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PROSPECTS FOR USING ESSENTIAL OILS IN THE MEAT INDUSTRY: A REVIEW

PERSPECTIVELE UTILIZĂRII ULEIURILOR ESENȚIALE ÎN INDUSTRIA DE OBȚINERE A PRODUSELOR ȘI PREPARATELOR DIN CARNE: REVIEW

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ABSTRACT | REZUMAT

Historically, the identification of an effective method for preserving or improving the sensory qualities of food has been a matter of intense concern in the context of limited resources and a variety of associated factors. The methods and techniques used to achieve this have undergone considerable changes over time, which have been in line with legislative regulations, traditions, eating habits, economic considerations and much more. Thus, the extensive research into alternative methods or improvements to existing ones concluded that a multitude of food additives present a risk to consumers' health, whilst also considering the balance between risk and benefits. Current trends in food are linked to the bilateral concern of consumers and operators toward a healthy and economical solution. For these reasons, the usefulness of essential oils in terms of food safety and quality is acknowledged. Other health-enhancing effects are associated with the possibility of producing "functional foods". Current scientific studies aim at applying essential oils from different plant species to a multitude of food substrates and obtaining relevant information on their subsequent effects. This paper presents some of the most relevant vegetal extracts which have been studied with the use and efficiency in the meat or general food industry in mind, along with their main compounds and associated effects.

Keywords: essential oils, safety, quality, meat products

Din punct de vedere istoric, identificarea unei metode eficiente pentru conservarea sau îmbunătățirea calităților senzoriale ale alimentelor a reprezentat o preocupare intensă în contextul unor resurse limitate și a unei varietăți de factori asociați. Metodele și tehnicile destinate îndeplinirii acestui deziderat au suferit modificări considerabile de-a lungul timpului, fiind corelate cu reglementările legislative, tradiții, obiceiuri alimentare, considerente economice și multe altele. Astfel, ulterior cercetărilor intense direcționate către identificarea unor metode alternative sau îmbunătățirii celor existente, a fost observat faptul că o multitudine de aditivi alimentari prezintă riscuri pentru sănătatea consumatorilor, fiind considerat echilibrul dintre acestea și beneficii. Tendințele actuale în domeniul alimentar sunt corelate cu preocuparea bilaterală a consumatorilor și operatorilor în direcția obținerii unei soluții sănătoase și economice. Din aceste considerente, este remarcată utilitatea uleiurilor esențiale din punct de vedere al siguranței și calității alimentare, fiind totodată asociate și alte efecte benefice sănătății cu posibilitatea obținerii unor alimente funcționale. Studiile științifice actuale vizează aplicarea uleiurilor esențiale provenite de la diverse specii de plante pe o multitudine de substraturi alimentare și obținerea unor informații relevante cu privire la efectele ulterioare ale acestora. In prezenta lucrare sunt prezentate câteva dintre aceste extracte vegetale studiate prin perspectiva utilizării și eficienței în industria de obținere a produselor din carne sau alimentară generală, împreună cu principalii compuși decelați și efectele asociate.

Cuvinte cheie: uleiuri esențiale, siguranță, calitate, produse din carne

Essential oils (EO) are concentrated liquids of complex mixtures of volatile (90-95%) and non-volatile compounds, which can be extracted from various parts of plants (27, 49, 56). They are an important source of phytochemicals that have antioxidant, antimicrobial, antiparasitic, antifungal, and antiviral properties.

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Thus, the current applicability of essential oils also pertains to the food industry (soft drinks, confectionery food products, and distilled alcoholic beverages), as well as to related fields, such as the nutritional and agricultural ones (11, 26, 56). Regarding the versatility of essential oils and the selection of those applicable in the meat industry, there are currently approximately 3000 different essential oils have been studied and almost 300 of those are used in the flavouring and fragrances market. It is also noted that the chemical composition of essential oils is highly influenced by numerous factors, apart from the plant genetics ones (49, 56). There are numerous studies indicating that EOs might be a plausible alternative to the synthetic chemicals used in food preservation, being also environmentally friendly. However, from an economical point of view, the cost can be influenced by the amount of essential oil contained by a plant, which may limit its applicability in practice (53, 56). Furthermore, the potential of the EOs in the meat industry is enhanced by its application possibilities, including incorporating into or coating onto synthetic packaging films along with the conventional methods (35, 53).

HISTORICAL PERSPECTIVE AND IMPORTANCE OF FOOD ADDITIVES

According to Regulation (EC) no. 1333/2008 of the European Parliament and of the Council of 16 December 2008 on food additives, "preservatives are substances which prolong the shelf-life of foodstuffs by protecting them against spoilage caused by micro-organisms and/or by protecting against the development of pathogenic micro-organisms". In this regard, the main purpose of food additives is to ensure food safety from a microbiological point of view, to prevent oxidation, and other undesirable biochemical changes, as well as to improve organoleptic qualities (53). Therefore, they have beneficial associations from the perspective of both operators and consumers. There have been intense concerns since ancient times regarding methods of food preservation identification or improving organoleptic qualities. For example, saffron was used as an alternative to food colouring in Ancient Egypt, while the Romans added alum to bakery products in order to make them whiter (38, 40). The use of food additives was expanded during the Industrial Revolution, with meat processing units using a multitude of toxic compounds (40, 41). As the processing industry developed and researchers in the field synthesized new preservatives, emulsifiers, thickeners, flavourings and dyes, regulatory bodies were also established to control various types of food-industry-related fraud, as well as spoilage of food for human consumption (39, 40). Thus, the current legislative purpose of the European Union is to list the approved additives by the E numbering system.

In this regard, the most commonly used preservatives in meat products are nitrites and nitrates (E249, E250), sodium erythorbate (E316), sodium ascorbate (E301), triphosphates, and sodium acetates (15).

Although beneficial for food quality and safety, the use of nitrites and nitrates is a globally controversial issue. Increased levels of reactive nitrogen species can cause nitrosative stress, a deletion process that can mediate cell destruction, including lipids, membranes, proteins, and DNA, causing cytotoxicity, genotoxicity, and carcinogenesis (36, 37). A recent study indicates that sodium nitrate may be one of the leading causes of colorectal cancer. Moreover, nitrites cause an increase in the degree of methaemoglobin formation, making it possible for methemoglobinemia to occur in children under 6 months of age.

Another controversial situation is represented by the use of BHA (E320 - Butylhydroxyanisole) and BHT (E321 - Butylhydroxytoluene), which are reported as having both carcinogenic and anticarcinogenic effects (56).

Regarding sodium erisorbate (E316), the acute toxicity associated with its consumption is low, with no indications of adverse effects in sub-chronic toxicity studies, so there are no concerns about carcinogenesis (8, 22). In the case of genotoxicity, sporadic positive tests have been reported in some studies (56).

Sodium ascorbate (E301) consumed in high doses (>5 mg/kg) may cause digestive disorders such as hypermotility or diarrhoea, but no data are available on the presence of acute toxicity or adverse effects in sub-chronic toxicity studies (23, 32).

Triphosphates may contribute to vascular pathologies (e.g., endothelial dysfunction and vascular calcification), with an increased risk, especially for people with chronic renal failure (29, 51).

Sodium acetate contributes to increased blood D-lactate levels, associated with brain dysfunction. It also contributes to metabolic disorders and increased blood sugar levels that can lead to carbohydrate intolerance; a situation encountered in uremic patients (57).

In the meat processing industry, other preservatives are also available. These include sulphur dioxide, sodium sulphite, sodium hydrogen sulphite, sodium bisulphite, potassium bisulphite, potassium sulphite, calcium sulphite, calcium and potassium acid sulphite (E220-228), glacial acetyl acid (E260), potassium acetate (E261), and sodium acetate (E262), calcium acetate (E263), sorbic acid-sorbates (E200-203), benzoic acid benzoates (E210 -213), p-hydroxybenzoate (E214-219), natamycin (E 235), and lactic acid (E270).

Lactic acid, acetic acid, and acetates are generally considered to be harmless. When used in proper doses, it should not affect human health. However, their safety is questionable, as they may be associated with hypersensitivity, asthma, cancer, skin irritations, allergies, or gastrointestinal problems (3).

From the perspective of the consumption of more or less processed foods, eating habits vary greatly globally, being subjected to traditions, customs, religion, and also industrialization. These differences underline the heterogeneity of pathologies associated with populations on different continents. According to the European Food Safety Authority (EFSA), the most common diseases in Europe are cardiovascular diseases, obesity, dyslipidaemia, hypertension, type II diabetes, osteoporosis, and tooth decay (20). In light of these, the necessity of a proactive perspective regarding nutrition can be observed, as well as the way in which this might be an adjuvant in the control and prevention of the pathologies mentioned.

The current trend of consumers and industrial operators is to limit the use of chemical preservatives in meat products, requiring new methods of natural conservation (48). The antimicrobial and antioxidant activities of natural extracts have been widely discussed in the literature. For example, the antioxidant potential of sage and rosemary essential oils is more pronounced compared to BHA and BHT, the most commonly used synthetic antioxidants (30, 49). In addition to the aforementioned benefits, natural alternatives represented by plant extracts can also have the role of health promoter, including for the pathologies listed above, thus leading to the terms "nutraceuticals" and "functional foods" (20).The term "nutraceutical" substance or food was introduced in 1989 by Stephen DeFelice, defining it as "a food or ingredient of a food that provides medical or health benefits, including the prevention and/or treatment of a pathology." It should be noted that there is no legislative definition of the term. When a functional food helps prevent and/or treat a pathology other than anaemia, it is called a nutraceutical (30). "Functional" foods are similar in appearance to conventional ones, but have a demonstrated beneficial physiological effect and can reduce the risk of chronic pathologies beyond nutritional functions (14, 30). Consequently, the use of natural alternatives represents the transition from "safe food" to "healthy food".

BIOACTIVE PLANT COMPOUNDS

Terpenes or terpenoids represent the largest and most diverse group of natural compounds, being identifiable mostly in plants. They are responsible for the aroma, taste, and pigment of plants (10, 39).

In addition to anti-insect and anti-herbivore properties, terpenes also have antimicrobial properties with the ability to stop microbial development, a characteristic deeply exploited in traditional and modern medicine. The main plants that produce terpenes with antimicrobial properties are *Pinus ponderosa* (Pinaceae), spices (sage, rosemary, cumin, cloves, and thyme), *Helichrysum italicum, Rosmarinus officinalis*, etc.

Monoterpenes are known as the main compounds of essential oils, perfumes, and many structural isomers. An example of this is α-pinene which gives the specific smell of fir and lemon. They are isolated by steam distillation and have a boiling point between 150 and 185°C. They are also purified by fractional distillation under reduced pressure or through another process to form crystalline derivatives (17). Sesquiterpenes are larger and more stable compared to monoterpenes. They are considered to have multiple properties, including anti-cancer, anti-plasmoid, and anti-inflammatory ones. Among sesquiterpenoids, abscisic acid is thought to have a role similar to the pro-inflammatory and insulin-stimulating cytokines of the human pancreas. Gossypol has anti-cancer properties and is a potential inhibitor of fertility in females, for this reason being removed from essential oils and other products intended for human consumption. Avarol is known to have antimicrobial and antifungal activity (12).Sesquiterpenes are isolated by steam distillation or by extraction and purification by methods such as fractional vacuum distillation or gas chromatography.

Diterpenes can be classified as phytols, and are oxygenated acyclic diterpenes. These compounds have a multitude of therapeutic benefits such as antitumor, cytotoxic and anti-inflammatory, having an antioxidant activity that is associated with the prevention of many diseases. Tanshinone is a class of diterpenes recently researched for its in vitro and in vivo anti-cancer properties, having anti-proliferative and inhibitory activities of adhesion, migration, and invasion (17).

Triterpenes are made up of three or six isoprene units, including steroids and sterols that have squalene as a biological precursor. The medicinal usefulness of these compounds is not yet fully known, but there is research indicating an imminent potential for their applicability in diabetes. Saponins have detoxifying and diuretic properties, which also contribute to the wound healing process.

Tetraterpenes are highly unsaturated, which is why they are difficult to isolate and purify. This category is associated with pigments (17).

As for alkaloids, their dose-dependent consumption is not recommended, especially for pyrrolizidine alkaloids due to their bioactivation in alkylated intermediates. Also, some of the quinoline alkaloids, ergot alkaloids and steroids, are active without bioactivation and have neurotoxic activity (39, 44).

Polyphenols are known for their powerful antioxidant properties. Their activity is based on the elimination of free radicals and reactive oxygen/nitrogen species, the reduction of oxidized intermediates, the binding of metals (mainly iron and copper), the inhibition of enzymes responsible for the formation of free radicals (oxidase, peroxidase), the activation of antioxidant enzymes, (superoxide dismutase), and prevention of oxidation of other antioxidants (ascorbic acid, vitamin E) (16).

These compounds can play an important role in cancer prevention and therapy, due to the antioxidant properties of polyphenols. Moreover, polyphenolic compounds have many other beneficial effects on human health, including anti-inflammatory, antidiabetic, antiallergic, antiatherogenic, antihypertensive, antithrombotic, anti-cancer, cardioprotective, osteoprotective, neuroprotective, hepatoprotective, and anti-aging (56). There is also considerable research on the antibacterial, antitoxic, antiviral and antifungal properties of polyphenols (47).

Despite the many health benefits, there are also some dangers related to the consumption of polyphenols. The toxicity of polyphenols is strictly dose-related. Depending on the concentration, polyphenols can have both toxic and non-toxic activity. Polyphenols may have carcinogenic/genotoxic effects and may interfere with thyroid hormone biosynthesis. They also have estrogenic activity, which can cause both harmful and beneficial effects, and have antinutrient effects (iron depletion). They may also interact with certain pharmaceuticals. However, the risk of these toxic effects is very low (16). Due to the antioxidant and antimicrobial properties of polyphenols, their use as substitutes for artificial preservatives in meat products and preparations is of great interest today. Plant extracts rich in polyphenols can prolong shelf life by inhibiting the development of spoilage and pathogenic microflora, inhibiting the oxidation of meat products, preventing discoloration, as well as organoleptic changes (47).

Table 1

Essential oils used in the food industry and their main compounds

Nr crt	Plant of origin	Common name	The main bioactive compounds	Effect	Ref.
1.	**Aframomum danielli**	Cardamon	1,8- cineole (50.95%), β-pinene (11.79%), terpineol (9.15%), γ – terpinene (7.45%), Sabinene (6.03%), pinene (3.41%), α –terpinenly acetate (3.38%), terpinene-4-of(2.44%) and α-thujene (2.11%)	Antimicrobial anti-browning antioxidant, antimicrobial, anticancer, antiinflammatory	24
2.	**Ocimum basilicum L.**	Basil	Estragole (41.40%), 1,6-Octadien-3-ol, 3,7-dimethyl (29.49%), trans-.alpha.-Bergamotene (5.32%), Eucalyptol (3.51), Citral (3.31%), N-Cyano-3-methylbut-2-enamine (3.08%), cis-.alpha.-Bisabolene (1.92%), Levomenthol (1.81%), and beta.-Myrcene (1.11%)	Insecticidal, antimicrobial, antioxidant, antiprotozoal, anticancer activity, antifungal	5
3.	**Laurus nobilis**	Bay	α-Pinene, sabinene, β-Pinene, α-Terpinen, α-Terpineol, γ-terpinene, δ-Terpineol, Eucalyptol Linalool, Eugenol, Methyl-Eugenol	Antiseptic, antimicrobial, anti-inflammatory, anticancer,antioxidant, antifungal,anticorrosive	43
4.	**Citrus bergamia**	Bergamot	Limonene, Linalool, Linalyl acetate	Antimicrobial, antifungal, anti-inflammatory	25
5.	**Aquilaria malaccensis**	Agar/ Gaharu	Pentadecanal (%32.082), 9-Octadecenal, (Z) (%15.894), and Tetradecanal (%6.927) α-agarofuran, β-agarofuran, agarosipol, jinkohol, jinkohol II, valerianol, guaiol, Guaia-1 (10), 11-dien-9-one, α-Copaen-11-ol	Anti-inflammatory, antioxidant, antimicrobial, laxative	52
6.	**Trachyspermum ammi L.**	Indian caraway	thymol (38.75%), p-cymene (31.61%), γ-terpinene (23.70%) and β-pinene (3.32%), α-tuien, myrcene, 1,8-Cineole, carvacrol	Antibacterial, antifungal antioxidant	21
7.	**Angelica glauca**	Angelica	a-phellandrene (18.0 %), β -pinene (14.0 %), b-caryophyllene (8.6 %), γ - terpinene (6.7 %), b-bisaboline (5.2 %), germicene-D (4.5 %), Trans-carveol, Tuien, Caryophyll oxide, γ-terpinene, nerolidol, β-bisabolen, Germacren	Antibacterial, insecticide, antioxidant	45
8.	**Pimpinella anisum**	Anise	Carvone (45.221 %), trans-anethole (86.898 %), (Z-)-Anethole (92.478 %), cumin aldehyde (42.900 %), linalool (87.238 %), Methyl chavicol, linalool, α-Terpineol, Himachalen	Flavouring, antioxidant, antimicrobial	9, 46
9.	**Momordica charantia**	Bitter cucumber	5-(Hydroxymethyl) -2-(1-methyl-2-imidazolyl)-1H-benzimidazole (79.18 %), 2-Cyclohexen-1-one, 2-methyl-5-(1-methylethenyl), (R)- (13.90 %), Trans-nerolidol, Apiol, Cis-dihydrocarveol, Germacren D, Spatulenol, β-Selin, α-Selinen, carvone, β-Pines, Octanal, p-Cimene, Limonen, Linalool	Antimicrobial, antioxidant, antitumor, anti-inflammatory, antidiabetes	50
10.	**Citrus aurantium L.**	Bitter orange	Dl-limonene (94.81%), β-myrcene (1%) and α-pinene (0.65%), α-terpineol, E-β-ocimen, δ-3-caren, (E) -nerodiol	Antifungal, antioxidant, flavoring, antibacterial	35
11.	**Nigella sativa**	Black cumin	p-cymene (18.46-52.64 %), α-thujene (4.5-10.23 %), α-terpineol (5.11-9.72 %), thymoquinone (0.14-9.2 %), longifolene (3.07-8.34 %), carvacrol (0.87-5.19 %), limonene, terpinene-4-ol, thimoquinon,	Antifungal, antioxidant, antibacterial	1, 34
12.	**Piper nigrum L.**	Black pepper	α-pinene, sabinene, β-pinene, δ-3-carene, limonene, and β-caryophyllene, α-Thujen, Sabinene, Myrzene	Antioxidant, antimicrobial	4
13.	**Carum carvi L.**	Chinese araway	Limonene (43.5 %), carvone (32.6 %), apiole (15.1 %), α-Pinene, Camphene, β-Pinene, β-Myrcene Limonene, γ-Terpinene, (E) -β-Ocymene p-Cymene, Terpinolene, Spathulenol Thymol, Carvacrol	Antioxidant, antimicrobial	10

Table 1

Essential oils used in the food industry and their main compounds

Nr crt	Plant of origin	Common name	The main bioactive compounds	Effect	Ref.
14.	***Daucus carota***	Carrot	carotol (3.5 – 5.2%), β-bisabolene (5.5-7.6), α-selinene (7.4-8.6%), eudesm-7(11)-en-4-ol (8.2 – 8.5%), sabinene (12.0 - 14.5%) and 11-α-(H)-himachal-4-en-1-β-ol (12.7 – 17.4%), α-humulene, α-pinene, β-caryophyllene, β-sitosterol, campesterol, cycloartenol, 1-hexacosanol, linolenic acid, 24-methylencycloartanol, sabinene, stigmasterol, trilinolein	Atimicrobian, antioxidant, anticancer, metabolical effects	19, 41
15.	***Cryptomeria japonica***	Sugi	3-carene (21.03%), p-cymene (10.95%), limonene (9.49%), β-myrcene (9.39%), γ-terpinene (9.10%), α-terpinene (8.57%), α-Cubebene, α-Muurolene, δ-Cadinene, Gleenol, Cubenol, Epicubenol, Elemol, T-Cadinol, γ-Eudesmol, Torreyol, α-Eudesmol, β-Eudesmol, Kongol	Antimicrobial, insecticide antifungal	6
16.	***Apium graveolens var. Sweet***	Celery	Limonene, α- and β-pinene, myrcene, β-selinene, 3-n-butylphthalide, sedanolide, and sedanenolide	Antibacterial, antioxidant, antifungal, flavouring	55
17.	***Cinnamomum zeylanicum***	Cinnamon	eugenol (76.60%), linalool (8.5%) and piperitone (3.31%) cinnamaldehyde, camphor, cinnamyl acetate, caryophyllene, trans α-bergamotene, caryophilene oxide, linalool, geraniol, bornyl acetate, α-cubebene, γ-elemene, α-copaene, guaiol, eugenol	Antioxidant, antibacterial, antifungal, insecticide, nematicide, aroma enhancer	7
18.	***Syzygium aromaticum***	Cloves	eugenol (78.72%), β-caryophyllene (8.82%) and eugenyl acetate (8.74%), α-humelene Caryophyllene oxide	Antimicrobial, antioxidants	2
19.	***Coriandrum sativum***	Coriander	linalool (72.7%) followed by λ-terpinene (8.8%), α-pinene (5.5%), camphor (3.7%), limonene (2.3%), geranyl acetate (1.9%) and p-cymene (1.5%) camphor cyclohexanol acetate, Terpineol	Antioxidants, flavorings, antibacterial, antifungal	54
20.	***Chrysathemum balsamita***	Costmary	Carvone, camphor, camphor – thujone, camphor-α-thujone, bornyl acetate	Antimicrobial, antioxidant, flavoring, insecticide	13
21.	***Cuminum cyminum L.***	Cumin	α–Pinene (29.2%), limonene (21.7%), 1,8-cineole (18.1%), linalool (10.5%), linalyl acetate (4.8%), and α-terpineole (3.17%) Cuminal, β-pinene, β-myrcene, ρ-cymene, γ-terpinene, ρ-mint-1,4-dien-7-ol	Antioxidant, antimicrobial, antifungal	31
22.	***Murraya koenigii***	Curry tree	Linalool, elemol, geranyl acetate, myrcene, allo-Ocimene and α-terpinene, α-Pinene, Sabinene, β-Pinene, δ-3-Carene, β-Phellandrene, (Z) -β-Ocimene, α-Copaene, β-Caryophyllene, β-Gurjunene	Antioxidant, insecticide, antibacterial, antifungal	42
23.	***Helichrysum italicum***	Imortele	α-Cedrene (13.61%), α-Curcumene (11.41%), Geranyl acetate (10.05%), Limonene (6.07%), Nerol (5.04%), Neryl acetate (4.91%) and α-Pinene (3.78%) γ 1,8-cineole, borneol, (E) -caryophyllene, β-pinene, eugenol, 3-ethyl2,5-dimethylhexane-1,3-diene, α-farnesene, α-humulene, bicyclosesquiphellandrene, γ-turmeric, bicyclogermacrene, α-amorphene, trans-caryophyllene, caryophyllene oxide, p-cymene, spathulenol, β-bourbonene,camphor, linalool,thymol	Antimicrobial, antioxidant, antifungal, anti-inflammatory, insecticide, flavouring, anti-neoplasic	28
24.	***Anethum graveolens L.***	Dill	Carvone, limonene, dihydrocarvone, carvacrol, p-cymen, α-phellandrene dill apiole	Antimicrobial, antioxidant, flavouring, other pharmacological activities	46
25.	***Eucalyptus citriodora***	Lemon eucalyptus Lemon-scented gum	citronellal (29.31 %), geraniol (27.63 %), β-citronellol (14.88 %) and δ-cadinene (6.32 %). α-Pinene, o-Cymene, Limonene, 1,8-Cineole, Citronellal	Antimicrobial, antifungal, flavouring	33

ESSENTIAL OILS APPLICABLE IN THE FOOD INDUSTRY

Regarding the identification of plant extracts that have antimicrobial and antioxidant potential with applicability in the food industry, several factors such as stability, efficacy against targeted pathogens, safety, and cost-benefit ratio must be considered. The sensory compatibility and chemical interferences of the extract with the food matrix must also be researched, which underlines the importance of conducting preliminary studies on in vitro efficacy (56). Subsequently, considering the results obtained and the characteristics of the food, the in vivo efficacy should also be studied. The effectiveness of essential oils depends on the method used to expose fungi or bacteria to antimicrobial compounds. In general, a much higher concentration (2-100 times) of the essential oil is required to obtain an antibacterial effect similar to in vitro tests. For this reason, it may often be necessary to modulate some intrinsic characteristics of the food substrate in order to achieve the intended effect.

What is more, in order to have an antimicrobial effect, essential oils must be polar enough to dissolve to some extent at the cellular level, but non-polar enough to interact with the non-polar structures of the cell. It is believed that the polarity of the compounds of essential oil must be within a certain range to reach lethal levels of microbial cell structures. Therefore, the observed efficacy for the direct and vapor application of essential oils can be explained by the differences between the polarities and the volatility of the individual compounds of the essential oils. Less volatile hydrophilic (polar) compounds tend to diffuse more easily in aqueous media, having a stronger activity in direct contact (disk diffusion).Essential oils that have antibacterial properties often contain compounds such as carvacrol, thymol, citral, eugenol, 1,8-cineole, limonene, pinene, linalool, and their precursors.

It was observed that in terms of antibacterial properties, the most effective essential oils added to food substrates are oregano, cloves, coriander, and cinnamon, followed by thyme, mint, rosemary, mustard, coriander, and sage. These antibacterial properties have been attributed to the compound carvone (antimicrobial and antifungal agent) (56). In most cases, the antimicrobial activity of these substances is low in concentrations and does not interfere with the organoleptic characteristics of foods, so the use of combined oils with a synergistic role may be more practical. Additionally, in order to enhance the effects of these plant extracts, the packaging can play a significant role. For example, vacuum or modified atmosphere packaging has been shown to be effective (56).

Another very important aspect regarding the identification of essential oils suitable for the meat products industry is the possibility of certain extracts to express cytotoxic prooxidant properties in eukaryotic cells, by destroying the mitochondrial membrane and releasing superoxide ions. Phenols, similar to other antioxidants (retinol, tocopherol), can reach a prooxidant state if used in high concentrations (56).

In order to summarize the relevant information on the aforementioned issues, Table 1 presents some of the essential oils used so far in the food industry, along with their main active compounds. Moreover, in correlation with the composition, the effects demonstrated in vivo or in vitro are presented. It should be noted that in addition to the necessary attributes (antimicrobial, antioxidant, antifungal effect, etc.), all the essential oils have additional effects associated with biological activities (e.g., anticancer, antimutagenic, antispasmodic, analgesics, anti-inflammatory drugs, anxiolytics), being suitable to be classified as nutraceuticals.

CONCLUSIONS

The secondary metabolites of plants (EOs) can be successfully used in the meat industry as natural additives, being functional alternatives to the existing synthetic ones. In addition to the useful properties that contribute to shelf-life extension, essential oils may also contribute to additional health benefits creating the premises for "nutraceuticals" or "functional foods". There are many types of essential oils described by the relevant literature and existing studies regarding their application in food substrates. However, essential oils with the highest efficacy, that also consider the cost-benefit ratio for both consumers and operators should be further investigated.

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