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Review

Pimenta dioica: a review on its composition, phytochemistry, and applications in food technology

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Abstract

Recently, the utilisation of essential oils extracted from spices has been garnering interest due to their phytochemical constituents which could be extracted using various techniques. Studies have demonstrated antimicrobial activities from essential oils against foodborne pathogens, and thus, their application has been considered to be a possible preservative for foods. *Pimenta dioica* is a type of aromatic plant, and its essential oil is is rich in eugenol, a phenolic compound with wide antimicrobial spectrum. Other bioactive compounds in *P. dioica* extract include glycosides, alkaloids, carbohydrates, proteins, flavonoids, and tannins. The incorporation of essential oils into food is limited because they have an intense aroma, and might affect consumer acceptance. Therefore, nanotechnology is applied as a tool to rectify this limitation, and it is now possible to apply essential oils in active packaging, or to encapsulate them in biodegradable materials or edible coatings with controlled release. However, there is little information on the interaction of nanoencapsulated bioactive composites, and thus, it is essential to assess the viability of biomaterials before their use. The objective of this work is to show the use of the essential oil of *Pimenta dioica* and its phytochemical composites in a general way for its potential application in food technology.

Introduction

The use of spices and their extracts for medicinal and gastronomic purposes dates back to ancient Egypt, with preservation of meat products being the first application. Now, they are used as seasonings and preservatives due to their antioxidant and antimicrobial properties (Clemenson, 2019).

Essential oils (EOs) are chemical compounds obtained from different parts of plants such as seed, leaf, and bark by different techniques. EOs are volatile and lipophilic bioactive compounds that generate different properties in plants (Calo *et al.,* 2015). They are aromatic compounds used in the food, cosmetic, and pharmaceutical industries (Oussalah *et al.,* 2007; Bhargava *et al.,* 2015). The use of natural compounds for human and animal consumption has been increasing, and stimulated research that explores new applications for EOs (Perricone *et al.,* 2015).

Research has reported the antimicrobial properties of EOs against microorganisms that spoil food, and the application of EOs as a type of potential green preservative for foods has been considered (Passarinho *et al.,* 2014; Calo *et al.,* 2015; Bhargava *et al.,* 2015; Zhang *et al.,* 2016). The antimicrobial activity of EOs implies the ability of its hydrophobic compounds to alter the cell membranes of microorganisms, thus modifying their cell structure and membrane permeability which eventually leads to cell death (Zhang *et al.,* 2016). The antimicrobial properties of EOs are due to the interactions among their chemical compounds (Chouhan *et al.,* 2017; Marchese *et al.,* 2017).

The EO of *Pimenta dioica*, which is an aromatic plant, has also been reported to have antimicrobial and antioxidant properties (Dima *et al.,* 2014) due to the abundance of eugenol (Priya *et al.,* 2012), a phenolic compound with a wide spectrum antimicrobial property, in its EO (Monteiro *et al.,* 2011; Marchese *et al.,* 2017). Phytochemical analyses of *P. dioica* leaf extract report the presence of glycosides, alkaloids, carbohydrates, flavonoids, tannins, and proteins (Mathew and Lincy, 2013). Methyl eugenol, eugenol, myrcene, β-caryophyllene, cineole, and limonene have also been reported (Kikiuzaki *et al.,* 1999; Jirovetz *et al.,* 2007; Tucker and Maciarello, 1991; Mohamed *et al.,* 2007; Siju *et al.,* 2014).

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Origin, taxonomy, and distribution

Pimenta dioica (L.) Merr. (Merrill, 1947), commonly known as allspice, is a tree producing fruits which are dried and used as spice in culinary. Allspice belongs to the family Myrtaceae, and is known in French as *le piment de la Jamaique piment*, in Spanish as *pimenta gorda*, and in Portuguese as pimenta da Jamaica. The common name allspice was proposed by John Ray, an English botanist, who identified its flavour as a combination of cloves, cinnamon, and nutmeg (Rema and Krishnamoorthy, 2012). The family Myrtaceae consists of approximately 3,000 species, most of which grow in the tropics. The genus *Pimenta* Lindl. consists of approximately 18 species of aromatic shrubs and trees native to the tropical America (Willis, 1966). The trees grow to a height of 7 m, the trunk has reddish brown bark, and the seed is dark green and becomes brown to black when dried as a single seed (Vasconcelos *et al.,* 2018).

Pimenta dioica is native to the West Indies (Jamaica; hence its French and Portuguese name). However, it is also found in Central America (Mexico, Guatemala, Cuba, Honduras, and Costa Rica) and the neighbouring Caribbean islands, although its original home is under debate. Currently, Jamaica produces 70% of the world's production of *P. dioica*, and the remaining 30% is produced by Brazil, Mexico, Honduras, Guatemala, and Belize combined. Ripe berries, due to their oleoresin content, are commercially important in the pharmaceutical, cosmetic, and food industries. They are of high quality due to their flavour, size, and appearance, giving them a good price in the market. The main importing countries are the UK, Germany, Finland, Sweden, USA, and Canada. Its leaf oil is mainly exported to the UK and USA (Rema and Krishnamoorthy, 2012).

Phytochemical constituents

Essential oils (EOs) are volatile liquids extracted from bark, bud, flower, fruit, leaf, root, and stem. In EOs, more than 50 phytochemical species such as terpenes, terpenoids, and aromatic constituents have been isolated and identified, and they play vital roles in the antimicrobial property of EOs (Mariod, 2016). Nowadays, EOs have been used as flavouring and functional ingredients in foods (Kalantari *et al.,* 2012). The highest concentration of EOs allowed in foods is approximately 0.025% (Krishnamoorthy and Rema, 2004). EOs differ in their odours, optical properties, and refractive indices. They are soluble in alcohol and ether, but immiscible in water. EOs contain alcohols, hydrocarbons, aldehydes, and ketones, among others (Noudogbessi *et al.,* 2012). Of late, the interest in the direct or synergistic application of EOs in the food industry has been increasing (Carocho *et al.,* 2014). For *P. dioica*, its EO is extracted from the berries and leaves, and is also applied in the food, cosmetic, and pharmaceutical industries (Rao *et al.,* 2012).

Generally, phytochemical compounds are non-nutritive secondary metabolites, and they often have other functional properties such as antimicrobial against wide range of foodborne microorganisms. Based on their complex chemical structure, phytochemicals are generally classified into major groups such as polyphenols, carotenoids, alkaloids, sulphur-containing groups, terpenes, and terpenoids (Prakash *et al.,* 2020).

The partitioning of phenolic compounds depends on the part of the tissue/plant (Robards, 2003). The precursor phenolic compounds are tyrosine and phenylalanine, which have hydroxyl groups attached to the aromatic ring, and are aromatic compounds of plants (Naczk and Shahidi, 2004; Muchuweti *et al.,* 2007). Phenolic compounds are soluble in water, and when combined with a sugar molecule, they can be found as glycosides (Muchuweti *et al.,* 2007). Phytoalexins are phenolic compounds that act as antimicrobial compounds (Naczk and Shahidi, 2004). The phytochemical compounds found in EOs could also have antimicrobial, antidiabetic, and anticancer properties (Mahomoodally *et al.,* 2018). Approximately, 8,000 polyphenols have been identified thus far, and these can be subclassified into various groups ranging from phenolic acids to tannins (Muchuweti *et al.,* 2007).

Dima *et al.* (2014) identified 23 phytochemical compounds in *P. dioica* EO obtained by supercritical CO_2 extraction, which are represented in Table 1, with eugenol being the most abundant (68.06%). In another study, Suprani-Marques *et al.* (2019) identified the compounds in *P. dioica* leaves, extracted by hydrodistillation utilising gas chromatography with flame ionisation (Table 2).

Biological activities

For decades, EOs have been used due to their various biological activities. However, the scientific basis for these activities is still being investigated (El-Soud *et al.,* 2012; Raut and Karuppayil, 2014). Due to their biological activities, more than 300 EOs have industrial importance (El-Soud *et al.,* 2012; Raut and Karuppayil, 2014). They can be applied both in the food industry and for medical purposes due to their wide spectrum (Bakkali *et al.,* 2008; Perricone *et al.,* 2015; Pandey *et al.,* 2016;

Table 1. Chemical compounds in *Pimenta dioica* essential oil obtained by supercritical fluid extraction (Dima *et al.,* 2014).

Compound	% area[a]	RI[b]
γ-Terpinene	0.48	1060
γ-Cardinene	0.48	1520
β-Selinene	0.38	1488
β-Phellandrene	1.34	1031
α-Pinene	0.27	934
α-Phellandrene	6.67	1006
α-Humulene	1.51	1454
α-(E,E)-Farnesene	0.09	1508
Trans-β-ocimene	0.72	1050
Trans-nerolidol	0.04	1560
Teroinolene	1.36	1086
p-Cymene	1.11	1026
Myrcene	0.23	990
Methyl eugenol	9.37	1403
Linalool	0.12	1100
Limonene	0.35	1029
Isoeugenol	0.12	1405
Eugenol	68.06	1357
Chavicol	0.26	1248
1,8-Cineole	1.65	1035

[a]The quantitative results were obtained electronically from FID area data without using correction factors, and [b]retention index.

Table 2. Chemical compounds in the essential oil of *Pimenta dioica* essential oil (Suprani-Marques *et al.,* 2019).

Compound	RI_{lit}[a]	RI_{exp}[b]	%[c]
Trans-hex-2-enal	-	-	0.5
α-Thujene	931	927	1.0
α-Pinene	939	933	0.6
5-Methylheptan-3-one	-	988	2.4
β-Myrcene	991	992	57.8
Octan-3-ol	993	996	0.8
α-Phellandrene	1005	1000	1.9
α-Terpinene	1018	1014	0.3
p-Cymene	1026	1023	0.8
D-Limonene	1031	1028	10.1
Linalool	1098	1098	2.8
Terpinene-4-ol	1177	1175	0.8
Chavicol	1253	1255	1.9
Eugenol	1356	1345	18.3

[a]Literature retention index, [b]Experimental retention index, and [c]% area obtained by GC-FID with the Rtx-5MS capillary column.

Ribeiro-Santos *et al.,* 2017). The synergistic effect of essential oils has been shown to be due to the biological properties of their compounds (Ribeiro-Santos *et al.,* 2017).

Most EOs from spices and herbs such as oregano, thyme, cinnamon, cloves, and their phytochemical compounds such as thymol, cinnamaldehyde, eugenol, and carvacrol are classified as generally recognised as safe (GRAS) by the FDA. EOs have also been analysed for their antimicrobial capacity against pathogens (Burt, 2004; Shaaban *et al.,* 2012; Pandey *et al.,* 2016). The lipid composition allows transport through the cytoplasmic membrane and the cell wall of pathogenic microorganisms, thus altering their structure. EO-based products are available to control the growth or inhibition of microorganisms in food (Bakkali *et al.,* 2008; Saad *et al.,* 2013).

Antibacterial activity

Bacteria are the leading cause of foodborne illnesses (USDA, 2012). The demand for more natural (minimally processed) foods has been increasing; therefore, it is suggested to use preservatives of natural origin such as herbal and spice extracts (Hyldgaard *et al.,* 2012; Kim *et al.,* 2012) to reduce bacterial contamination. Several studies report the direct addition of aromatic plant essential oils and extracts to foodstuffs to exert antibacterial or antioxidant effects (Carvalho-Costa *et al.,* 2015). The application of an EO is due to its antibacterial activity, especially in the food and pharmaceutical industries (Burt, 2004; Lang and Buchbauer, 2012). The literature reports the activities of the EOs of aromatic plant species against Gram-negative and Gram-positive bacteria (Calvo-Irabien, 2018).

The EO of *P. dioica* has been shown to have antibacterial properties with wide spectrum (Zabka *et al.,* 2009; Rao *et al.,* 2010). Table 3 shows an example of the application of chitosan and microencapsulated carrageenan against microorganisms (Dima *et al.,* 2014). In another study, Lorenzo-Leal *et al.* (2019) reported antibacterial activity against *Salmonella* Typhimurium and *Listeria monocytogenes* in alfalfa seeds.

Antifungal activity

The greatest postharvest damage to food is caused by fungi which leads to great economic losses (Sivakumar and Bautista-Baños, 2014). In the field of food safety, due to the production of mycotoxins, fungi of the genera *Fusarium, Aspergillus*, and *Penicillium* are the most analysed (D'Mello *et al.,* 1998; Serra *et al.,* 2006). The damages caused by mycotoxins in fresh and packaged products have been shown to be a health hazard (Yaouba *et al.,* 2010; Lang and Buchbauer, 2012). The use of EOs as alternatives in food preservation due to their low toxicity and antifungal activity could be promising (Burt, 2004).

Fusarium and *Aspergillus* cause very serious human mycoses. The treatment of these species is most problematic and questionable due to the toxicity

Table 3. Antibacterial potential of raw and encapsulated *Pimenta dioica* essential oil (Dima *et al.,* 2014).

Diameter of inhibition zone (mm)	**Sample**		
	Raw *P. dioica* EO	**Microspheres type A**	**Microspheres type B**
Bacillus subtilis MIUG B106B	1.2 ± 0.02^{a}	3.2 ± 0.17^{b}	2.7 ± 0.10^{c}
Bacillus cereus MIUG B107B	1.0 ± 0.01^{a}	5.5 ± 0.11^{b}	4.8 ± 0.21^{c}
Rhodotorula glutinis MIUG D7	1.0 ± 0.01^{a}	1.8 ± 0.02^{b}	1.1 ± 0.13^{a}
Candida utilis MIUG D8	2.3 ± 0.03^{a}	4.2 ± 0.20^{b}	3.5 ± 0.17^{c}
Saccharomyces cerevisiae	0.9 ± 0.12^{ab}	1.1 ± 0.07^{a}	0.7 ± 0.07^{b}
Aspergillus niger MIUG M5	1.0 ± 0.05^{a}	3.1 ± 0.19^{b}	2.8 ± 0.11^{b}
Penicillium glaucum MIUG M9	2.0 ± 0.13^{a}	1.0 ± 0.08^{b}	0.6 ± 0.05^{c}
Geotrichum candidum MIUG M13	1.0 ± 0.09^{a}	2.1 ± 0.04^{b}	1.6 ± 0.05^{c}

Values are mean ± SD of triplicates ($n = 3$). Means with different lowercase superscripts in the same row are significantly different, as determined by Tukey's test ($\alpha = 0.05$).

and side effects of synthetic fungicides (Johnson and Kauffman, 2003; Scott *et al.,* 2007; Nucci and Anaissie, 2007; Howard *et al.,* 2008) which could potentially lead to health risks (Scordino *et al.,* 2008). Due to the increasing incidence of resistant fungal pathogenic species (Deising *et al.,* 2008), the search for novel antifungal compounds from natural sources have also been increasing (Pinto *et al.,* 2007; Kumar *et al.,* 2008; Srivastava *et al.,* 2008).

Dima *et al.* (2014) reported two types of microspheres: chitosan microspheres with *P. dioica* EO covered with κ-carrageenan (type A), and chitosan/κ-carrageenan microspheres with P. dioica EO (type B), both of which had inhibitory effect at different degrees against the tested microorganisms as shown in Table 3. In order to know the significant differences between treatments, we added to Table 3 a Tukey's analysis. *Pimenta dioica* EO microencapsulated in chitosan/κ-carrageenan exhibited an increase in bioactive potential unlike *P. dioica* EO that was not encapsulated. The antibacterial activity of chitosan (Dutta *et al.,* 2009) and the antifungal activity of *P. dioica* EO against *Saccharomyces cerevisiae*, *Candida* sp., and *Aspergillus niger* (Oussualah *et al.,* 2006; 2007; Kamble-Vilas and Patil, 2008) have been well documented.

Anti-inflammatory, sedative, and spasmolytic activity

Some EOs have also been considered as anti-inflammatory drugs (Pérez *et al.,* 2011) due to their ability to eliminate some free radicals (Miguel, 2010). Among the effects reported by EOs' bioactive compounds is the reduction of pain sensitivity (Lenardao *et al.,* 2016). Some EOs also have activities such as anxiolytics and pain relievers (Dobetsberger and Buchbauer, 2011). Plant extracts have been used as home remedies against gastrointestinal disorders (Bakkali et al., 2008).

Antioxidant activity

Most EOs have antioxidant potential because they can scavenge free radicals, and therefore, play an important role in the prevention or control of various diseases, as evidence suggests that many diseases may be the result of cell damage caused by free radicals (Edris, 2007; Adorjan and Buchbauer, 2010). This property generates an alternative for the use of EOs as organic preservatives with antioxidant effects. The antioxidant effects of EOs are due to the inherent properties of some of their bioactive components, particularly phenols, to inhibit or delay the aerobic oxidation of organic matter (Miguel, 2010; Amorati *et al.,* 2013).

Research has reported a correlation between the resistance to oxidative degradation and hydroxyl (OH) groups of chemical compounds in EOs, which may be cytotoxic. The hydroxyl groups of EOs are donors of hydrogen, thus eliminating the production of free radicals in the oxidative process of lipids. In the case of *P. dioica* EO, the antioxidant activity is mainly due to methyl eugenol and eugenol, as shown in Table 4.

Table 4. Phenolic content and antioxidant activity of *Pimenta dioica* essential oil.

Antioxidant content (FRAP) (mmol/100 g)	100.4	Carlsen *et al.* (2010)
DPPH (% Inhibition)	545.4	Embuscado (2015)
Total phenolic content (mg/g)	421.5	Embuscado (2015)

Toxicity

The bioactive compounds of EOs is functional and beneficial; however, some could be cytotoxic (Bakkali *et al.,* 2008; Raut and Karuppayil, 2014), irritant, corrosive, and phytotoxic. For this reason, it is necessary to generate the toxicity profile of each EO since the toxicity of an EO can vary based on its composition (Tisserand and Young, 2014). *Pimenta dioica* extract is, however, non-toxic and reports indicate significant cytoprotective activities (Al-Rehaily *et al.,* 2002; Ramos *et al.,* 2003; Nayak and Abhilash, 2008). They can be applied as safe and organic antifungal treatments. This could lead to the recommendation of *P. dioica* EO as a modern and effective alternative fungicide without risks to the health of consumers (Vaccari *et al.,* 1999; Gray *et al.,* 1999; Hojo *et al.,* 2000).

Applications in food technology

Currently, novel techniques such as the nanoencapsulation of EOs to improve their thermal stability, controlled release in food, and bioactivity are being developed (Lopez-Rubio *et al.,* 2006; Bilia *et al.,* 2014). The common materials used to encapsulate EOs are cellulose, starch, chitosan, pectin, carrageenan, alginate, and xanthan. The microencapsulation technique helps to retain and control the release rate of active compounds, and avoid light and heat-induced oxidation in elaborate particles of polysaccharides and proteins between 1 and 1,000 μm in size (Martins *et al.,* 2014).

In general, the nanoencapsulated bioactive compounds exhibited significant efficacy over the free form due to the increased surface area and the protection of the encapsulated compounds from both

Table 5. Encapsulating materials, sources, and applications (Carlsen *et al.,* 2010).

Encapsulating material		**Source**	**Application**	**Reference**
Plant origin	Starch	Legume, cereal, potato, carrot, and banana	Food preservation	Fathi *et al.* (2014)
	Cellulose	Wood pulp and cotton fibre	Essential oil encapsulation enzyme and biosensing	George and Sabapathi (2015)
	Pectin	Plant cell wall	Pharmaceutic gelling agents and food preservation	Srivastava and Malviya (2011)
	Guar gum	*Cyamopsis tetragonoloba*	Food applications, encapsulation, and food preservation	Mudgil *et al.* (2014)
Animal origin	Chitosan	Crustacean shell	Food applications, encapsulation, and food preservation	Elgadir *et al.* (2015)
Algal origin	Alginate	Brown sea algae	Food applications, gelling agents, encapsulation, and food preservation	Lee and Mooney (2012)
	Carrageenan	Rhodophyceae family member such as *Chondrus crispus*, *Eucheuma*, *Gigartina stellate*, *Iridaea*, *Hypnea*, *Solieria*, *Agardhiella*, and *Sarconema*	Gelling agents, encapsulation, food application, food preservation, and stabilizing agents	Stanley (1987)
Microbial origin	Xanthan	*Xanthomonas campestris*	Food preservation, hydrogel, matrix systems, and nanoparticles	Benny *et al.* (2014)
	Dextran	Family Lactobacillaceae	Food applications, gelling agents, encapsulation, and food preservation	Fathi *et al.* (2014)
	Cyclodextrin	*Bacillus amylobacter*	Anticancer food preservation, food application, and reduction in toxicity	Gidwani and Vyas (2015)

external (oxygen, light, and moisture) and internal environments (pH variation, chemical composition of food, and water activity) of food systems with the controlled release of bioactive compounds.

Although the use of nanotechnology in food science has higher potential to boost the preservative capacity of plant-based bioactive compounds, the lack of information about the possible interaction of nanoparticles with food components and living cells limits the regulatory approval of most agents in food systems. Therefore, a detailed understanding of the possible interactions between nanomaterials and food components, as well as the intended effects on consumer health must be explored for their application worldwide (Clemenson, 2019).

Due to the intense aroma of some EOs, their application is limited to avoid consumer rejection (Hyldgaard *et al.,* 2012). For this reason, one way to apply EOs is to encapsulate them in order to avoid evaporation and control their release, and they can also be applied to active packaging (Sanches-Silva *et al.,* 2014). The encapsulated EOs can be incorporated into edible coatings to avoid denaturation and delay the oxidation (Sanches-Silva *et al.,* 2014). The industrial application of EOs is also limited due to their high volatility, low stability, solubility, hydrophobicity, and photosensitivity. One way to overcome these limitations is nanoencapsulation applications, as they have proven to be effective in preserving the properties of EOs in foodstuffs. Some of the advantages offered by this technique are to mask the intense aroma of essential oils, increase their solubility in aqueous medium, and avoid negative interactions with food components (Ribeiro-Santos *et al.,* 2017).

Flores-Martínez *et al.* (2017) reported the incorporation of *P. dioica* EO in edible films based on *Aloe vera* gelatine, producing a significant effect on the water vapour permeability of the material that was directly proportional to the concentration of the EO. Badee *et al.* (2012) found greater flavour retention in encapsulated oil with Arabic gum. Ahn *et al.* (2008) found that rosemary extracts can inhibit lipid oxidation by microencapsulating it. Almeida *et al.* (2013) encapsulated oregano EO in starches from different sources, and found different biological activities. Gundewadi *et al.* (2018a; 2018b) described that the nanoemulsion of basil oil showed improved antimicrobial activity (≤ 20%) against the two most common food spoilage fungi, *Penicillium chrysogenum* and *Aspergillus flavus*. Lee *et al.* (2017) prepared silymarin nanocapsules of water-soluble chitosan and glutamic acid. They stated that the nanoencapsulation process significantly enhanced both the solubility (7.7-fold) and antimicrobial activity of silymarin. Mohammadi *et al.* (2015) examined the *in vitro* and *in vivo* antimicrobial activities of nanoencapsulated *Cinnamomum zeylanicum* EO (Ne-CEO) against *Phytophthora drechsleri*. The *in vivo* findings showed that Ne-CEO significantly decreased the severity of the disease and incidence of pathogens at 1.5 g/L. Hasani *et al.* (2018) prepared a mixture of lemon EO using chitosan (CS) and modified starch (Hicap) to boost the physicochemical properties and thermal stability of the EO by using the freeze-drying method. These studies confirm that nanotechnology enhances the bioactive properties of EOs.

The molecular structures of encapsulating agents based on plant extracts such as cellulose, pectin, starch, and guar gum are usually used to encapsulate EOs. In recent years, encapsulating agents, whether animal/vegetable/microbial-based have been used in the food industry as carriers of volatile agents in food systems (Prakash *et al.,* 2018). Table 5 shows the materials used as encapsulants, sources, and applications.

Finally, different techniques are used to encapsulate EOs such as freeze-drying, nanoemulsion, spray drying, and coacervation. One of the most widely used techniques for the encapsulation of EOs is spray drying, since its handling is relatively simple, and the process is fast at a relatively low cost (Yeo *et al.,* 2001).

Conclusions

Today, there is a special interest in characterising products such as spices since they are majorly used by the food industry. Their properties also justify their applications in other industries such as cosmetics, fragrances, and pharmaceuticals. Within the context of cultivated spices, *P. dioica* is one of the most important, as a source for essential oils rich in eugenol, which is a phenolic compound with a wide spectrum of antioxidant and antimicrobial activities against various microorganisms. In Central America, *P. dioica* produced is sent to the international market since its consumption in the local market is insignificant. However, its production and drying are largely traditional. Therefore, it is necessary to develop mechanised technology which requires less drying time while preserving its quality. Regarding its application, nanoencapsulation will facilitate the use of essential oils by protecting them against oxygen degradation, masking the intense aroma, increasing their solubility, and using them as natural preservatives. Therefore, the challenge is to develop and optimise techniques that can quantify the phenolic compounds in essential oils that have potential applications in the food industry.

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