# Nanoencapsulation of essential oils (EOs) and the emerging role of Intellectual Property Rights in food and agriculture

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## Abstract

Nanoencapsulation of essential oils (EOs) represents a significant advancement in the application of nanotechnology in food and agriculture. This technique improves the stability, solubility, bioavailability, and controlled release of EOs, thereby enhancing their efficacy as natural preservatives, functional food ingredients, and eco-friendly biopesticides. These properties address limitations associated with EO volatility, degradation, and poor water solubility. As the utilization of nano encapsulated EOs expands, the role of Intellectual Property Rights (IPRs) becomes critical in safeguarding innovative nano formulation processes, delivery systems, and carrier materials. Effective IPR protection not only ensures the commercial viability of these technologies but also promotes research investment and technological advancement. This review examines the scientific applications of nano encapsulated EOs in food preservation and sustainable agriculture, while highlighting the importance of IPRs in facilitating innovation, regulatory compliance, and ethical commercialization.

**Keywords:** Nanoencapsulation, Essential oils, Food technology, Sustainable agriculture, Intellectual property rights.

## Introduction

Essential oils (EOs) are complex mixtures of volatile and aromatic compounds extracted from various parts of plants such as leaves, flowers, stems, bark, and roots. They are well-recognized for their broad spectrum of biological activities, including antimicrobial, antioxidant, antifungal, antiviral, and anti-inflammatory properties, which make them highly valuable in food preservation, pharmaceuticals, cosmetics, and agriculture (Deepika et al., 2021). Despite their promising potential, the direct application of EOs is often hindered by several physicochemical limitations such as high volatility, hydrophobic nature, thermal sensitivity, and susceptibility to degradation in the presence of light, oxygen, and elevated temperatures (Al-Maqtari et al., 2021).

To address these challenges, nanoencapsulation has emerged as an innovative and efficient approach. Nanoencapsulation refers to the entrapment of active substances within nanometer-scale carrier systems such as liposomes, solid lipid nanoparticles, nano emulsions, and polymeric nanoparticles (Jafari, 2017). This technology not only protects EOs from environmental degradation but also improves their water dispersibility, enhances bioavailability, and facilitates controlled and targeted release at the site of action (Deepika et al., 2021). These attributes make nano encapsulated EOs more effective and practical for a wide range of applications, especially in the food and agricultural sectors where safety and efficacy are critical. There are several advantages of encapsulation in which some are addressed below as:

***Enhanced Stability:***

One of the primary challenges in using EOs is their high sensitivity to environmental factors such as oxygen, light, temperature, and PH. Nanoencapsulation offers a protective barrier around the EOs, significantly reducing their exposure to these degrading factors. This helps maintain their chemical integrity and biological activity over time, thereby extending their shelf life. For instance, nano emulsions and polymer-based nanoparticles can provide oxidative and thermal stability to sensitive EOs.

***Controlled Release:***

Nanoencapsulation systems can be engineered to allow for sustained, controlled, or stimuli-responsive release of the encapsulated Eos. This is particularly beneficial for applications where prolonged or site-specific activity is required, such as in antimicrobial food packaging, pharmaceuticals, or cosmetic formulations. Controlled release also helps maintain the therapeutic levels of EOs for a longer duration and reduces the frequency of application, enhancing overall efficacy.

***Improved Bioavailability:***

Many EOs are lipophilic and have low solubility in water, which hinders their absorption and effectiveness in biological systems.

Nanoencapsulation improves the dispersibility and solubility of these oils in aqueous environments, thus enhancing their bioavailability. By increasing surface area and interaction with biological membranes, nano-sized carriers facilitate more efficient absorption.

***Masking Undesirable Properties:***

Some EOs possess strong odors or flavors that may be undesirable in food or pharmaceutical formulations. Nanoencapsulation can help mask these sensory properties, allowing their incorporation without negatively affecting the taste or aroma of the final product. This is particularly valuable in food preservation, where EOs can act as natural preservatives without compromising sensory quality.

As the commercial potential of these nano-formulations grows, the role of intellectual property rights (IPR) becomes increasingly significant, affecting research investments, innovation diffusion, and regulatory policies (Henry & Stiglitz, 2010). This review explores the technological advances, applications, IPR implications, and future directions in the field of nano encapsulated EOs.

## Intellectual Property Rights (IPR) and Patent Trends

The nano encapsulated bioactive compounds of EO or EO control the transfer and degradation rate of core material to the outside environment as well as masking the interaction that would otherwise react with food items responsible for alteration in flavor or taste (Fang and Bhandari, 2010). Therefore, several workers have authorized the patent of some EOs in the food system as well as in clinical trials along with consumer acceptance. For this, Martínez *et al*. (2016) have selected *Salvia hispanica* plant for extraction of EO due to presence of high content of Ω-3 fatty acids and prepared juices and jellies with use of edible nano emulsion and then patented (WO2018029626) by Argentina. Similarly, curcuminoid with turmeric EO was patented (US7879373) by Antony (2011) for improvement of bioavailability of curcumin and now safely used in different food sectors as well as in pharmacological industries. Tad tong (2020) blended eucalyptus, rosemary, patchouli oil and sweet marjoram EO and prepare a mixture that used to relieving muscular pain in volunteers. Thus, the growing demands for trademark applications and patent authorization have been made new innovations to these modern technologies in the global market. In the last few years, encapsulated EOs have found several applications in the field of biotechnology, cosmetics, foods, pharmaceutics and in form of agrochemicals (Jemaa *et al.*, 2019). Therefore, keeping these benefits after encapsulation, the EO is subjected to be patent for

human welfare. There are some examples of EO with their patent authorization by different countries and numbers are summarized in figure 1 and table 1.

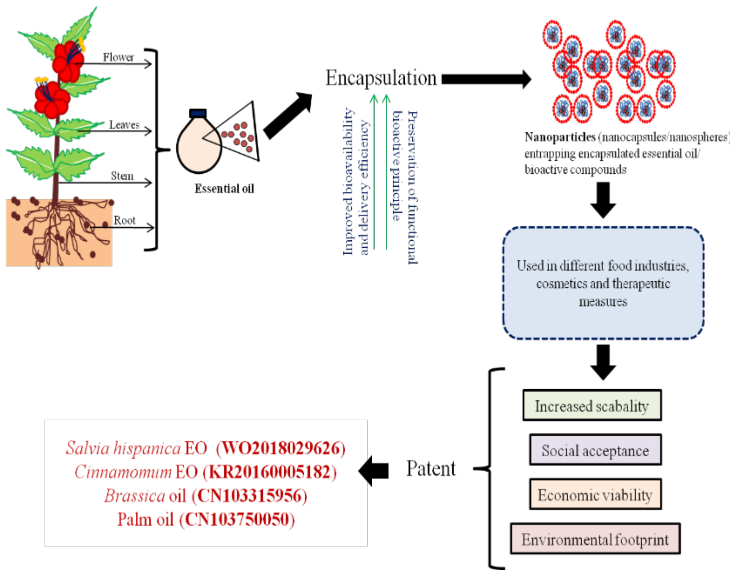


**Figure 1. Example of some patented nanoencapsulated EOs with consumer acceptance**

**Table 1. Intellectual property right (IPR) and patent of some plant EOs and their nanoformulations**

| S. No. | Nanoencapsulated EOs | Country | Number | Properties | Used by | Reference |
|---|---|---|---|---|---|---|
| 1. | *Allium cepa*, *Lavandula officinalis* and *Calophyllum inophyllum* | France | FR2876031 | Strong antimicrobial and anti-inflammatory activity | Therapeutic measures | Taleb (2006) |

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|---|---|---|---|---|---|---|
| 2. | *Brassica* oil nano emulsion | China | CN103315956 | Alleviate the pungent odour of mustard | Food industries | Houbin *al.* (2013) |
| 3. | *Cinnamomum* EO nano emulsion | Republic of Korea | KR20160005182 | Inhibit the growth of microorganisms in food | Cosmetics and therapeutic measures | Gi *et al.* (2016) |
| 4. | Curcuminoid and turmeric EO | United State of America | US7879373 | Enhance the curcumin bioavailability | Therapeutic measures and food industries | Antony (2011) |
| 5. | *Mentha piperita* | United State of America | US7344740 | Symptoms of nausea | Therapeutic measures | Vail and Vail (2008) |
| 6. | *Mentha suaveolens* | World Intellectual Property Organization | WO201 1092655 | For preparation of soaps, mouthwashes and shampoo cosmetics | Cosmetics industries | Angiolella an d Ragno (2011) |
| 7. | Palm oil nanoemulsion | China | CN10375 0050 | Good digestive livestock | Therapeutic measures | Weichun *et al.* (2014) |
| 8. | *Salvia hispanica* EO in edible nanoemulsion | Argentina | WO201802 9626 | Juices and jellies | Food industries | Martínez *et al.* (2016) |
| 9. | Tea tree oil | United Sta te of America | US7807202 | Skin diseases in children and adults both | Therapeutic measures | Burke (2010) |
| 10. | Thyme oil | United Sta te of America | US0206790 A1 | Ecofriendly antimicrobial foamable soap against *Staphylococcus aureus* | Therapeutic measures | |

## Applications of Nanoencapsulated EOs

Nanoencapsulation significantly enhances the functional attributes and application potential of EOs by improving their stability, solubility, and bioavailability. In the food industry, nanoencapsulated EOs exhibit potent antimicrobial and antioxidant activities, making them effective natural preservatives. Their encapsulation reduces volatility and odor intensity, enables sustained release, and enhances microbial inhibition against foodborne pathogens such as *Escherichia coli*, *Listeria monocytogenes*, and *Salmonella spp.* For example, cinnamon EO nano formulations have shown efficacy in extending shelf life by minimizing microbial load (Gi et al., 2016). In functional food development, nanoencapsulation facilitates the incorporation of hydrophobic bioactives like curcumin by improving solubility and gastrointestinal absorption. The encapsulation process also masks undesirable flavors and protects sensitive compounds during processing. A patented curcuminoid-turmeric EO nano formulation (Antony, 2011) exemplifies improved curcumin bioavailability and stability, supporting its use in nutraceuticals and pharmacological applications. In sustainable agriculture, nano encapsulated EOs act as biopesticides, offering targeted delivery, controlled release, and reduced environmental toxicity. Encapsulated clove, neem, and eucalyptus oils have demonstrated efficacy in managing crop pests with minimal ecological impact. Overall, nanoencapsulation represents a promising approach for enhancing EO functionality in food safety, nutrition, and eco-friendly agricultural practices.

## Challenges and Future Directions

Despite the promising potential of nano encapsulated EOs across various sectors, several challenges must be addressed to facilitate their widespread adoption. One of the primary concerns is the scalability and cost-effectiveness of nanoencapsulation techniques. Many current methods are suitable for laboratory-scale production but may not be economically viable or technically feasible on an industrial scale. Developing efficient, scalable processes with low production costs is essential for commercial success. Another significant challenge lies in ensuring the safety and assessing the toxicity of nano-carriers and their formulations. As nanoparticles may behave differently from their bulk counterparts, comprehensive toxicological studies and regulatory evaluations are required to confirm their safety for human consumption and environmental exposure. Additionally, consumer acceptance remains a barrier, as public perception of nanotechnology in food and agriculture is still cautious. Addressing these concerns through transparent labeling, education, and regulatory oversight is vital to build consumer trust and promote the responsible use of nanoencapsulated EOs.

## Conclusion

The nanoencapsulation of EOs marks a transformative leap in the fields of food preservation and sustainable agriculture, providing increased stability, bioavailability, and controlled administration of bioactive molecules. These developments address the inherent limits of EOs, such as volatility and low water solubility, while also encouraging safer, environmentally acceptable alternatives to synthetic chemicals and pesticides. As technology advances, Intellectual Property Rights (IPRs) play an increasingly important strategic role; not just in protecting breakthrough formulations and delivery methods, but also in encouraging investment, cooperation, and ethical commercialisation. Strengthening IPR frameworks will be critical for closing the gap between laboratory innovation and market adoption, eventually aiding worldwide efforts to improve food security, environmental sustainability, and technical fairness in agriculture.

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