calitate este în creștere atât pe piața internă, cât și pe cea internațională. În acest context, această lucrare este un studiu de sinteză care analizează rolul și potențialul tehnologiilor de extracție a principiilor active din plante medicinale, evidențiind aplicabilitatea lor în ferme și contribuția la dezvoltarea unei agriculturi sustenabile. Pe lângă importanța economică, tehnologiile moderne de extracție pot contribui la dezvoltarea sustenabilă prin mai multe mecanisme: pe plan economic, prin obținerea de produse cu valoare adăugată și reducerea dependenței de culturile agricole clasice; pe plan ecologic, prin utilizarea unor procedee eficiente și prietenoase cu mediul, care reduc consumul de resurse și risipa; iar pe plan social, prin crearea de noi locuri de muncă și prin facilitarea accesului fermierilor la piețele locale.

INTRODUCTION
Although the use of medicinal plant extracts has been extensively investigated, large-scale solutions derived from these natural products have not yet been widely developed. This article aims to provide a critical synthesis of the specialized literature regarding methods of extracting bioactive compounds, their applicability in agriculture and related industries, as well as the ways in which they may contribute to farm sustainability. The objective is to highlight the practical benefits and economic potential of plant extracts, while also identifying future research directions.

Extracts from medicinal and aromatic plants may be obtained as liquids or powders derived from different plant parts, preserving their active compounds. They can support crop growth while simultaneously protecting plants against diseases and pests. Their use may enable farmers to reduce chemical inputs and obtain healthier and safer products for consumption *(Kisiriko et al., 2021; Tăbărașu et al., 2023*).

The most common methods for obtaining plant extracts include classical approaches such as maceration, percolation, infusion, or Soxhlet extraction, as well as modern techniques based on ultrasound, microwaves, supercritical fluids, or pressurized liquids.

Classical Extraction Methods

- *Maceration* is a technique in which plant material is left for an extended period in a liquid, such as water or alcohol, until the active compounds gradually diffuse into the solvent. The efficiency of the process depends on several factors, including the degree of plant comminution, the ratio between plant material and solvent volume, as well as the duration of maceration. Among the *advantages* of this technique are its simplicity, low cost, and the fact that it does not require specialized equipment, which explains its use for centuries both in research and in traditional preparations. Moreover, it is particularly suitable for extracting heat-sensitive compounds such as polyphenols and flavonoids. On the other hand, the main *disadvantages* are the long processing time and the large solvent consumption, while the overall yield remains generally lower compared to modern methods *(Chongo, 2025).*
- *Percolation* is a widely used extraction method for tinctures and fluid extracts of medicinal plants, in which the solvent slowly passes through a layer of finely comminuted plant material placed in a percolator. The process can be carried out either with or without the application of pressure (*Tăbărașu et al., 2024*). This method has the *advantage* of being faster than maceration, providing good yields, and allowing the recovery of heat-sensitive compounds. However, its *disadvantages* include the requirement for larger volumes of solvent, the need for precise control of particle size, and the operator's expertise, which makes it not always the most practical solution on a large scale *(Patil et al., 2023).*
- *Decoction* involves boiling plant material in water to extract highly soluble compounds. The *advantage* of this method lies in its simplicity and accessibility, being particularly effective for obtaining polyphenols and flavonoids, while the resulting extracts have demonstrated significant antioxidant and antimicrobial activity. The main *disadvantage* of decoction is that it cannot be applied to plants rich in starch, mucilage, or volatile substances, as these degrade at high temperatures, thereby limiting the applicability of the method *(Zhang et al., 2023).*
- *Soxhlet Extraction* involves the continuous circulation of solvent through the plant material, enabling efficient extraction with high yields. Among its *advantages* are the reduced solvent consumption, shorter processing time compared to other traditional methods, and improved recovery of valuable compounds, particularly phenolics and flavonoids. The main *disadvantage* lies in the prolonged heating of the sample, which may lead to the degradation of heat-sensitive substances, coupled with a relatively high energy consumption *(Mokaizh et al., 2024).*

Modern Extraction Methods

- *Ultrasound-Assisted Extraction (UAE)* employs ultrasonic waves to induce cavitation phenomena in the solvent, thereby releasing bioactive compounds from plant tissues. Compared to conventional techniques, UAE is faster, requires less solvent, and provides higher yields, particularly for polyphenols and related compounds. Its main *advantages* include reduced extraction time, high efficiency, and preservation of heat-sensitive compounds. The *disadvantage*, however, is that it sometimes requires alcoholic solvents, which may limit the direct application of the extracts in agriculture or the food industry *(Tăbărașu et al., 2024).*
- *Microwave-Assisted Extraction (MAE)* employs electromagnetic waves to rapidly heat the solvent and plant cells, causing the rupture of cell walls and the release of bioactive compounds. Compared to traditional techniques, MAE offers the *advantages* of significantly shorter extraction times, reduced solvent consumption, and high yields even for heat-sensitive compounds. The *disadvantages* include the higher cost of equipment, lower efficiency for non-polar compounds, and the risk of compound degradation if the process parameters are not carefully controlled *(Tanruean et al., 2025).*
- *Supercritical Fluid Extraction (SFE)* employs fluids at temperatures and pressures above their critical point, most commonly carbon dioxide. In this state, CO_2 exhibits properties intermediate between those of a liquid and a gas, enabling it to penetrate deeply into plant material and dissolve bioactive compounds. After extraction, by reducing the pressure, the solvent completely evaporates, leaving a clean extract free of chemical residues.

The *advantages* of this method include the production of pure and safe extracts, the use of an environmentally friendly and inexpensive solvent, and the possibility of operating at moderate temperatures, which helps preserve heat-sensitive compounds. Moreover, process parameters can be adjusted to selectively target certain compounds such as essential oils, pigments, or antioxidants. The *disadvantages* are mainly related to the high cost of equipment, the energy consumption required for high pressures, and the reduced efficiency for highly polar compounds, which require the use of co-solvents *(Perez-Vazquez et al., 2023; Fraguela-Meissimilly et al., 2023).*

- *Pressurized Liquid Extraction (PLE)* uses solvents maintained at elevated temperatures and pressures, but below their critical point, to enhance the solubility and diffusion of bioactive compounds. The method offers several *advantages*, including reduced extraction time, low solvent consumption, high yields, and the possibility of automation, making it a more environmentally friendly technique. The *disadvantages* are mainly associated with the high cost of equipment, the more labour-intensive sample preparation, and the risk of degradation of certain heat-sensitive compounds *(Barp et al., 2023; Chatzimitakos et al., 2024).*

The Use of Plant Extracts to Reduce the Consumption of Pesticides and Chemical Fertilizers

A major challenge in modern agriculture is reducing dependence on chemical pesticides, which, although they have contributed to increased productivity, have also generated serious problems: the emergence of pest resistance, contamination of soil, water, and air, harmful effects on human and animal health, as well as the destruction of beneficial organisms. In this context, plant-derived pesticides are proposed as a viable and sustainable alternative. These substances are considered biodegradable and environmentally friendly, reducing the risk of accumulation in ecosystems and the negative effects on natural resources. Unlike many synthetic pesticides, they exhibit lower persistence, thereby decreasing the likelihood of bioaccumulation and long-term environmental impact (*Kumar, 2012; Ayilara et al., 2023; Daraban et al., 2021; Fusar Poli et al., 2025; Godlewska et al., 2021*).

Medicinal and aromatic plants yield a wide diversity of bioactive compounds (Table 1), which act through multiple mechanisms against pests. This confers high efficacy and makes the development of pest resistance to plant extracts less likely. Some of these substances affect the insect nervous system, while others disrupt cellular respiration or water balance, providing a broad spectrum of action and greater flexibility for their integration into plant protection programs (*Souto et al., 2021; Bharadwaz et al., 2024; Tembo et al., 2018; Boruah et al., 2025*).

Table 1

Classification of the Main Classes of Bioactive Compounds from Medicinal and Aromatic Plants

Class of Compounds	Group of Compounds	References
Polyphenols	*Flavonoids* *Phenolic Acids* *Stilbenes* *Lignans*	(*Ciupei et al., 2024*)
Alkaloids	*Tetrahydroisoquinoline alkaloids* *Indole alkaloids* *Pyrrolizidine alkaloids* *Tropane alkaloids* *Piperidine alkaloids* *Quinolizidine alkaloids* *Indolizidine alkaloids* *Pyridine alkaloids* *Pyridinone alkaloids* *Quinoline alkaloids* *Quinazoline alkaloids* *Xanthine alkaloid* *Steroid alkaloids* *Terpenoidalkaloids* *Chromone alkaloids* *Flavoalkaloids*	(*Bhambhani et al., 2021*)
Terpenoids	*Hemiterpenes* *Monoterpenes* *Sesquiterpenes*	(*Mabou and Nzeuwa Yossa, 2021*)

Class of Compounds	Group of Compounds	References
	Diterpenes *Sesterpenes* *Triterpenes* *Tetraterpenes* *Polyterpenes*	
Saponins	*Glycone: Sugar (Glucose, Arabinose, Xylose, Glucuronic acid)* *Aglycone: Sapogenin (Steroids, Triterpenoids)*	(*Desai et al., 2009*)
Glucosinolates	*Aliphatic* *Aromatic* *Indolic*	(*Kitainda and Jez, 2021*)

Biopesticides generally exhibit low toxicity to mammals and other non-target organisms, making them safer for consumers, agricultural workers, and biodiversity (*Suteu et al., 2020*). For example, natural pyrethrins, azadirachtin from neem, or essential oils of clove, mint, and eucalyptus are effective against certain pests but pose a much lower risk to human health compared to synthetic insecticides. Moreover, these products are often more economically accessible for small-scale farmers, as they can be obtained from local plant resources and adapted to the specific conditions of each region. In addition, they can be integrated with other ecological control methods, becoming an essential component of integrated pest management (*Souto et al., 2021; Cui et al., 2019; Du et al., 2013; Fenibo et al., 2022; Kovács-Hostyánszki et al., 2017; Najberek et al., 2024; Benbrook et al., 2021*).

Reducing dependence on chemical inputs in agriculture can be achieved through the large-scale use of plant-derived substances acting as biostimulants or crop protection agents. Recent studies indicate that plant-based biostimulants can lower the required doses of nitrogen fertilizers without compromising crop productivity. For example, in tomato cultivation, the application of plant and algal extracts as biostimulants, combined with reduced nitrogen fertilization, maintained both yield and plant quality while decreasing chemical fertilizer use by up to 30% (*Farneselli et al., 2025*).

In another study, tomatoes cultivated with and without plant extracts showed clear differences: treated plants exhibited greater biomass (+17% total, +21% roots) and higher nitrogen content in leaves (+6.2%), confirming that plant extracts enhance nitrogen use efficiency even under reduced chemical fertilization (*Sestili et al., 2018*).

Similar effects were observed in leafy vegetables, where plant-derived extracts increased yields in lettuce (+26%) and spinach (+29%), even under reduced nitrogen fertilization. For basil, yield increased by 16%, while for arugula leaf production, it was 15–29% higher. Moreover, these treatments reduced nitrate accumulation and enhanced the content of antioxidants and vitamin C, demonstrating not only an economic and environmental advantage, but also an improvement in product quality (*Ciriello et al., 2024*).

Regarding the reduction of dependence on chemical herbicides, research has highlighted the value of certain plant-derived substances with bioherbicidal effects, such as pelargonic acid (a natural fatty acid found in vegetable oils) which has been shown to be effective against several weed species by inducing necrosis of leaf tissues. Although its efficacy varies depending on the species and the cultivation environment (open field or protected conditions), pelargonic acid represents a valuable ecological alternative when integrated into comprehensive weed management strategies (*Loddo et al., 2023*).

Another example is the use of substances released by certain plants into the soil or their surrounding environment, which can inhibit the germination or growth of seeds from other plants. Species such as sorghum, walnut, eucalyptus, or sunflower produce bioactive compounds that can be applied as aqueous extracts, mulches, or commercial bioherbicides, thereby reducing weed infestations and dependence on synthetic herbicides (*Khamare et al., 2022*). In the same direction, the application of aqueous extracts from sorghum and sunflower, combined with herbicides at doses reduced by 70%, resulted in more than 90% weed suppression in wheat crops and a 34% yield increase, proving even more effective than the full herbicide dose (*Razzaq et al., 2012*).

In addition to their effects on nutrition and weed control, plants provide substances with insecticidal and antifungal properties. Phytopesticides, obtained from extracts and essential oils, have proven effective against insects, fungi, bacteria, and even certain viruses. Examples such as neem, eucalyptus, wormwood, garlic, chili pepper, tobacco, and chrysanthemum have demonstrated insecticidal, antifungal, bactericidal, and antiviral effects and are already successfully used in crop protection (*Ayilara et al., 2023; Ngegba et al., 2022*). One prominent example is azadirachtin, extracted from neem seeds, which acts by inhibiting insect feeding and development, thereby reducing their reproductive capacity. This compound is effective against a wide range of pests and exhibits low toxicity to humans and beneficial organisms, being commercialized in numerous products used in both conventional and organic agriculture (*Kilani-Morakchi et al., 2021*). In a field study on cauliflower, *NeemAzal* and neem extract demonstrated efficacy comparable to synthetic insecticides, maintaining over 90% of yield at good quality and reducing oviposition by *Spodoptera litura*, an effect absent in synthetic pesticides (*Shah et al., 2019*).

The study by (*Kessy et al., 2024*) reports recent experiments conducted on *Vigna radiata* cultivation. Extracts from four plants with insecticidal potential: *Tephrosia vogelii*, *Clutia abbsynica*, *Clausena anisata*, and *Lobelia gibelloa*, were applied during the trials. Field results revealed clear differences among treatments. *Clausena anisata* proved to be the most effective in reducing infestations of aphids, whiteflies, and pod weevils, achieving the highest insect population suppression rates. In contrast, *Lobelia gibelloa* was the least effective, showing low levels of pest control. In addition to phytosanitary protection during the growing season, the study also evaluated seed quality during storage. Here as well, significant differences were observed: seeds treated with *Tephrosia vogelii* and *Clutia abbsynica* exhibited the fewest insect-bored holes and minimal seed mass loss, demonstrating high efficacy in preserving post-harvest quality. Conversely, treatments with *Clausena anisata* and *Lobelia gibelloa*, particularly at higher doses, resulted in greater seed mass losses, suggesting a less favourable effect on storage.

The examples presented above are complemented by other findings from the scientific literature, summarized in Table 2, which indicates the plants used, extraction methods, and observed effects.

Table 2

Properties and Biological Effects of Plant Extracts According to Extraction Technology

Plant Extract	Extraction Technology	Target Organism	Effect	References
Melia azedarach L., *Peganum harmala* L., *Calendula officinalis* L., *Otostegia persica Boissier*, *Lantana hirta*, *Argemone ochroleuca*, *Adenophyllum porophyllum*	Maceration	*Brevicoryne brassicae* L., Pestalotiopsis clavispora, *Colletotrichum gloeosporioides*	Reduced aphid population growth; Antifeedant activity; Fungal growth inhibition.	(*Shafie et al., 2018; Hernández-Ceja et al., 2021*)
Nicotiana tabacum L.	Ultrasound-Assisted Extraction (UAE), Maceration, Infusion, Decoction.	*Mahanarva spectabilis*	Insecticide	(*Nascimento et al., 2022*)
Origanum vulgare, *Thymus citriodorus* *Lippia graveolens* Kunth, *Primula veris*, *Achillea millefolium*, *Artemisia absinthium*	Ultrasound-Assisted Extraction (UAE)	*Meloidogyne incognita*, *M. javanica*, *Colletotrichum asianum*, *Acanthoscelides obtectus*	Nematicidal / nematostatic activity; Antifungal activity; Insecticidal activity.	(*Ntalli et al., 2020; Manjarrez-Quintero et al., 2024; Daraban et al., 2021*)
Citrus bergamia, *Schinus molle*, *Plectranthus amboinicus*, *Syzygium aromaticum*, *Lippia alba*, *Rosmarinus officinalis*	Microwave	*Aspergillus niger*, *Penicillium expansum*, *Bactericera cockerelli*, *Fusarium oxysporum*	Antifungal activity; Antibacterial activity; Growth inhibition.	(*Landero-Valenzuela et al., 2022; Antonio-Gutiérrez et al., 2023*)

Plant Extract	Extraction Technology	Target Organism	Effect	References
Chamomilla recutita, Helichrysum arenarium, Humulus lupulus, Origanum vulgare L.	Supercritical CO_2 Extraction	*Botrytis cinerea, Epicoccum nigrum, Fusarium spp., Fusarium culmorum, Aspergillus niger, Fusarium graminearum, F. culmorum, F. avenaceum, F. poae, F. equiseti.*	Antifungal activity; Antibacterial activity; Antibiofilm activity.	(*Schoss et al., 2022; Tyśkiewicz et al., 2024; Gwiazdowska et al., 2024*)
Illicium pachyphyllum, Pinus halepensis, Mentha pulegium L., *Lavandula angustifolia, Rosmarinus officinalis, Syzygium aromaticum, Melaleuca alternifolia*	Hydrodistillation	*Sitophilus zeamais, Tribolium castaneum, Rhyzopertha dominica, Botrytis cinerea, Monilinia fructicola, Neosartorya spp.*	Insecticidal activity; Repellent activity; Antifungal activity; Fungal growth inhibition.	(*Liu et al., 2012 Naimi et al., 2025; Montenegro et al., 2020; Maj et al., 2024*)
Mammea americana L., *Helicteres isora* L.	Soxhlet	*Larve de Artemia salina, Ferrisia sp., Escherichia coli, Aspergillus niger*	Insecticidal activity; Antibacterial and antifungal activity.	(*Vázquez-Torres et al., 2025; Mahire and Patel, 2020*)
Allium sativum, Armoracia rusticana, Artemisia absinthium, Calendula officinalis, Matricaria chamomilla, Ocimum basilicum, Origanum vulgare, Salvia officinalis, Satureja hortensis, Thymus vulgaris, Calendula officinalis, Lavandula angustifolia	Conventional solvent extraction	*Fusarium spp., Neosartorya spp.*	Antifungal activity (fungal growth inhibition)	(*Kursa et al, 2022; Maj et al., 2024*)
Ocimum basilicum, Peganum harmala, Caralluma europaea, Nerium oleander, Eucalyptus globulus	Aqueous plant infusion	*Botrytis cinerea, Oidium oxysporum, Alternaria solani, Phytophthora infestans*	Fungal Inhibition	(*Abbad et al., 2023*)
Anacyclus pyrethrum, Artemisia vulgaris, Chrysanthemum coccineum, Fallopia japonica, Sonchus arvensis, Tanacetum vulgare, Taraxacum kok-saghyz, T. officinale	Accelerated Solvent Extraction (ASE)	*Botrytis cinerea, Fusarium oxysporum f. sp. radicis-lycopersici, Rhizoctonia solani, Sclerotinia minor*	Antifungal activity	(*Wens and Guens, 2022*)
Lavandula × intermedia 'Budrovka', Cissampelos pareira L., *Cissampelos pareira*	Percolation	*Fusarium spp., Aspergillus spp., Penicillium spp., Aphis craccivora*	Antifungal activity; Insecticidal activity.	(*Blazekovic et al., 2011; Kumari et al., 2022*)

The studies presented confirm that extracts from medicinal and aromatic plants can partially replace chemical inputs, exhibiting biostimulant, bioherbicidal, insecticidal, and antifungal effects. This multifunctional capacity, combined with a low toxicity profile and the accessibility of plant resources, confers upon them an essential role in the development of sustainable agricultural practices and in reducing the negative impact of chemicals on the environment and human health.

The Impact of Reducing Chemical Inputs on Biodiversity and Pollinators

Reducing the use of chemical substances in agriculture has become a priority not only for soil and plant health but also for maintaining natural balance.

Synthetic pesticides and fertilizers affect not only pests but also beneficial organisms, contributing to the decline in biodiversity and the alarming reduction of pollinator populations. The protection of bees and other pollinating insects, which are vital for the reproduction of many agricultural crops, largely depends on the adoption of sustainable practices and the limitation of excessive chemical use.

A study on essential oils such as citronella, thyme, mint, oregano, and cinnamon demonstrated their effectiveness against several agricultural insects and mites, positioning them as more environmentally friendly alternatives to conventional pesticides due to their biodegradability and low residue levels. However, research indicates that depending on the type of oil, concentration, and mode of application, these substances may also affect beneficial insects, including pollinators. At low doses, some oils appear safe for bees, while others can cause mortality or behavioural changes (*Gostin and Popescu, 2024; Catania et al., 2023; Chavana and Joschi, 2024*). Overall, the impact of botanical biopesticides on pollinators is considered lower than that of synthetic chemical pesticides, though it remains dependent on the concentration applied.

Nicodemo and Nogueira, (2004), evaluated the efficacy of natural and synthetic substances with repellent effects on honeybees (*Apis mellifera*) in two contexts: yellow passion fruit (*Passiflora edulis*) cultivation and cattle feeding areas, where bees consumed resources intended for livestock. Laboratory tests showed that extracts of tobacco, rue, garlic, parsley, and agave exerted repellent effects for approximately 25 minutes. In field conditions, garlic extract and the compound 2-heptanone kept bees away for about 2.5 hours, a sufficient period for the manual collection of pollen required for pollination. In cattle feeding areas, garlic and citronella reduced bee presence for up to 6 hours, with garlic proving more effective. Thus, it was concluded that plant extracts and synthetic pheromone-like compounds represent a viable alternative to toxic chemicals, providing a practical solution for managing bee presence in situations where they cause economic losses.

Sabahi et al., (2018), sought natural solutions for controlling one of the most dangerous pests of honeybees, the mite Varroa destructor. This parasite weakens bees and is considered a major cause of colony losses worldwide. Currently, beekeepers often use synthetic chemicals, but these can be toxic to bees and leave residues in honey and the environment. The study tested three plant-derived products: anethole (extracted from anise), lemongrass oil, and sweet marigold oil. The aim was to determine how effective these substances are against the parasite and how safe they are for bees. The results showed that anethole and lemongrass oil were effective in reducing Varroa populations while displaying low toxicity to adult bees. By contrast, sweet marigold oil proved less effective against the parasite and even harmful to bee larvae.

According to *Parekh et al., (2021*), exposure of bees to a very low dose of thyme oil (0.16 ppb) activates their immune system and significantly reduces the rate of infections with certain viruses.

Studies have shown that peppermint oil, when administered at high doses, either 12 mL per beehive (*Helaly et al., 2022*) or at a concentration of 2% (*Ardeshir et al., 2002*), exerts toxic effects and causes increased colony mortality. By contrast, when provided in smaller amounts, through sugar syrup supplemented with only 0.1 mL/L of peppermint oil, an improvement in honey production per hive was observed (*Pătruică et al., 2023*).

Several studies have shown that sweet orange oil, applied at doses ranging from 1 to 40 µL per beehive (*Fuselli et al., 2009*) or at concentrations of 0.5–2 mg/mL (*Souza et al., 2023; Bava et al., 2021*), did not cause mortality in *Apis mellifera* bees subjected to testing. By contrast, dangerous parasites such as *Varroa destructor* were significantly affected by these oils.

The results of the studies presented highlight the real potential of essential oils and plant extracts to protect pollinators by reducing exposure to synthetic pesticides and controlling parasites such as *Varroa destructor*. However, the considerable variability depending on species, concentration, and method of application indicates that these solutions must be carefully adapted to avoid adverse effects on bee colonies.

Improving the Quality of Soils Degraded by Long-Term Use of Chemical Inputs

Another major benefit of using extracts from aromatic and medicinal plants, beyond their biopesticidal effects, is their ability to improve the quality of soils degraded by the long-term use of chemical substances in agriculture (*Vanghele et al., 2025*).

According to *Greff et al., 2023*), extracts from aromatic and medicinal plants represent a natural alternative to synthetic chemicals, playing an important role in the regeneration of degraded soils. When applied as solutions or incorporated through plant residues, these extracts increase organic matter, restore the physicochemical structure of the soil, and improve water retention and fertility.

Their bioactive compounds (essential oils, phenols, flavonoids) stimulate beneficial microorganisms and limit the development of pathogens, helping the soil regain its biological balance. In this way, plant extracts not only protect crops but also actively contribute to restoring the health and quality of soils affected by excessive pesticide use (Figure 1).

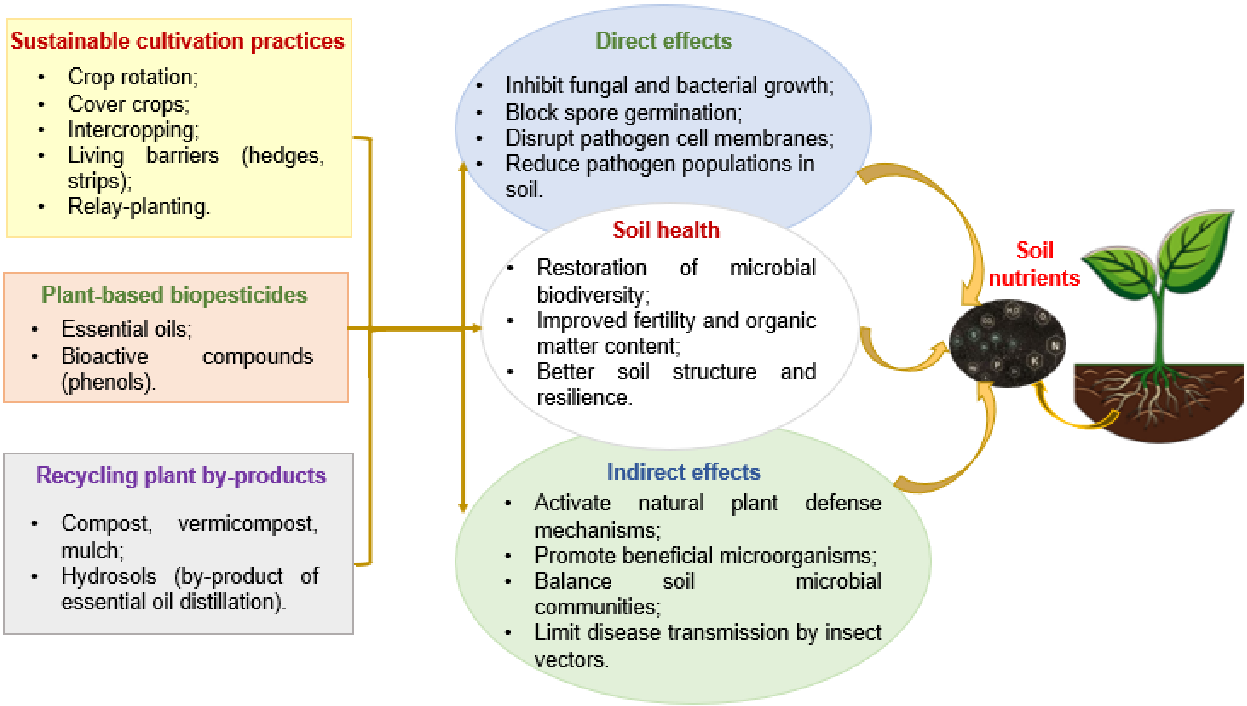

Fig. 1 - Contribution of Aromatic and Medicinal Plants to Soil Restoration and Pathogen Control
(adapted from *Greff et al., 2023*)

According to *Sempere-Ferre et al., (2021*), natural compounds from aromatic plants such as eugenol (clove), carvacrol and thymol (oregano, thyme), and cinnamaldehyde (cinnamon) have demonstrated high efficacy against soilborne pathogens (*Rhizoctonia solani, Botrytis*). The use of these plant-derived substances as alternatives to synthetic fungicides can reduce soil contamination and the negative effects on beneficial microorganisms, thereby indirectly contributing to the restoration of soil quality degraded by the long-term use of chemicals in agriculture.

Amira Jouini et al., (2020), evaluated the effects of essential oils extracted from *Thymbra capitata*, *Mentha* × *piperita*, and *Santolina chamaecyparissus* on weeds and soil microorganisms. The oils were applied at different concentrations directly into the soil, and their impact was monitored by measuring microbial respiration, biomass, and the structure of fungal and bacterial communities. The tests showed that treatments initially caused a decrease in microbial activity and biomass, but after 14 days the microbial communities returned to their initial levels, demonstrating a high capacity for resilience. Only in the case of high doses of *T. capitata* was recovery incomplete.

Vokou et al., (1984), tested the influence of volatile oils from *Thymus capitatus*, *Satureja thymbra*, and *Rosmarinus officinalis* on soil microflora. The oils of *T. capitatus* and *S. thymbra* strongly stimulated soil respiration and greatly increased bacterial populations, as these organisms used the oils as a source of carbon and energy. At the same time, the oil of *S. thymbra* had a pronounced fungistatic effect, inhibiting spore germination of *Penicillium citrinum* and mycelial growth of *Mucor hiemalis*. In the long term, repeated additions led to an increase in soil organic carbon.

In monoculture systems, aromatic plants such as *Mentha arvensis* and *Artemisia annua*, along with their bioactive metabolites, including menthol, limonene, menthyl acetate, and artemisinin, can alter the balance of the soil microbiome through their antimicrobial effects. These compounds act indirectly on phytopathogens by reducing fungal diversity and shifting the structure of the microbial community, thereby influencing soil ecological processes. At the same time, the application of organic amendments and the introduction of associated crops such as *Sesbania* and *Chlorophytum* can restore microbial diversity, support soil resilience, and improve the productivity of aromatic crops (*Misra et al., 2019*).

For medicinal and aromatic plants: basil, mint, dill, and marigold cultivated under both conventional and organic systems, tests were conducted to evaluate their effects on rhizosphere microbial communities. It was found that the organic system generally favoured a greater abundance of microorganisms, with differences being more pronounced during the second harvest period. Among the plants, distinct effects were observed: mint stimulated the growth of total microorganisms, as well as Azotobacter, free nitrogen fixers, and cellulolytic microorganisms, but reduced ammonifying bacteria; marigold promoted the multiplication of total microorganisms, ammonifiers, Azotobacter, and fungi; basil increased the number of ammonifiers but reduced total microorganisms and fungi; while dill stimulated ammonifiers but reduced nitrogen fixers and fungi (*Adamović et al., 2015*).

Bi et al., (2011), demonstrated that the soil population of *Phytophthora capsici* can be reduced through the application of fatty acids extracted from oregano, red thyme, and palmarosa, at concentrations above 0.1 µg/mL, with a significant decrease observed after 21 days.

The examples analysed highlight that extracts and essential oils from medicinal and aromatic plants can contribute to the regeneration of soils affected by long-term chemical use through multiple mechanisms: enrichment of organic matter, improvement of soil structure and water retention, stimulation of beneficial microorganisms, and inhibition of soilborne pathogens. At the same time, studies show that the effects vary depending on the plant species, the bioactive compounds present, and the applied dose, which may differentially influence fungal and bacterial communities.

Plant Extracts as an Innovative Approach to Enhancing the Sustainability of Smallholder Agriculture

The positive impact on soil and biodiversity intertwines with economic opportunities, making medicinal and aromatic plants a strategic resource for small-scale farms. Through cultivation and processing, farmers can obtain active compounds that support crop management in an ecological manner by reducing dependence on chemicals, while at the same time generating products with pharmaceutical, cosmetic, or food applications for expanding markets. Thus, medicinal plants contribute both to environmental protection and to the sustainable development of farms by diversifying production, creating additional income, and strengthening rural economies (Figure 2) (*Smith-Hall et al., 2012; Hishe et al., 2016*). At the same time, the cultivation of medicinal and aromatic plants by farmers (MAPs farmers) reduces pressure on unsustainable harvesting from wild flora, supporting biodiversity conservation and ensuring a steady, high-quality supply of raw materials for industry (*Mofokeng et al., 2022*).

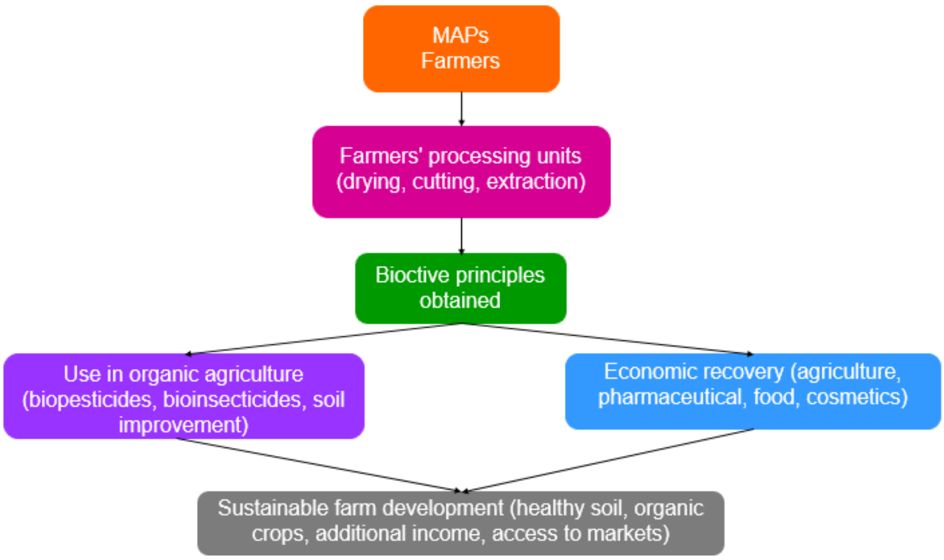

Fig. 2 - The Value Chain of Medicinal Plants for the Sustainable Development of Farms

Panda and Giri, (2023), conducted a study on 700 farmers, which revealed that the majority do not yet practice the cultivation of medicinal plants, despite their high agricultural and economic potential. The main challenges identified include lack of profitability, limited access to financing, climatic conditions, absence of reliable buyers, insufficient government support, and lack of training. Nevertheless, the results indicate that with adequate institutional support, a significant proportion of farmers would be willing to engage in this sector, and that the establishment of contract farming agreements would ensure farmers a stable income and secure market access for their production (Figure 3).

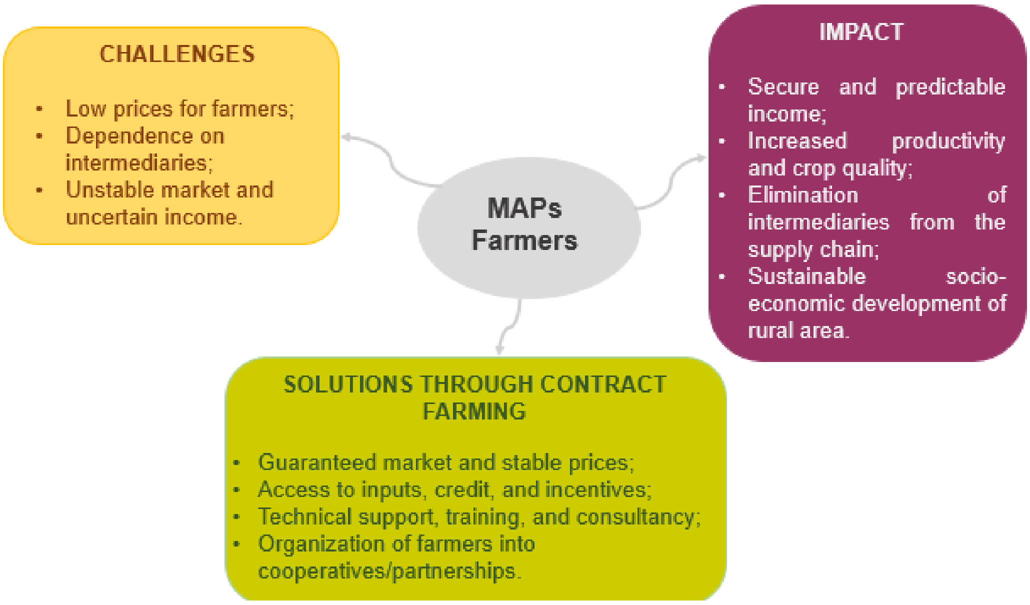

Fig. 3 - Challenges, Solutions, and Impact of Contract Farming on MAPs Farmers

The study made by *Keshet Alipour et al., (2021*), examines the role of medicinal plants in diversifying the rural economy and increasing household income. The results confirm that these crops generate significantly higher net revenues than conventional agricultural crops, with an advantage exceeding 500%. In addition, medicinal plants were found to require fewer resources than conventional crops, can be cultivated on small areas, contribute to job creation, and also support the sustainable development of communities by reducing migration and promoting economic diversification.

Agricultural diversification is regarded as a strategy for stabilizing income, compensating for losses in one crop with gains from others (*Heady, 1968; Haque, 1996*). However, under unpredictable climatic conditions, it may involve additional risks (*Joshi et al., 2004; Mandal, 2010*). Relevant examples come from studies on high-yield turmeric, where *Choudhary and Rahi, (2018*), reported a threefold increase in production and more than 200% higher profitability compared to local varieties, highlighting the real potential of diversification. Similarly, studies such as that of *Suresh et al., (2012*), have shown that crops like vetiver, menthol mint, and tulsi generate substantial net profits and favourable benefit–cost ratios.

To date, Romania is not among the European countries with the largest cultivated areas or the highest production of medicinal and aromatic plants. According to official data from the Ministry of Agriculture and Rural Development (MADR) (*https://www.madr.ro/culturi-de-camp/plante-medicinale-si-aromatice.html*), during the period 2015–2023 the cultivated area of such plants ranged between 1,745 and 4,395 hectares, while production varied between 1,932 and 5,627 tons (Figure 4 a, b).

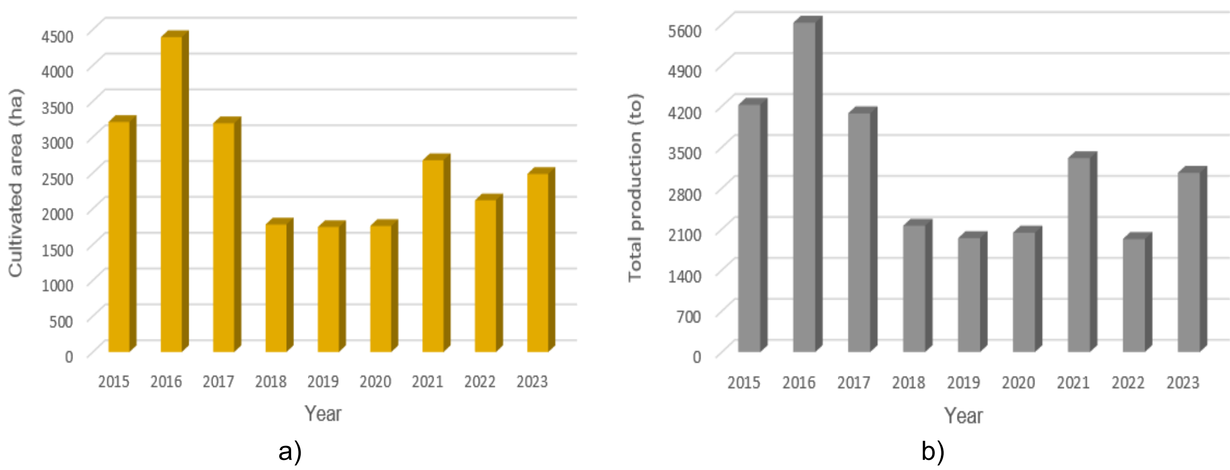

Fig. 4 - Evolution of cultivated areas and production of medicinal and aromatic plants in Romania (2015–2023)
(adopted from *https://www.madr.ro/culturi-de-camp/plante-medicinale-si-aromatice.html*)

In Figure 4 a, b, a peak in cultivated areas and production can be observed in 2016, followed by a sharp decline during 2018–2020. After 2020, a slight recovery occurred; however, the levels remain below those of the initial years, indicating the instability of the sector.

In Romania, the cultivation of medicinal and aromatic plants is not widespread, mainly due to economic and organizational factors. The market is weakly structured, farmers depend on intermediaries, and they face unstable prices, which makes these crops less attractive. Additional challenges include the lack of high-quality plant materials, the absence of specific technologies and equipment, and the high costs of processing. Another obstacle is the low level of cooperation among producers and the limited support through agricultural policies compared to staple crops.

In Romania, farmers are required by national and European legislation to include cover crops or nitrogen-fixing plants on part of their land, a measure introduced through the National Strategic Plan 2023–2027 and linked to the Common Agricultural Policy. This condition, necessary for receiving APIA subsidies, is intended to protect the soil, improve biodiversity, and reduce dependence on chemical inputs. Although it may appear as a constraint, in reality it represents an opportunity, as it provides farmers with both financial support and long-term agronomic benefits, thereby contributing to the modernization and sustainability of Romanian agriculture (*Stoicea et al., 2023*).

On the other hand, the report of *Smit et al., (2019*), shows that in the European Union, the use of cover crops and trap crops varies considerably between countries, yet they play an essential role in sustainable agriculture and in mitigating the effects of climate change. They are cultivated mainly after cereals and oilseeds, with species such as rye, mustard, clover, and oats being frequently used. Adoption rates range from only 12% in Spain to nearly 99% in the Netherlands, with intermediate values in France and Romania. Farmers report benefits such as a 6.6% reduction in fertilizer requirements and a 4.2% increase in yields, but also additional costs of approximately €144/ha. Adoption is driven primarily by policies and subsidies, while reluctance stems from costs, lack of information, or unfavourable climatic conditions.

According to the studies presented, medicinal and aromatic plants can become a strategic resource for small-scale farms and for the development of rural economies by diversifying production and providing access to niche markets with added value. At the same time, their cultivation supports biodiversity conservation, reduces pressure on unsustainable wild harvesting, contributes to soil restoration, and decreases the use of chemical inputs. However, the expansion of these crops depends on economic and organizational factors such as market stability, access to financing, the presence of reliable buyers, and institutional support. In Romania, where the sector remains unstable and weakly structured, agricultural policies and subsidy schemes, including those related to cover crops, can transform this “constraint” into a real opportunity for the modernization and sustainability of agriculture.

Improving Horticultural Production Quality with Natural Solutions

Plant extracts obtained from medicinal and aromatic species represent a valuable natural resource for sustainable agriculture, as their complex composition of bioactive compounds allows them to act simultaneously as bioherbicides, bioinsecticides, and biofungicides, thus providing an ecological alternative to synthetic pesticides (table 3). Unlike conventional chemical substances, these extracts are biodegradable, safe for human health, and environmentally friendly, with reduced impact on non-target organisms. Moreover, through their diverse mechanisms of action against weeds, insects, and fungal pathogens, they also contribute to lowering the risk of resistance development. All these qualities explain the growing interest in their application, particularly for small-scale farms, where the cultivation of medicinal plants and their processing into extracts can become a real opportunity for diversification and for the advancement of modern agricultural production (*Gupta et al., 2023*).

Table 3

Examples of natural extracts used to improve horticultural production quality

Tested plant species	Source plant (extract origin)	Extract	Effect	Benefit	References
Lettuce	*Moringa oleifera*	Aqueous leaf extract	Increased yield, more green leaves, higher chlorophyll, carotenoids, and phenolics,	Higher productivity, reduced post-harvest losses	(*Admane et al., 2023*)

Tested plant species	Source plant (extract origin)	Extract	Effect	Benefit	References
			enhanced antioxidant activity, improved resistance to Botrytis cinerea		
Soybean	*Origanum majorana, Salvia sclarea, Perilla frutescens, Mentha spicata*	Essential oils	Insecticidal effect against Thrips flavus, >90% mortality after one week	Pest control, reduced need for chemical insecticides	(*Yulong Niu et al., 2024*)
Rhopalosiphum padi	Thyme, rosemary, and lavender	Essential oils	Significant insecticidal activity, thyme oil ~80% mortality	Natural pest control alternative	(*Casas et al., 2023*)
Grapes	Oregano and thyme	Essential oils	Reduced grey mould incidence, maintained firmness and visual quality	Extended shelf life, better post-harvest quality	(*El-Abbasy et al., 2023*)
Green bean	*Urtica dioica* L.	Fermented plant extract	Stimulated vegetative growth, improved leaf development, increased iron content	Comparable results to mineral fertilization	(*Maričić et al., 2021*)
Strawberry	Thyme, sage, and mint	Essential oils	Controlled anthracnose, thyme oil completely inhibited pathogen at high concentration	Reduced disease impact, natural protection	(*Morkeliūnė et al., 2021*)
Cucumber	Lemongrass, lemon, thyme, and mint	Essential oils	Reduced powdery mildew severity up to 77%, stimulated plant growth (high doses phytotoxic)	Disease control, improved growth, need for optimized doses	(*Mostafa et al., 2021*)
Tomato	Patchouli	Essential oil and 18% oil emulsion	High larval mortality, reduced reproduction and oviposition of Tuta absoluta	Effective pest control, lower active ingredient use	(*Costa et al., 2023*)

The high efficacy of medicinal plant extracts, demonstrated on diverse crops such as lettuce, green beans, strawberry, tomato, cucumber, and grape, validates the idea that these natural substances can represent a viable alternative to chemical inputs, both for plant health and for maintaining the quality of fruits and vegetables in the long term. At the same time, the results of the studies presented emphasize the importance of establishing optimal dosages in order to maximize benefits and avoid phytotoxic effects.

Expansion Trends in the Organic Food Market

The organic food market is expanding through the use of pesticides derived from plant extracts, which enhance product attractiveness and increase consumers' willingness to pay a higher price (Figure 5) (*Ngegba et al., 2022*). In 2020, the world market for organic food and drink exceeded 120 billion, the EU being situated on the second place with 44.8 billion Euro retail sales. The EU market's trend is to further expand, reaching 46.5 billion Euro in 2023, according to reports from the European Commission and IFOAM.

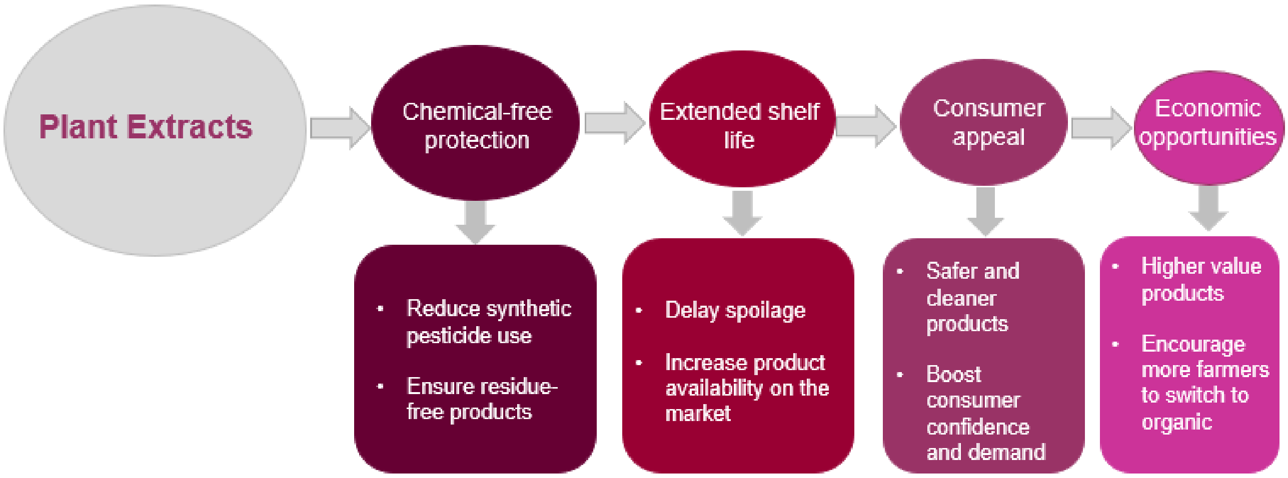

Fig. 5 - Contribution of Plant Extracts to the Expansion of the Organic Food Market

One example is provided by foliar treatments with aqueous nettle (*Urtica dioica* L.) extracts applied to oat crops at concentrations of 25–100%, which had significant biostimulant effects, leading to increases in plant height, stem diameter, total weight, and root development. The best results were obtained at the 75% concentration, where biomass and stem diameter increased by more than 20–30% compared with the control (*Eremi and Sala, 2023*). *Nxumalo et al., (2021*), observed that the application of *Ruta chalepensis* extract reduced soft rot severity in mango from 93% to 26%, while Aloe vera gel decreased post-harvest disease incidence in nectarines by up to 70%. Similarly, neem and turmeric extracts reduced dragon fruit anthracnose by 90% after 28 days, and guava treated with ginger and garlic lost significantly less water compared with the control batches. Therefore, farmers who choose to use natural extracts can offer healthier and safer products on the market, which ultimately reshapes the way the entire food chain is perceived.

It has been demonstrated that treatment with lemon verbena extract applied to strawberries stored under refrigeration reduced the rate of fungal spoilage and better-preserved quality parameters. At a concentration of 600 mg/L, the best results were obtained, with fruits showing the lowest level of decay and the highest antioxidant capacity, along with increased contents of vitamin C, flavonoids, and phenolic compounds (*Moshari–Nasirkandi et al., 2020*). Other tests involved the application of Aloe vera gel and basil seed mucilage to apricot fruits, which significantly reduced post-harvest losses and maintained nutritional quality during storage. After 28 days, control fruits lost 14.4% of their weight, while those treated with plant extracts lost only 5–6%, while retaining higher levels of vitamin C, phenolics, and antioxidant activity (*Nourozi and Sayyari, 2019*).

Wijewardane and Guleria, (2009), applied neem oil and marigold extracts to apples and found that, in combination with pre-cooling and appropriate packaging, post-harvest losses were reduced, and quality was maintained for up to 150 days. These natural treatments preserved fruit firmness, acidity, and bioactive compounds, offering a viable alternative to conventional chemicals. By contrast, *Ahmed M.J. et al. (2009*) tested the application of an edible coating based on Aloe vera gel on nectarines and found significant effects during storage, reducing ethylene production by up to 62%, respiration rate by 41%, and weight loss by 65% compared with control fruits. In addition, treated fruits better retained firmness and acidity, showing superior physical and sensory quality.

Recent research shows that the use of plant extracts, either alone or in combination with essential oils, has positive effects on meat by reducing the development of pathogenic bacteria, slowing oxidation processes, and extending shelf life. Such applications confirm that natural ingredients can replace synthetic preservatives, providing safer and more attractive products for consumers and contributing to the expansion of the organic food market (*Mantzourani et al., 2022; Damani and Topi, 2022; Pabón-Baquero et al., 2018*).

The studies discussed above have demonstrated that plant extracts, when applied to crops or food products, can stimulate plant growth, reduce post-harvest diseases, and extend the shelf life of fruits and meat, thereby providing healthier and safer products. Through these effects, they support the expansion of the organic food market, responding to consumer demand for natural alternatives to synthetic chemicals.

CONCLUSIONS

- **Agronomic Benefits**

The integration of extracts from medicinal and aromatic plants (MAPs) outlines a unified technological framework for the transition toward sustainable agriculture: the same plant resources can support field-level productivity (biostimulation), partially replace synthetic inputs in crop protection (bioherbicides, bioinsecticides, biofungicides), and enhance the stability and safety of food products during post-harvest. This multifunctionality grants them strategic value both agronomically and economically.

At farm level, research shows that plant extracts can reduce the need for chemical pesticides and fertilizers without compromising crop yields, provided they are applied at the appropriate doses and times. These extracts stimulate plant growth and improve nutrient use efficiency, while simultaneously protecting crops from diseases and pests. Some extracts inhibit fungal spore germination, others affect insect functions, or suppress weed development, making them valuable tools in ecological crop protection programs.

In the post-harvest–processing chain, the use of extracts and essential oils, including in the form of edible coatings and surface treatments, contributes to slowing microbial spoilage, reducing oxidation, and extending the shelf life of fruits and meat. The benefit is not only technological (maintained quality, reduced losses) but also systemic: decreasing food waste and increasing the availability of products that meet consumer expectations for a “clean label.”

- **Environmental Impact**

The environmental impact is twofold: on the one hand, reduced chemical pressure on agroecosystems (soil, water, air) and improved protection of non-target organisms, including pollinators; on the other hand, the restoration of soil functions (organic matter, microbial activity, structure), especially when botanical resources are integrated through rotations, cover crops, valorised residues, and organic amendments. These effects support the resilience of agroecosystems in the face of climate variability.

From a market perspective, the combination of safer products with reduced residues and superior post-harvest quality fuels demand for organic and “natural-friendly” foods, strengthening the expansion of the organic market. For small-scale farmers, MAPs can become a high value-added diversification line, particularly when supported by local processing capacity, standardization, and access to contracts or cooperatives.

From a technological perspective, traditional extraction methods (such as maceration, percolation, or Soxhlet) now coexist with modern and “green” techniques (such as ultrasound, microwaves, or supercritical fluids). This combination allows to produce extracts tailored both to the intended purpose and to requirements of cost, safety, and environmental protection. However, for these methods to be applied on a large scale, it is necessary to standardize raw materials, verify chemical composition, ensure batch quality control, and conduct practical testing on farms, along with assessments of environmental impact across the entire production cycle.

- **Policy Needs and Future Research**

Limitations and cautions remain, such as: natural variability in composition depending on species, ecotype, phenophase, and extraction method; sometimes narrow dose–response relationships (with risks of phytotoxicity at high doses); potential adverse effects on beneficial organisms if concentrations and application windows are not properly observed; and the need for stable formulations (nanoemulsions, microencapsulation) to ensure consistent efficacy and safe handling.

The policy and regulatory dimension have a decisive role. Financial support programs and eco-conditionality requirements can accelerate the adoption of plant extracts, while alignment with organic farming standards and objectives of European agricultural policy provides farmers with greater investment security. In addition, practical training, advisory services, and the existence of collection and processing centres are the key elements that make the difference between potential and real, large-scale application.

Overall, plant extracts from MAPs do not represent merely a punctual substitution for synthetic inputs, but rather an operational platform for sustainable intensification: they increase resource efficiency, reduce negative externalities, improve food quality and availability, and open pathways for economic development for farms and rural communities. Future priorities should focus on multi-annual farm-scale studies, good practice guidelines (doses, timing, compatibilities), safe and stable formulations, as well as decision-support tools that link biological efficacy with economic feasibility.

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